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NEW DIRECTIONS

New Directions: Airborne ultrafine particle dust from building activities – A source in need of quantification

Urban infrastructure, such as bridges, roads and buildings, is constructed from a complex mixture of construction materials including concrete, metals, ceramics and plastics. The creation and operation of this infrastructure requires building activities (referring here to construction, refurbishment, demolition and recycling) over the life cycle of individual assets. Such building-related activities are recognised as important but poorly quantified sources of coarse particles (i.e. $\leq$10 μm, PM_{10}). However, far less attention has been paid to associated emissions of fine (i.e. $\leq$2.5 μm, $PM_{2.5}$) and ultrafine particles (UFP; <100 nm in diameter). In fact, it remains largely unknown whether these activities also cause the unintended release of UFPs. As a consequence the focus of this article is limited to the UFP fraction arising from building activities, both due to length constraints and the lack of published information compared with larger size fractions. This should not distract from the fact that investigation of the release and exposure to both the coarse and fine fractions of particles from building activities are important and worthy of investigation. In seeking to address this under-explored topic preliminary evidence of UFP dust release during the processing of concrete materials is presented and the importance of such emissions and associated exposure discussed. The need for risk assessment and management strategies is also examined and some of the research gaps highlighted. The term 'UFP dust' is used throughout this article to refer to the UFP produced from the building activities to make them distinct from those arising from combustion or other engineering processes (Kumar et al., 2010).

Why does this source need to be investigated? Over the past 50 years, the world's population has grown at a rate of 1.8% yr^{-1}. The rate of growth of the urban population has been even larger (2.7% yr^{-1}) with the total predicted to reach 5 billion by 2030 (Parrish et al., 2011). The development of urban infrastructure is an inevitable consequence of this growth and implies the need for both new construction and concurrent demolition or refurbishment. Worldwide, billions of tonnes of construction materials are used annually and significant quantities of waste materials are produced as a result of building-related activities. For example, the Department for Environment, Food and Rural Affairs estimated that in the UK 101 million tonnes of construction and demolition waste were produced in 2008. The proportion of construction and demolition waste recycled by crushers and screeners was reported to increase from 35 to 61% between 1999 and 2008. The increased recycling and reuse of such materials is usually considered environmentally sustainable but the potential impacts of any release of UFP dust into the ambient environment needs to be considered. Currently, no health and safety regulations exist to limit UFP dust emissions, and related exposure, nor does there appear to be any visible immediate plan by relevant authorities to address this issue. Hence, there is a clear need to investigate the release of emerging pollutants, such as UFP dust, so that appropriate risk assessment and management measures can be implemented.

Preliminary evidence of UFP dust release. Published information on emissions of UFP dust is nearly non-existent. A recent study by Kumar et al. (2012) investigated the release rates of UFP dust from simulated building activities on hardened concrete. These included refurbishment and demolition using crushing and impact methods and the dry and wet processing of recycled concrete aggregates. The sampling points were kept close to the test samples (~0.05 m) so that the source strength in the form of new release of UFP dust during these processes could be estimated. A fast response differential mobility spectrometer (DMS50) was deployed to simultaneously measure the number and size distributions of particles in the 5–560 nm size range at a sampling frequency of 10 Hz. Background particle number concentrations (PNCs) were subtracted from the PNCs measured during the *actual work time* (i.e. crushing, demolition and recycling of concrete) to identify the release of newly produced particles. The study, for the first time, confirmed that the majority of new particles *by number* were released in the UFP size range whilst the bulk of particle mass concentration (PMC) consisted of particles over 100 nm in size. More precisely, proportions of particles on a number (<100 nm) and a mass (>100 nm) basis were noted as ~95, 79, 73 and 90% of total PNCs, and ~71, 92, 93 and 91% of total PMCs, during crushing, impact demolition, "dry" and "wet" recycling, respectively. It is worth noting that the reported statistics of PMCs are for the 5–560 nm size range only; these fractions are expected to vary according to the upper particle size range (i.e. $PM_{2.5}$ or PM_{10}) considered since only a few 10's of bigger sized particles can contribute equal mass to 10^4's of tiny sized particles. Furthermore, the total PNCs during the *actual work time* increased between 2 and 17 times over the background concentrations. The lowest and the highest UFP contributions came from the crushing and the 'dry' recycling operations, respectively. Similar to PM_{10} and $PM_{2.5}$, the use of water spraying was found to be effective in suppressing the UFP emissions by up to an order of magnitude during the 'wet' recycling when compared with the 'dry' recycling process.

What are the consequences for human exposure and local air quality? The work of Kumar et al. (2012), though preliminary, can be considered in a broader perspective and the following conclusions can be drawn. Firstly, certain building-related

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activities have the potential to generate UFP dust when applied to concrete materials. The release rates, and size distributions, of particles can vary significantly depending on the process used and local control measures employed. Secondly, the building processes used in the construction and operation of urban infrastructure assets are essentially transient and time limited. However, when in continuous operation their relative impact remains to be established. It is interesting to note that the net release of PNCs (adjusted for the background) during crushing, impact demolition, "dry" and "wet" recycling, events were ~0.77, 19.1, 22.7 and 1.76 ($\times$ 10^4) cm^{-3}, respectively (Kumar et al., 2012). These values are comparable with, and in some cases up to an order of magnitude larger than, the levels of PNCs generated in the 15–700 nm size range from road–tyre interactions between 1.81–2.65, 0.72–0.82, and 0.14–0.17 ($\times$ 10^4) cm^{-3} (against background of 0.12–0.17 $\times$ 10^4 cm^{-3}) for different road surfaces at vehicle speeds 70, 50 and 30 km h^{-1}, respectively (Gustafsson et al., 2008). This suggests that building activities can be an unexpectedly large local source of UFP dust which, hitherto, has been ignored. A risk assessment and exposure estimation for local communities (and key groups and individuals) are therefore important. This is especially true given that unlike traffic-generated UFP, which have a substantial volatile fraction (Dall'Osto et al., 2011), the UFP dust particles produced by building-related activities are likely to be non-volatile and may have a much longer atmospheric lifetime.

Who are likely to be exposed and to what extent? The total exposure level to UFP dust will vary depending on a number of factors. The extent of exposure can be broadly divided into three different categories depending on the location of a receptor: (i) those "on-site", (ii) passers-by, and (iii) the occupants of nearby buildings. The "on-site" category could include construction, demolition, maintenance (e.g. plumbers, electricians) and cleaning workers, janitorial staff (e.g. site office workers), and the workers involved in re-furbishing and re-modelling activities. The latter two categories include people passing by the building activity and the occupants of buildings in close proximity to the activity, respectively. The levels of exposure are likely to further vary substantially within these categories. For instance, demolition and construction workers are likely to experience the highest levels of exposures due to their close proximity to the source, and their long-term, cumulative risk may be significant. However, such workers are likely to employ personal protection equipment that might help mitigate their risk of exposure (discussed later). In contrast, passers-by and nearby building residents are likely to be exposed to relatively lower levels on a transient and occasional basis. Hence their overall exposure can be expected to be small compared with construction and demolition workers. Somewhere in between lie the exposure of other individuals on the site, not directly involved in the building activities. It should be noted that these observations are 'qualitative', and no relevant UFP dust data is currently available to 'quantitatively' substantiate the above statements. However, what may be expected in the case of UFP emissions are that the highest concentrations will occur closest to the source and their dispersion into the surrounding environment will be driven by meteorological conditions such as wind speed and direction (Dall'Osto et al., 2011). When diluting with the ambient air during their dispersion, the UFP undergo transformation processes (e.g. coagulation, condensation, dry deposition) that result in the change of their number and size distributions in time and space during the travel from the source to the receptor (Kumar et al., 2011). Similar behaviour is expected for UFP dust which might have longer atmospheric residence time (and hence the greater likelihood of exposure) compared with traffic-generated UFP. Furthermore, field measurements of PM_{10} have shown increased concentrations downwind of demolished buildings, indicating an enhanced level of exposure compared with normal conditions. For example, Dorevitch et al. (2006) found ~4–9 times increase in 6-h averaged PM_{10} concentrations relative to background at 42 m downwind during the demolition of a high rise buildings in Chicago (Illinois, USA). Likewise, another study reported downwind peak PM_{10} levels to increase to ~3000- and 20-times over the pre-implosion levels at 100 and 1130 m downwind during the demolition of a 22-storey residential building in Baltimore, USA (Beck et al., 2003). Based on these findings there is certainly a need for field measurements of UFP dust in the context of their redistribution into the surrounding environment in order to accurately quantify the magnitude of exposure of different population groups.

What could be other possible sources of UFP dust? Besides the aforementioned sources and diesel fuel combustion in construction machinery, other sources of UFP dust could include crushers, screeners, construction plants, cutting and drilling activities and earthworks (e.g. excavation, soil-stripping, ground levelling). Furthermore, recent trends to incorporate carbon nanotubes and nano-size additives (e.g. nano-silica, Fe_2O_3, SiO_2 and TiO_2) within concrete mixes (to improve workability and strength) introduce additional source of UFPs. Such nano-modifications to concrete mean that building activities, such as demolition and recycling, might release potentially hazardous particles in the UFP size range.

What common methods are there to suppress UFP dust generation? One of the most common ways in practice to suppress the generation, and local transport, of coarse particle dust is the frequent watering of the ground surface during construction and spraying of a fine water mist during demolition processes. Covering structures with temporary shades is another common method to restrict the escape of dust from building activities, and use of masks by site workers is a widespread measure to limit their exposure. All these measures are effective for PM_{10} mass, suppressing concentrations during demolition by up to ~10 times (Kukadia et al., 2003), and possibly for the $PM_{2.5}$ too. However, this may not be so for the tiny sized UFP dust fraction. Field studies have reported an increase in PM_{10} emission from building works in London, causing a breach of the EU limit value (Fuller and Green, 2004). On the other hand, no emission inventories and few published articles offer information on UFP dust generation with the exception of a few studies carried out for different reasons. For instance, a study by Hansen et al. (2008) measured UFP concentrations close to the demolition site of an old four-storey hospital building and they found up to 1.6 times increase when compared with background concentrations. Knowledge of UFP dust is thus still in its infancy but is important for numerous reasons, e.g. for assessing the extent of UFP dust generated from building-related activities and their subsequent redistribution within the surrounding environment and adjacent buildings, for assessing the likely exposure of people in close vicinity of building sites, and providing health and safety regulatory bodies a basis for forming guidelines (Kumar et al., 2012). Consequently, extensive research work is warranted to understand and quantify the physical (e.g. size, shape, morphology), chemical (e.g. oxidation potential and toxicity) and biological (e.g. fungal spores, moulds) nature of the UFP dust and hence design relevant exposure mitigation measures.

Are any UFP dust risk assessment and management strategies currently in place or in the pipeline? Globally, the construction industry spends about US $3 trillion each year, accounting for 7% of global employment and 10% of the world's gross domestic product (GDP) and employing ~180 million people (Murie, 2007). Thousands of workers everyday engage in building activities, millions of people living, working or passing by sites where building activities occur may get unintentionally exposed to UFP dust. At the same time billions of tonnes of construction material are being used and, concurrently, building waste produced and reprocessed. A Health and Safety Research Report (HSE, 2006) suggests assessment measures for nano (ultrafine) particles but its scope is limited to UFP produced from engineering processes and related workplace exposures. Despite the many advances in construction methods and materials used within urban infrastructure, the increasing awareness of emerging air pollutants and ever increasing strictness of associated Health and Safety regulations, no existing or visible plans appear to be in the pipeline to develop risk assessment and management strategies for UFP dust.

What are the missing science links and possible research priorities for UFP dust? Many types of exposure risks and psychosocial hazards occur routinely at building sites and their prevention requires close co-operation between governments, employers and workers (Murie, 2007). The first step in this direction should be to determine emission rates of UFP dust arising from a number of building-related activities, develop emission inventories for different situations, and estimate their typical contribution to the total UFPs produced in an urban environment by all sources. Detailed investigations of the physical, chemical and biological characteristics of the UFP dust are warranted to determine their potential effects on the local air quality and the health risks posed to the people working, or living, close to such activities. There is also a need to devise research strategies capable of determining the exposure levels of different categories of population (e.g. site workers, passers-by, or nearby building residents) in and around the sites where building-related activities occur. The eco-toxicity and the environmental dispersion of UFP dust also deserve to be investigated as thoroughly as for UFP evolving from combustion or engineering/manufacturing processes to design efficient risk assessment and management strategies. These can assist the building industry to employ safe, sustainable and environmentally friendly construction methods that counter the possible exposure risks from the UFP dust.

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