CHEMICAL ANALYSIS OF MOUDI™ IMPACTOR SAMPLES

APPLICATION NOTE MOUDI-002 (A4)

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Performing a Chemical Analysis of Impactor Samples

The chemical composition of aerosols, particularly when coupled with information about their size, has significant implications for human health, atmospheric science, and the environment. Characterizing the chemical makeup of aerosols in a size-segregated fashion is made possible by sampling the aerosols with cascade impactors, and then analyzing each of size-resolved particle samples using an appropriate chemical technique. Well-established in the scientific literature, chemical analysis of MOUDI™ impactor samples has provided significant insight into the chemistry of atmospheric aerosols, cloud condensation nuclei (CCN) processes, public health hazards and worker aerosol exposures.

Analytical Techniques

A wide variety of chemical analysis techniques can be used for aerosol samples collected in MOUDI impactors. The most common techniques are listed in Table 1; listed references for each represent a small sample of the available literature.

Table 1: Selected chemical analysis techniques used for MOUDI impactor samples, and selected references for each.

Chemical Analysis Technique			
Name	**Abbrev.**	**Species Analyzed**	**References**
Ion chromatography	IC	Ions and polar molecules	Dall'Osto *et al* 2008, Maudlin *et al* 2015, Cena *et al* 2014, Tao *et al* 2016
Inductively coupled plasma mass spectrometry	ICP-MS	Metals and non-metallic elements	Felix *et al* 2015, Dall'Osto *et al* 2008, Maudlin *et al* 2015, Cena *et al* 2014, Chen *et al* 2016
Organic carbon / elemental carbon	EC/OC	Thermal treatment, optical transmittance	Yu & Yu 2012
Gas chromatography – mass spectrometry	GC-MS	Volatile, semi-volatile molecules	Yang *et al* 2006, Tsai *et al* 2011, Park *et al* 2007, Yu & Yu 2012
X-ray fluorescence	XRF	Elements	Kuhn *et al* 2005

Numerous other techniques, such as PIXE, HPLC, and electron microscopy may also be used. Published peer-reviewed literature is available describing the use of each of these techniques, as well as others not listed here, in the analysis of MOUDI particle samples. If you would like more information on what analysis techniques can be used, please contact your TSI representative.

Kinds of Research Benefiting from Chemical Analysis

Since aerosol composition has important implications in human health and atmospheric chemistry, research in these fields can benefit from gaining insight into the size-resolved composition of aerosols. Such research can focus only on ambient aerosols, only on the emissions from known aerosol sources, or on the relationship between the two.

Ambient Aerosol Characterization

One of the most common applications of MOUDI™ impactors is for characterizing ambient aerosols. Chemical analysis of these size-segregated samples can provide valuable insights into public health hazards and numerous aspects of atmospheric chemistry.

New Particle Formation

One important area of atmospheric research is new particle formation (NPF), a highly chemistry-dependent process that starts with precursor vapors (i.e. H_2SO_4). Tao and colleagues analyzed MOUDI impactor samples via ion chromatography (IC) to identify six protonated amine species in samples collected in urban Shanghai (Tao *et al* 2016). The amine abundance was likely correlated with the high frequency of NPF events in Shanghai, and the correlation between sub-180 nm amines and aerosol acidity provides insight into the chemistry of the NPF process.

Polycyclic Aromatic Hydrocarbons (PAH)

Figure 1: Ambient air quality is a significant problem worldwide. Chemical composition and particle size data are critical to understanding the public health risks posed by poor ambient air quality. MOUDI impactors have been used to investigate the size distribution of particle-sorbed PAHs in Guangzhou, China (pictured).

PAHs are a family of combustion-generated molecules which are abundant pollutants and known carcinogens (Srogi *et al* 2007). Investigations into the loading of PAHs to ambient aerosols of varying sizes have enhanced our ability to predict PAH fate and transport in the environment and in the human respiratory system.

Miguel and colleagues used high performance liquid chromatography (HPLC) to analyze MOUDI samples collected downwind of Los Angeles, California, USA (Miguel *et al* 2004). Their results demonstrated a seasonality to the distribution of PAH across the particle size distribution, with a more significant portion of the total PAH load being found on ultrafine particles in October to February. Park and colleagues observed PAH distributions peaking in the 300 to 500 nm range in urban Seoul (Park *et al* 2007), while PAH loading to particles sampled in urban Guangzhou, China was found to be distributed across particles 100 nm to 1.2 um (Yu & Yu 2012).

Since some PAH species are more volatile than others, the potential for sampling artifacts must be considered when using impactors. McMurry (2000) provides an excellent review of atmospheric aerosol measurements, and discusses the phenomenon of artifacts in impactor samples.

Heavy Metals

While not as abundant as PAHs, aerosol-phase heavy metals pose a particular human health risk. Chen and colleagues examined the size-specific loading of mercury to aerosols on haze and non-haze days in Shanghai, finding that while all days exhibited a bimodal distribution of particle-bound mercury, one of the modes shifted on haze days (Chen *et al* 2016). The shift from the size bin of 0.32 to 0.56 μm (non-haze days) to 0.56 to 1.0 μm (haze days), along with other features of the air quality on haze days, may represent a change in the public health and environmental hazards posed by particle-bound mercury.

Effects of Certain Aerosol Emissions on Ambient Air

While characterizing ambient aerosol composition is a very worthwhile effort, taking control of the situation requires knowledge of how emissions from certain sources affect ambient air quality. Research on the impacts of biomass burning, vehicle emissions, and certain point sources on ambient air have all benefitted from chemical analysis of size-segregated particle samples.

Biomass Burning

Wildfires have significant effects on ambient air, which are influential both for human health (i.e. air quality) and for atmospheric processes such as cloud formation. Maudlin and colleagues used a MOUDI impactor to investigate the influence of wildfires in California on both the composition of cloud condensation nuclei (CCN) and coastal air quality (Maudlin et al 2015) The size distributions of numerous chemical compounds (including non-sea-salt sulfate, ammonium, oxalate, and methanesulfonate) shifted in samples influenced by biomass burning, relative to samples that were not biomass-influenced. Such studies permit the identification of likely 'markers' for biomass burning-influenced air masses.

Agricultural burning a widespread practice in many areas of the world, as it is an economical way to dispose of agricultural wastes. When burned in a combustion chamber, rice straw and almond prunings (common agricultural wastes in California, USA) produced differing total PAH content (Keshtkar and Ashbaugh, 2007). Chemical analysis of the MOUDI impactor samples revealed that the content of specific PAH species varied by particle size, with larger PAH species being present on smaller particles, and vice versa.

Figure 2: Agricultural burning is a significant source of particles to ambient air. Burning of rice straw (pictured) can be a significant source of PAH to the surrounding environment.

Yang and colleagues have also used a MOUDI impactor to confirm rice straw burning to be a significant PAH source in Taiwan, with the majority of total particle-bound PAHs being found on accumulation-mode particles (approximately 0.1 to 2 µm) (Yang *et al* 2006, Kulkarni, Baron, and Willeke 2011). As with PAHs measured in ambient air (discussed above), this size-resolved chemical signature has important implications for public health.

Vehicle Emissions

Vehicle emissions are a significant source of ambient aerosols across the world. Because they have a large influence on air quality, public health, and the environment, they have been the subject of ever-tightening regulations in the last few decades. The diversity of fuel types, after-treatment devices, engine types, and driving conditions lends complexity to assessing the influence of vehicle emissions on ambient air quality.

Taking advantage of an uncommon opportunity to assess air quality near a freeway populated with only light-duty gasoline vehicles, Kuhn and colleagues used a MOUDI impactor to discover that, relative to a background site, sampling near the freeway produced elevated ultrafine mass, nitrate, and elemental carbon (EC) concentrations (Kuhn *et al* 2005). Mass concentrations of eleven elements in the coarse mode were higher at the background site than they were near the (light duty-only) freeway, suggesting that light-duty vehicle traffic does not produce coarse particles as significantly as does heavy-duty traffic.

Emissions from ships are the focus of increasing attention in recent years, particularly in cities with large ports. Murphy and colleagues used a MOUDI on board a typical container ship burning heavy fuel oil to investigate the ship's emissions during normal operation (Murphy *et al* 2009). Among other findings, they concluded that depending upon the size of the emitted particles and the supersaturation ratio to which they were exposed, the size-resolved chemical composition (made possible via MOUDI impactor sampling) is critical to making accurate predictions of CCN concentrations.

Figure 3: Vehicle emissions are a significant contributor to ambient air pollution globally, despite ever-tightening regulations.

Point Sources

Processes such as welding, mining, and steel working also contribute to ambient aerosol concentrations. Steel working has been observed to emit aerosols into the ambient air that are enriched in iron, lead, manganese and zinc, with mass size distributions of lead and iron coinciding (Dall'Osto *et al* 2008). Copper mining has also been linked to elevated concentrations of lead in aerosol, particularly in the accumulation mode (Felix *et al* 2015).

Characterizing Emissions from Known Sources

In addition to affecting ambient air in the surrounding area, emissions generated by point sources can result in worker exposure. Because of these impacts, characterizing emissions from specific sources can be a very informative exercise.

For example, Cena and colleagues used a MOUDI impactor to characterize the size-resolved composition of arc welding fume emissions (Cena *et al* 2014). Relative to the other metals analyzed (total chromium, manganese, and nickel), Cr(VI) exhibited a slightly smaller average size, resulting in the majority of airway-deposited Cr(VI) being located in the alveolar region. This may represent an inhalation hazard for welding workers.

Figure 4: Welding fumes may be hazardous to workers' neurological health.

Similarly, Zhang and colleagues used energy-dispersive x-ray spectroscopy (SEM-EDX) on MOUDI impactor collected samples to show that the iron content of welding fume aerosols was elevated relative to background aerosols at all three particle sizes investigated (10 nm, 100 nm, and 1 µm), while at the ultrafine sizes of 10 and 100 nm, welding fumes were enriched in silicon, oxygen, manganese, and zinc (Zhang et al 2013). Manganese content is of concern due a potential link between occupational exposure to welding fume and Parkinson's-like neurological disorders (Sriram et al 2015).

Summary

Chemical analysis of size-segregated aerosol particles can provide valuable scientific information on topics as wide-ranging as inhalation hazards for welders to new particle formation in the atmosphere. MOUDI™ impactors are well-established in the literature as high-quality tools for collecting such size-segregated particle samples. If you have any questions as to whether a MOUDI cascade impactor may be beneficial to your work, please contact TSI Incorporated. Our sales and applications teams will be happy to discuss your needs with you and recommend the product that will be the best fit for your needs.

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