Efficiency of scavenging of atmospheric carbonaceous nanoparticles by human lungs

Paul. A. Sermon[1] and Victoria E. Bull[2]

[1] Nanomaterials Laboratory, Wolfson Centre, Brunel University, Uxbridge, UB8 3PH, UK

[2]Faculty of Health and Medical Sciences, University of Surrey, Guildford, GU2 7XH, UK

Inhalation of real diesel-emitted carbonaceous particles (DEPs) by volunteers in an exposure cabinet [1] represents a significant risk to experimenters; might it not be far better to generate experimental evidence of rates/extents of uptake of UFPs in an urban atmospheric as humans inhale-exhale in a recently recommended [2] multidisciplinary environmental approach; it appears that *>50%* of the prevailing urban atmospheric UFPs are retained in adults.

Our lungs provide the first line of defence against airborne irritants and infectious agents and remove various products of the body's metabolic reactions as a result of a rapid establishment by molecular diffusion of a dynamic equilibrium between air and pulmonary blood in the lung alveoli.

The inhaled atmosphere inevitably contains pollutants and particulates (carbonaceous [3] and inorganic [4]) of varying type and concentration. There may be a synergy between organic and particulate [5] pollutants that aggravates their impact. Ultrafine particles (UFP; diameters<100nm) are of especial concern, causing health impacts (e.g. cardiovascular and hypertensive) even after a delay of 2 days after exposure. Their effect is more significant than larger airborne particulates (e.g. $PM_{2.5}$ (d<2.5μm) and PM_{10} (d<10μm) [6]; in this context, smaller is worse [6], making them dangerous like no other particulate material (PM) [7]. Fibres can be deposited and retained in human airways [8] and are therefore notorious occupational hazards, with their size and aspect ratios affecting deposition efficiencies. Some of the most frequently inhaled particles are those from diesel engine emissions that contain over 40 mutagenic and carcinogenic chemicals [9]. Both experimental [10] and modelling [11] studies suggest that inhaled diesel soot particles accumulate/are retained in the lungs for days (i.e. elimination $t_{1/2}$~days); certainly nanoparticles are slowly cleared from the lungs [12] and UFP clearance from the respiratory system (assessed experimentally and modelled) takes days-months [13]. UFPs have temporal (daily and winter-summer) and spatial distributions in an urban atmosphere [14], with local hotspots [15]. There are differences in UFP exposure and doses that are dependent on gender and age [16], occupation [17] and type of activity [18]. UFPs may be locally generated in microenvironments (e.g. around 3D printers using poly(lactic) acid-ABS [19], emitted by vehicles [20], etc) but also transported in second-hand smoke [20]. It is suggested that UFP levels and exposures should be measured at a personal level for children of school age [21]. UFPs have been associated with increased cardiovascular morbidity/mortality and chronic obstructive pulmonary disease (COPD) [22]. However, the mechanisms that drive PM-associated cardiovascular disease and dysfunction remain unclear [23]. UFPs are certainly thought to have the potential to extend beyond pulmonary organs to the central nervous system (CNS) and ultimately, the brain [24]. Indeed some perceive that cardiovascular and pulmonary systems are the main targets of UFP exposure [7]. Some experimentally track model polystyrene UFPs in mice. They see after 48 h for asthmatic animals, just 28% of the initial dose being cleared from the lungs and note low level UFP accumulation in the gastrointestinal tract, liver, and bladder [25]. Others model UFP counts in the atmosphere [26] and track real UFP concentrations that surround us in real-time using 2-propanol condensation methods.

A similar approach is already used for real-time analysis of volatile biomarkers [27-36] in exhaled human breath, which is undertaken by those seeking a relationship between biomarkers and some health disorders. There are advantages of such a non-invasive approach. Certainly, off-line PTR-MS large-scale screening of exhaled air [37] has some disadvantages.

Multidisciplinary approaches are needed to understand airborne UFPs (out of the broad range of airborne particulate matter), their interaction with the biosphere, their health-economic impact [38] and their control. Environmental, forensics (fingerprinting and tracking sources [39]), nanomaterials science, process engineering, economics and design of circular economies [40] are all likely to be needed. The challenge of controlling atmospheric pollution may be tackled from a number of perspectives simultaneously.

The authors are here briefly exploring real-time analysis [41] of (i) CO_2 (m/z=44) and HCN (m/z=27) concentrations in exhaled air using an RGA (VG Sensorlab and ESS Genysis; RGA analysis of CO_2 is well established [42]) and (ii) UFP concentrations using a TSI P-Trak 8525 condensation particle number counter (whose performance has been reviewed [43]) as a function of time with a temporal resolution of 0.1s (RGA) or 1s (P-Trak 8525) during repeated inhalation-exhalation by one of the authors while they were sedentary and inactive during tidal breathing in urban air (see Figure 1).

RGA exhalation profiles do not show the presence biomarker HCN, but were reasonably consistent for CO_2 concentrations (red) falling during inhalation and rising to 3kPa during exhalation. The minima are above current atmospheric level (i.e. seasonal levels of CO_2 at the atmospheric boundary layer in 2013 were 450ppm (high; 0.045kPa) and 390ppm (low; 0.039kPa) at a suburban site [44]). On the other hand, the background urban UFP concentrations (blue; 18UFPs/mm^3 or 18000/cm^3) were in line with data for an urban atmosphere (e.g. in cities some find roadside concentrations of UFPs of 30-131/mm^3 [45]). Inhalation is when the UFPs are at this background level. Exhalation is when (there is some UFP retention) a minimum UFP level is seen. CO_2 maxima and UFP minima correlated with exhalation.

It is relevant that *more than half* of the prevailing UFPs were retained by the subject.

In this way UFP (and molecular) markers may unravel the complexity of the connection between exposure to atmospheric particles and respiratory health [46]. We probably do not know enough about UFP precise entry pathways [47], clearance processes [48], fractions that are captured or accumulated by the body and those responsible for the most serious adverse health effects [49] at an individual level, but the results reported may be a first step.

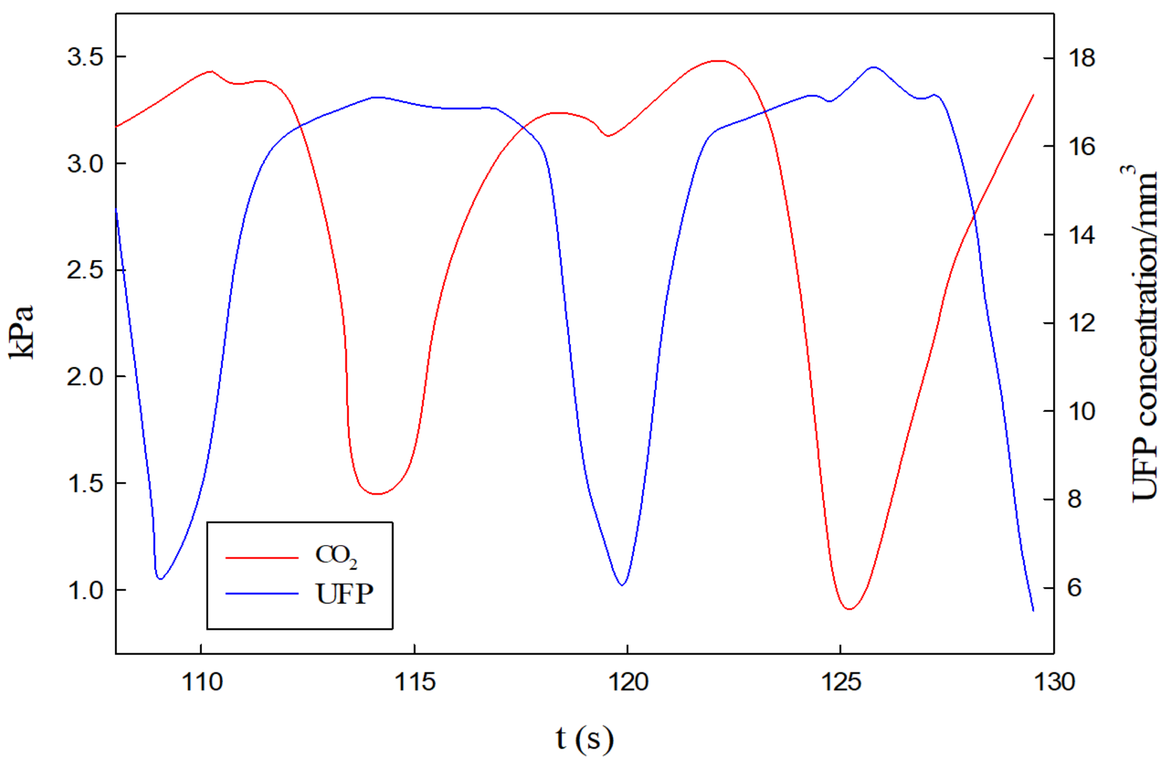

Figure 1. Profiles for concentrations of CO_2 (red) and UFPs (blue) in male adult inhaled-exhaled air.

If it is correct that 3.3±1.6 million (within 95% confidence limits) people world-wide currently die each year from the effects of airborne particles smaller than 2.5μm in prevailing outdoor air pollution [49]. Then the impact of this research may be significant.

References

[1] Mills, N.L., *et al. Euro.Heart J.* **32**, 2660-2671 (2011); [2] Lelieveld, J. & Poeschl, U. *Nature* **551**, 291-3 (2017); [3] Evelyn, A., Mannick, S. & Sermon, P.A. *Nano Lett.* **3**, 63-64 (2003); [4] Sanderson, P., *et al. Atmos.Environ.* **140**, 167-175 (2016); [5] Sosnowski, T.R., Kolinski, M. & Gradon, L. *Ann.Occup.Hyg.* **55**, 329-338 (2011); [6] Franck, U., Odeh, S., Wiedensohler, A., Wehner, B. & Herbarth, O. *Sci.Tot.Environ.* **409**, 4217-4221 (2011); [7] Politis, M., Pilinis, C. & Lekkas, T.D. *Global Nest J.* **10**, 439-452 (2008); [8] Su, W-C. & Cheng, Y.S. *Aerosol Sci.* **37**, 1429-1441 (2006); [9] Bari, S. & Marian, R. *Proc.ASME Internat.Mech.Eng.Cong.Expos.* **12**, ARUNSP V012T15A004 (2016); [10] Wolff, R.K., *et al. Fund.Appl.Toxicol.* **9**, 154-166 (1987); [11] Pauluhn, J. *Regulat.Toxicol.Pharmacol.* **86**, 319-331 (2017); [12] Buckley, A., *et al. Particle Fibre Toxicol.* 14, AR5 (2017); [13] Sturm, R. *Thoracic Cancer* **2**, 61-68 (2011); [14] Rivera, M., *et al. Atmos.Environ.* **54**, 657-666 (2012); [15] Tan, S.H., Roth, M. & Velasco, E. *ibid.* **170**,245-258 (2017); [16] Spinazze, A., Cattaneo, A., Peruzzo, C. & Cavallo, D.M. *Internat.J.Environ.Res.Pub.Health.* **11**, 10641-10662 (2014); [17] Viitanen, A-K., Uuksulainen, S., Koivisto, A.J., Hameri, K. & Kauppinen, T. *Annal.Work Expos.Health* **61**,749-758 (2017); [18] Manigrasso, M., Natale, C., Vitali, M., Protano, C. & Avino, P. *Internat.J.Environ.Res.Public Health* **14**, AR288,(2017); [19] Stephens, B., Azimi, P., El Orch, Z. & Ramos, T. *Atmos.Environ.* **79**, 334-339 (2013); [20] LeMasters, G., *et al. Obesity* **23**, 32-36 (2015); [21] Panella, P., *et al. Indoor Air* **27**, 891-899 (2017); [22] de Falco, G., *et al. Front.Immunol.* **8**, AR1415 (2017); [23] Holland, N.A., *et al. Cardiovas.Toxicol.* **17**, 441-450 (2017); [24] Loane, C., Pilinis, C., Lekkas, T.D. & Politis, M. *Rev.Neurosci.* **24**, 323-335 (2013); [25] Enright, H.A., Bratt, J.M., Bluhm, A.P., Kenyon, N.J. & Louie, A.Y. *Exptal.Lung Res.* **39**, 304-313 (2013); [26] Fischer, H.J., Zhang, Q.F., Zhu, Y.F. & Weiss, R.E. *Annal.Appl.Stat.* **11**, 297-319 (2017); [27] Amann, A., Spanel, P. & Smith, D. *Mini Rev. Med.Chem.* **7**, 115-129 (2007); [28] Wehinger A., *et al. Internat.J.Mass.Spectrom.* **265**, 49-59 (2007); [29] Mazzone, P.J., *et al. Thorax* **62**, 565-568 (2007); [30] Giardina, M., Olesik, S. & Phillips, S. *Anal.Chem.* **75**, 1604 (2003); [31] Montuschi, P., Kharitonov, S.A., Ciabattoni, G. & Barnes, P.J. *Thorax* **58**, 585-588 (2003); [32] Taucher, J., *et al. Top.Commun.Mass.Spec.* **11**, 1230 (1997); [33] Deng, C.H., Zhang, J., Yu, X.F., Zhang, W. & Zhang, X.M. *J.Chromatog.* **810B**, 269-275 (2004); [34] Phillips, M., M.Sabas, M. & Greenberg, J. *J.Clin.Pathology* **46**, 861 (1993); [35] Morselli-Labate, A.M., Fantini, L. & Pezzilli, R. *Pancreat.* **7**, 497-504 (2007); [36] Smith, D. & Spanel, P. *J.Breath Res.* **11**, 047106 (2017); [37] Steeghs, M.M.L., Cristescu, S.M., Munnik, P., Zanen, P. & Harren, F.J.M. *Physiol.Measurement* **28**, 503-514 (2007); [38] Lelieveld, J. & Poschl, U. Chemists can help to solve the air-pollution health crisis. *Nature* **551**, 291-3 (2017); [39] Jeon, W., *et al. Sci.Tot.Environ.* **613**, 820-828 (2018); [40] Singh, S., Ramakrishna, S. & Gupta, M.K. *J.Cleaner Prodn.* **168**, 1230-1243 (2017); [41] Saini, D., *et al. Pharmacol.Toxicol.Method* **63**, 143-149 (2011); [42] Delavari, S., Amin, N.A.S. & Ghaedi, M. *J.Cleaner Prodn.* **111**, 143-154 (2016); [43] Matson, U., Ekberg, L.E. & Afshari, A. *Aero.Sci.Technol.* **38**, 487-495 (2004); [44] Esteki, K., Prakash, N., Li, Y.L., Mu, C. & Du, K. *J.Environ.Res.* **11**, 707-721 (2017); [45] Kumar, P. *et al. Environment Internat.* **66**, 1-10 (2014); [46] Suhaimi, N.F. & Jalaludin, J. *Biomed.Res.Internat.* AR 962853 (2015); [47] Ganguly, K., *et al. Particle Fibre Toxicol.* **14**, AR19 (2017); [48] Sturm, R. *Annal.Work Exposures Health* **61**, 226-236 (2017); [49] Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., & Pozzer, A. *Nature* **525**, 367-371 (2015).