COMPARISON OF THE TEOM® AND NEPHELOMETRY FOR MONITORING HAZE PARTICLES

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ABSTRACT. *Continuous, real-time monitoring of aerosol particles during regional haze episodes from forest fires is necessary because of the considerable temporal variation in haze intensity. Atmospheric concentrations were determined simultaneously using a tapered element oscillating microbalance (TEOM®) and a nephelometer (personalDataRAM®) during a severe haze episode in Brunei during the 1998 haze episode. Although there was a significant correlation between measurements of particulate matter obtained with the two instruments, there were considerable differences in the absolute values of the concentration. The nephelometer registered concentrations approximately 2.5 times higher than the TEOM®, and the discrepancy is largely due to differences in the measurement principles of the two instruments. Water and other volatile compounds in aerosol particles are lost in the TEOM® due to heating of the sample to 50 °C. On the other hand, measurements using the nephelometer reflect the growth of aerosol particles with relative humidity as a result of absorption of water vapour by deliquescent and hygroscopic constituents in the particles, and they provide more representative measurements of real-time, in-situ wet aerosols.*

KEYWORDS. *TEOM®, Nephelometry, haze particles*

INTRODUCTION

Regional haze in SE Asia (Indonesia, Malaysia, Brunei, Singapore) has returned during July 2005 with such an intensity that it has prompted the declaration of a state of emergency by the Malaysian Government. Measurement of suspended particulate matter is the most important activity for monitoring haze intensity, and the various air quality indexes [Pollutant Standards Index (PSI) and Air Pollution Index (API)] are based exclusively on PM_{10} measurements during haze episodes. The standard method for monitoring PM_{10} is to determine its concentration from a single filter sample collected over a 24-hour period. Short-term variation in the concentration of atmospheric particles can only be determined with instruments capable of producing continuous, real-time measurements, and these are becoming more popular for air quality and haze monitoring.

Different techniques have been used for monitoring suspended particle concentrations at air quality monitoring stations. In addition to the US EPA's reference Hi-Vol (high volume) gravimetric method, techniques based on the attenuation of β-radiation, piezoelectric microbalance, tapered element oscillating microbalance (TEOM®), and nephelometry have also been employed. The latter methods are becoming increasingly popular as they can produce automatic, continuous measurements of particle concentrations, unlike the reference Hi-Vol method which gives longer-term (usually 24-h) averages. The TEOM® and methods based on nephelometry are especially useful since they give real-time (or near real-time) measurements which can reveal short-term variations in particle concentrations. Portable nephelometers are also useful for continuous monitoring of personal exposure to aerosol particles (Muraleedharan and Radojevic, 1999) and these are generally based on nephelometry.

Methods based on different measurement principles can give different results and there is considerable controversy in the literature regarding which is the most appropriate method for determining particle concentrations (Allen *et al*, 1997; Smith *et al*, 1997; Rupprecht and Meyer, 1998; Patashnik, 1998a; 1998b; Allen, 1998). There have been several intercomparison studies using different particle monitoring methods (Laskus, 1998a,b; Allen *et al*, 1997; Smith *et al*, 1997) and significant discrepancies were noted between different methods.

Although measurements of particulate matter <10μm in diameter (PM_{10}) using Hi-Vol methods at fixed outdoor monitoring stations have been correlated with health effects of the population as a whole, they cannot reveal short-term peak concentrations of airborne particles. During haze episodes in Brunei Darussalam, caused by emissions from forest fires, considerable temporal and spatial variation in particle concentrations was observed (Radojevic and Hassan, 1999; Muraleedharan and Radojevic, 1999) and short-term exposure to extremely high particle levels can be significant. Regional haze episodes in SE Asia can have numerous effects, the impacts on human health being the most important (Radojevic, 1998). There is, therefore, a need to select appropriate monitoring techniques which can produce data useful for interpreting and predicting the health effects. During a severe haze episode in 1998, we compared the TEOM® with a *personal*DataRAM® based on nephelometry.

EXPERIMENTAL

Real-time concentrations of particulate matter were monitored using a *personal*DataRAM® aerosol monitors from MIE, Inc. USA and a tapered element oscillating microbalance (TEOM®) from Rupprecht and Patashnick, USA. The *personal*DataRAM® is based on nephelometry (light scattering) and it responds to aerosol particles in the size range of 0.1 - 10 μm and concentrations from 1 μg m^{-3} to 400 mg m^{-3}. The precision of the instrument is reported as being ±10 μg m^{-3} for 1-second averaging and ±1.5 μg m^{-3} for 60 second averaging. The instrument is factory calibrated against a filter/gravimetric reference test dust (ISO Fine test dust). The TEOM® is equipped with a size-selective inlet used for sampling particles <10 μm and it determines particle concentrations by natural resonance after heating to 50 ºC.

RESULTS AND DISCUSSION

Simultaneous measurements were made using the *personal*DataRAM® and the tapered element oscillating microbalance (TEOM®) PM_{10} monitor on 5 April 1998 when the haze was extremely severe. Measurements were taken during a 24-h period at Jerudong Park Medical Centre, a coastal site approximately 15 km from Bandar Seri Begawan, the capital of Brunei Darussalam. The TEOM® has been recognised by the US Environmental Protection Agency (EPA) as an equivalent method for determining PM_{10} concentrations and it is widely used at air quality monitoring stations throughout the world to provide near real-time continuous measurements (Patashnick and Rupprecht, 1991). The correlation between the two instruments is illustrated in Figure 1. Although there was a significant correlation between the two sets of measurements (r=0.981), the *personal*DataRAM® registered considerably higher levels than the TEOM®. The measurements can be related using the following equation:

PM_{10} (*personal*DataRAM®) = 2.477 PM_{10} (TEOM®) -51.086

where PM_{10} is in μg m^{-3}. It should be noted that a particle size analysis of haze particles from forest fires, conducted during the same period, revealed that >99% of the particles were <2.5 μm in diameter (Muraleedharan *et al*, 1999).

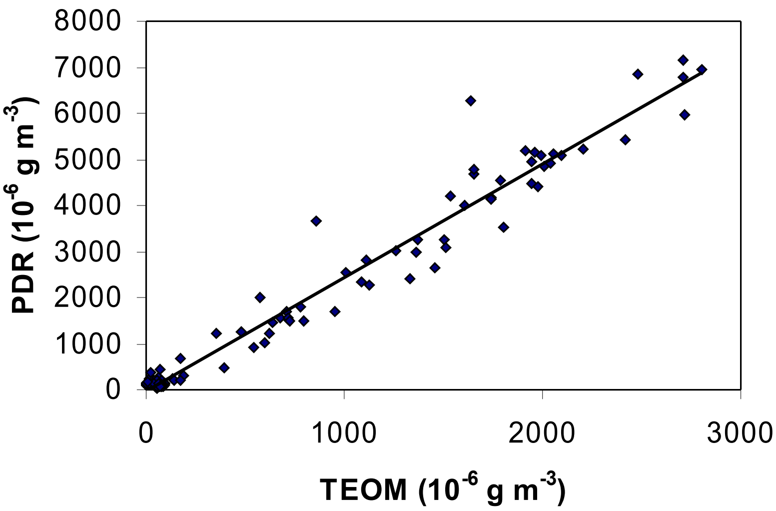

Figure. 1 Correlation between *personal*DataRAM® and TEOM® measurements of outdoor aerosol concentrations during haze in Brunei Darussalam (5th April 1998)

The discrepancy between *personal*DataRAM® and TEOM® measurements is largely due to the difference in measurement principles of the two instruments. The TEOM® determines particle concentrations by natural resonance after heating to 50°C (Patashnick and Rupprecht, 1991). This will remove water and many other volatile compounds (*e.g.* NH_4NO_3, $(NH4)_2SO_4$) from the aerosol particles (Allen *et al*, 1997; Smith *et al*, 1997). The *personal*DataRAM® does not heat the sample and it is based on light scattering by aerosol particles. The scattering coefficient increases with increasing humidity above approximately 60% (Horvath, 1992). Atmospheric particles are mixtures of various compounds, some of which deliquesce to form concentrated droplets at high humidity. The radius of aerosols, and hence the scattering coefficient, increases with increasing humidity; the effect is lowest for aerosols composed of elemental carbon and hydrocarbons and greatest for deliquescent salt aerosols (*e.g.* NaCl, $(NH_4)_2SO_4$, NH_4NO_3). Increasing the relative humidity from 85 to 95 % can increase the extinction coefficient by 2 times for NaCl and by 4 times for $(NH_4)_2SO_4$ (Horvath, 1992). Even for elemental carbon, the extinction coefficient may increase by 1.5 times on changing the humidity from <40% to >70% (Horvath, 1992). Although the major component of haze particles from biomass fires is carbon (Muraleedharan *et al*, 1999), soluble salts are also observed. For example, Zakaria *et al* (1995) observed elemental carbon, organic carbon, chloride, sulphate and nitrate in aerosol particles in Kuala Lumpur, Malaysia during the September 1994 haze episode. In Brunei the relative humidity is very high (>80%) and one may expect significant quantities of water to be associated with atmospheric aerosols. Since the dry particle concentrations could be as high as 3 $\mu g\ m^{-3}$ (TEOM® measurements) while the wet aerosol concentrations could be as high as 8 $\mu g\ m^{-3}$ (*personal*DataRAM® measurements), it can be concluded that up to 5 $\mu g\ m^{-3}$ of water may be associated with haze aerosols.

Furthermore, nephelometry may respond preferentially to sub-micron aerosols and this could contribute to the discrepancy between the two instruments. Also, the *personal*DataRAM® is designed for personal exposure and indoor pollution monitoring. Because it is based on passive air sampling, wind could affect the sampling. However, meteorological conditions during haze are generally stable with low wind speed, and the *personal*DataRAM® is expected to produce representative results under such quiescent conditions. Better agreement was found between the TEOM® and *personal*DataRAM® in comparison studies of indoor air (Lilienfeld, personal communication), although the *personal*DataRAM® generally produced somewhat higher measurements (*ca.* 50% higher than the TEOM®). Since air conditioning reduces indoor humidity, indoor measurements by nephelometry are essentially unaffected by water accretion and this explains the better agreement between the TEOM® and *personal*DataRAM® in the indoor study. In a comparison between a TEOM® and a nephelometer, Laskus (1998a) observed $PM_{2.5}$ concentrations in outdoor urban (Berlin) air *ca.* 50% higher using nephelometry at concentrations between 5 and 50 $\mu g\ m^{-3}$, levels considerably lower than those observed during regional haze from forest fires.

With regard to monitoring aerosol concentrations using instruments based on different measurement methods, it is arguable which method yields the most representative results. The EPA reference Hi-Vol method is itself sensitive to variations in temperature and humidity during the filter conditioning phase, and discrepancies have been found between the TEOM® and other standard methods in ambient intercomparison studies (Allen *et al*, 1997; Smith *et al*, 1997; Laskus, 1998a,b). Volatile compounds, including water, can be lost in the TEOM® method due to the high temperatures employed and it gave lower measurements than the reference method. Furthermore, the reference EPA method for PM_{10} determines 24-h average concentrations, unlike the TEOM® and *personal*DataRAM® which provide continuous, real-time measurements. During haze episodes caused by forest fires the PM_{10} concentration can fluctuate considerably over the period of several hours (Radojevic and Hassan, 1999) and extremely high peak concentrations would not be revealed with the reference Hi-Vol method.

CONCLUSIONS

Although there was a significant correlation between measurements of particulate matter obtained with the *personal*DataRAM® and fixed-site monitoring using TEOM®, there were considerable differences in the absolute values of the concentration. The nephelometer registered considerably higher concentrations (*ca.* 2.5×) than the TEOM®, and the discrepancy is largely due to differences in the measurement principles of the two instruments. Water and other volatile compounds in aerosol particles are lost in the TEOM® due to heating of the sample. On the other hand, measurements using the nephelometer reflect the growth of aerosol particles with relative humidity as a result of absorption of water vapour by deliquescent and hygroscopic constituents in the particles, and they provide more representative measurements of real-time, in-situ wet aerosols. Both instruments offer advantages over the reference Hi-Vol method since they produce continuous, real-time measurements, which can reveal short-term peak concentrations of particulate matter.

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