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The elemental ambiguity of $PM_{2.5}$

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Introduction

Particle pollution in the air is a mixture of solids and liquid droplets. Comprised of particles of different sizes, air borne particulate matter (PM) includes ash and dust emitted by anthropogenic and non-anthropogenic processes and gas-particle conversion. Predominantly emitted during combustion, for instance through power generation, domestic heating and vehicle engines, PM has diverse sources and is an umbrella term for a range of different chemical constituents. The physical and chemical structure of PM is also the subject of on-going science-policy debate. This is because what kind of chemical PM is, is always shifting: PM cannot be individuated or materially defined in any simple or deterministic way. As a result, the toxicity of PM is difficult to estimate, which poses a challenge to governments responsible for ensuring healthy environments for their citizens.


The sun has turned red over London today

Quantifying particulate matter: size, mass, number

A central way in which particle pollution has been researched and governed is through the generation of measurements that are organised by particle size, specifically PM_{10}, $PM_{2.5}$ and PM_1 (nanoparticles). The number represents particle diameter, which, at least for $PM_{2.5}$ and PM_{10}, are measured in the unit of aerodynamic micrometers. PM_{10} includes particles of a diameter of 10 micrometers in size and larger, and $PM_{2.5}$ a diameter of 2.5 micrometers or less. Nanoparticles are less than 1 micrometer in diameter and are measured in nanometers. PM_{10} and $PM_{2.5}$ are often measured by mass; particles are weighed to determine their ambient concentration. Yet, nanoparticles are too small to be weighed. With growing concerns about finer particles, researchers are now claiming that particle count, source and duration of exposure could be more important for determining toxicity than particle mass.

Particle size tells a history of environmental health science of air pollution, too. Broadly, PM_{10} was the problem particle size up until the late 1990s, and since then $PM_{2.5}$ has been the main particle size of concern[1]. The health effects of PM_{10} and $PM_{2.5}$ are highly correlated and their complex toxicity difficult to disentangle. What distinguishes $PM_{2.5}$'s toxicity from larger particles, however, is the risk of these finer particles getting deeply lodged in people's lungs, reacting with lunch tissue and absorbed into the blood stream. Nanoparticles bring further unknown health risks (see Walker's 'Sorting out the particles', EASST 2018, Lancaster University).

Chemical formations

Although particle size has, to date, framed science-policy understandings of the chemical and physical properties of PM, the 'matter' of particulate matter also differentiates particles from one another. PM has primary and secondary emission sources. For instance, black or elemental carbon (soot) is formed during high temperature combustion of fossil and biomass fuels. Nitrate, in contrast, is secondary PM formed through the oxidation of nitrogen oxides (NOx) - nitric oxide nitrogen monoxide, (NO) and nitrogen dioxide (NO_2) to form nitric acid - which reacts with ammonia (NH3) (emitted from agricultural fertilizers) to give ammonium nitrate. These two different chemical compositions of $PM_{2.5}$ illustrate the complex chemistry of $PM_{2.5}$ and how the formation of $PM_{2.5}$ is closely tied to atmospheric conditions, different emissions sources and other elemental relations.

Atmospheric conditions are not stable in space and time, and neither are particles, which means trying to measure and quantify relationships with health data is especially difficult. At the same time, attempting to manage and respond to these differences and divergences is part of conducting research of air pollution. As a science and technology studies researcher who examines the methods and technologies used to study and materialise air pollution, I have found the various situated actions and considerations taken when measuring air pollution useful for exploring the qualitative dimensions of numerical outputs. How we measure influences what we know and reflecting on that process an opportunity rises to think about the things we don't know and what we might be overlooking.

Ingress of particulate matter into the lungs - 3D rendering

Ways of measuring $PM_{2.5}$

Particles have piqued my interest during research with scientists and researchers of air pollution because they frequently challenge the expectations of those studying them. $PM_{2.5}$ might 'disrupt' measurement practices by resisting the actions of those who attempt to contain them as discrete, quantifiable entities. In scientific research, responding to the material agency of PM is part of getting to know it, a process during which particles are often found to ‘behave’ in surprising ways. I am going to introduce three commonplace ways of measuring $PM_{2.5}$ (with monitoring instruments, computer models and through implementing standards) to examine more specifically what the challenges involved in measuring particles might tell us about the ways we research, engage and intervene with pollution.

i. Monitoring instruments

Monitoring instruments determine the concentration of PM in outdoor air. The Automatic Rural and Urban Monitoring Network (AURN) in the UK started measuring $PM_{2.5}$ in 2009 (before that they only measured PM_{10}), mainly in response to the 2008 EU Air Quality Directive requirement that member states reduce the exposure of the population to $PM_{2.5}$. The reason for this uncertainty is partly due to the materiality of $PM_{2.5}$ (the diverse physical and chemical composition of particles) and partly the result of $PM_{2.5}$’s complex relations with wider atmospheric processes. In terms of the latter, numerical measurements do not tell us whether the particle is from a primary or secondary source, nor how particles change in concentration over time. This has led scientists to claim that measurements of particles are in fact effects of the measurement instrument because $PM_{2.5}$ mass does not correspond to a definite physical or chemical component.

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ii. Modelling atmospheres

Since PM episodes are strongly correlated with atmospheric and meteorological conditions, computer models and simulations of atmospheric processes have demonstrated the spatio-temporal ways in which particle compositions change. Unlike counting or weighing, models simulate the movement and fluctuation of particles and make visible its different emission sources. Measuring $PM_{2.5}$ in this way evokes different questions and actions. For instance, by understanding where air pollution comes from and the ways it travels across borders means policies can be targeted and responsibility more directly apportioned. Recent research using models has shown that the chemical composition of $PM_{2.5}$ during the 2014 Saharan dust episode in the UK was made up of anthropogenic as well as non-anthropogenic sources. It wasn’t only Saharan dust. The authors argue that the media’s framing of the episode as a purely natural phenomenon diminished opportunities for effective policy change. Not only are methods of measurement and measurements of particles closely entangled, but they also contribute to the construction of what kind of problem particle pollution is and thereby in what ways we can respond.

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iii. Policy thresholds

Measurements are also closely tied to policy and governance; they can tell us about air quality and whether policies are improving it. Since much $PM_{2.5}$ is emitted from vehicle emissions, policy changes and legislation influencing the fuel used by vehicles have altered chemical reactions of combustion and therefore the elemental composition and material form of $PM_{2.5}$. Actions implemented to reduce emissions do not necessarily lead to a simple reduction in levels of ambient $PM_{2.5}$. For example, there is a growing proportion of $PM_{2.5}$ from road tyre and brake wear from zero emission vehicles. A policy implemented to improve one source of fine particles can unexpectedly lead to the revealing of another.

Dirty dual exhaust pipes of car, failed emission test

The systems used to regulate transport emissions and ensure emissions standards are met are also tied to particle behaviour. Back in late 2015 it was revealed that Volkswagen were cheating emissions testing of their vehicles by using defeat devices. Vehicles that passed emissions tests in the lab failed on the road tests, which meant NO_x emissions were higher than previously thought. NO_x is highly reactive and can form secondary $PM_{2.5}$ and the number of airborne particles from the same source changed under these different measurement conditions. Consequently, the emissions tests became a problematic tool for testing a car's performance and undermined the capacity of government and policy to regulate it in this way. Here, measurement practices became political sites where questions of governance and responsibility were played out.

Thinking with **particles**

The elemental ambiguity of $PM_{2.5}$ opens-up particle pollution to questions of social relevance and political and ethical responsibility. I have shown that these concerns might sometimes be brought into discussions of measurement, for example in response to on-going inquiries around what metrics to use, or how to account for the inter-dependencies of different emission sources. Part of the challenge of particle pollution for environmental health, it seems, is that there are always going to be things we can't measure, the negation of which may be to our own detriment. Thinking critically with these challenges, or 'disruptions', is an opportunity to consider what lies outside of measurement whilst also remaining attentive to the concerns of the measurement practice itself. Numerical measurements are important but cannot alone tell us all we need to know about air pollution, or indeed inform an effective response without the consideration of other things, people and processes. As each of the three examples highlight, measurements do not simply reflect pollution ‘out there’ but contribute to a situated and partial understanding of it. Describing these partial, uncertain and challenging dimensions of measurement are also opportunities for developing different ways of engaging with air pollution science and governance, that highlight its social, ethical and political implications and effects.

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[1] Thank you to discussions during a related presentation I gave on the EASST 2018 panel, ‘Chemical Ontologies’ for elaborating this point. The panel was convened by Emma Cardwell and Claire Waterton and held in July 2018 at Lancaster University.