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COMMUTING BY SUBWAY? WHAT YOU NEED TO KNOW ABOUT AIR QUALITY*

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*Edited with *The Conversation*[1]

Subway, Tokyo, 2016. Mildiou/Flickr, © BY-SA

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Internationally, more than 120 million people commute by subway every day, and this number will keep increasing in the future as the United Nations predicts that 75% of the world's population will be urban by 2050. On top of being crucial to the mobility of city dwellers, subway systems can also play a pivotal role in reducing outdoor air pollution in large metropolises by helping to reduce motor-vehicle use. However, in response to increasing scientific and public awareness regarding the importance of clean air to human health, several studies have revealed unacceptably high levels of inhalable particulate matter (PM) in some subway systems. This article reviews some of these studies and puts their results in perspective, given World Health Organisation (WHO) guidelines concerning safe concentrations of particulate matter in the air. Following on from this, the authors identify some of the key factors influencing subway air pollution and put forward a number of recommendations to help city planners improve air quality in subway systems, as well as commuters protect themselves from the brunt of air pollution in the subway environment.

INTRODUCTION

Four more major Indian cities will soon have their own metro lines, the country's government has announced[2]. On the other side of the Himalayas, Shanghai is building its 15th subway line, set to open in 2020, adding 38.5 km and 32 stations to the world's largest subway network. And New Yorkers can finally enjoy their Second Avenue Subway line after waiting almost 100 years for it to arrive.

In Europe alone, commuters in more than 60 cities use rail subways. Internationally, more than 120 million people commute by subway every day. We count around 4.8 million users per day in London, 5.3 million in Paris, 6.8 million in Tokyo, 9.7 million in Moscow and 10 million in Beijing.

The use of public rather than private transport to abate urban atmospheric emissions is to be encouraged, and, in this context, subway systems are especially desirable.

1 https://theconversation.com/commuting-by-subway-what-you-need-to-know-about-air-quality-82859

2 In 2017.

Subways are vital for commuting in crowded cities, something that will become more and more important over time – according to a United Nations 2014 report, half of the world's population is now urban. They can play a part in reducing outdoor air pollution in large metropolises by helping to reduce motor-vehicle use. Large amounts of breathable particles (particulate matter, or PM) and nitrogen dioxide (NO_2), produced in part by road traffic, residential heating and industrial emissions, are responsible for shortening the lifespans of city dwellers. Public transportation systems such as subways have thus seemed like a solution to reduce air pollution in the urban environment. However, in response to increasing scientific and public awareness of the importance of clean air to human health, a number of studies have revealed unacceptably high levels of inhalable particulate matter (PM) in some subway systems.

As such, we may wonder what the air that we breathe is like underground, on rail platforms and inside trains.

MIXED AIR QUALITY

Over the last decade, several pioneering studies have monitored subway air quality across a range of cities in Europe, Asia and the Americas. The database is incomplete but is growing and is already valuable.

A number of studies have revealed unacceptably high levels of inhalable particulate matter (PM) in some subway systems

For example, comparing air quality on subway, bus, tram and walking journeys from the same origin to the same destination in Barcelona revealed that subway air had higher levels of air pollution (PM2.5 concentrations (43 μg/m^3: range, 37-49 μg/m^3)) than in trams or walking in the street (29 μg/m^3: range, 23-35 μg/m^3), but slightly lower than those in buses (45 μg/m^3: range, 39-49 μg/m^3 [3]). Similar lower values for subway environments compared to other public transport modes have been demonstrated by studies in Hong Kong[4], Mexico City[5], Istanbul[6], and Santiago de Chile[7].

Such differences have been attributed to different wheel materials and braking mechanisms, as well as to variations in ventilation and air conditioning systems, but may also relate to differences in measurement campaign protocols and choice of sampling sites.

In some cases, PM2.5 concentrations on a given platform can exceed 100 μg/m^3, as a daily mean, demonstrating a clear need for improving air quality underground in some stations. On the other hand, subway stations can be remarkably clean. Levels of PM2.5 on the Collblanc[8] L9S platform (26 μg/m^3) in Barcelona, for example, are close to the European limits for outdoor air, proving that it is perfectly possible to breathe relatively clean air even in the confined space of an underground train network.

THE EFFECTS ON HEALTH

Air quality inside underground rail systems is not yet included in legislation designed to clean up city air. Current European Commission rules require authorities to maintain ambient PM2.5 levels in outdoor air below an annual average of 25 μg/m^3 (2008/50/EC). World Health Organization (WHO) recommendations are more ambitious, calling for a tiered approach to reducing PM levels that starts with 35 μg/m^3 and works progressively towards an ideal level of just 10 μg/m^3. Given the fact that subway particles are chemically so different from most outdoor PM, the obvious question arises: are they more toxic than other commonly inhaled particles in the city, for example, those characterizing traffic-polluted outdoor air? Some studies have concluded that subway PM are indeed relatively more toxic[9], whereas others have failed to detect any difference between the bioreactivity of outdoor and subway air[10], while others still have reported higher oxidative potential (OP) of traffic PM as opposed to subway PM[11]. When looking at all studies published, the evidence so far suggests that subway commuters are not being exposed to a more toxic atmospheric environment underground than when traveling through the traffic-polluted city above.

To date, there is no clear epidemiological indication of abnormal health effects on underground workers and commuters. New York[12] subway workers have been exposed to such air without significant observed impacts on their health, and no increased risk of lung cancer was found among subway train drivers in the Stockholm[13] subway system. But a note of caution is struck by the

3 Moreno et al., Urban air quality comparison for bus, tram, subway and pedestrian commutes in Barcelona. Environ. Res., 142, 495–510.

4 Chan, L., La u, W., Lee, S. & Chan, C. (2002). Commuter exposure to particulate matter in public transportation modes in HongKong. Atmos. Environ., 36(21), 3363–3373.

5 Gómez-Perales, et al., (2007)Bus,minibus, metro inter-comparison of commuters' exposure to air pollution in Mexico City. Atmos. Environ., 41, 890–901.

6 Onat, B. & Stakeeva, B. (2013). Personal exposure of commuters in public transport to PM2.5 and fine particle counts. Atmos.Pol. Res., 4, 329–335.

7 Suárez et al., (2014). Personal exposure to particulate matter in commuters using different transport modes (bus, bicycle, car and subway) in an assigned route in downtown Santiago, Chile. *Environmental science.* Processes & impacts. 16. 10.1039/c3em00648d.

8 Moreno et al. (2017). The effect of ventilation protocols on subway system air quality *Science of the Total Environment* 584–585, 1317–1323.

9 Karlsson et al., (2006)., Comparison of genotoxic and inflammatory effects of particles generated by wood combustion, a road simulator and collected from street and subway. Toxicol. Letters, 165, 203-211.

10 Spagnolo et al ., (2015) Chemical Characterisation of the Coarse and Fine Particulate Matter in the Environment of an Underground Railway System: Cytotoxic Effects and Oxidative Stress—A Preliminary Study. Int. J. Environ. Res. Public Health 12, 4031-4046.

11 Janssen et al., (2014) (2014). Oxidative potential of particulate matter collected at sites with different source characteristics. Sci. Tot. Environ., 472, 572–581.

12 Chillrud et al., (2004). Elevated airborne exposures of teenagers to manganese, chromium, and steel dust and New York City's subway system. Environ. Sci. Technol., 38, 732–7.

13 Gustavsson et al., (2008). Incidence of lung cancer among subway drivers in Stockholm. Am. J. Ind. Med., 51, 545–7.

Second Avenue Subway in the making, New York, 2013. MTA Capital Construction/Rehema Trimiew/Wikimedia, © BY-SA

observations of employees working on the platforms of Stockholm underground (where PM concentrations were greatest), who tended to have higher levels of risk markers for cardiovascular disease than ticket sellers or train drivers.

Subway particulate matter is sourced from moving train parts such as wheels and brake pads, as well as from the steel rails and power-supply materials, making the particles dominantly iron-containing

OF WHEELS AND BRAKES

Much subway particulate matter is sourced from moving train parts such as wheels and brake pads, as well as from the steel rails and power-supply materials, making the particles dominantly iron-containing. The dominantly ferrous particles are mixed with particles from a range of other sources, including rock ballast from the track, biological aerosols (such as bacteria and viruses), and air from the outdoors, and driven through the tunnel system on turbulent air currents generated by the trains themselves and ventilation systems.

Key factors influencing subway air pollution include types of brakes (electromagnetic or conventional brake pads) and wheels (rubber or steel) used on the trains but also station depth, date of construction, type of ventilation (natural/air conditioning), , train frequency and more recently the presence or absence of platform screen-door systems.

COMPARING PLATFORMS

The most extensive measurement program on subway platforms to date has been carried out in the Barcelona subway system, where 30 stations with differing designs were studied under the frame of IMPROVE LIFE project[14],with additional support from the AXA Research Fund.

During this project, we sampled widely from a range of subway lines and station types. Conclusions can be reached concerning which kind of subway stations are likely to have the best and worst air quality in any given system:

- The subway stations likely to have the worst air quality will be those with limited air volume (such as single tube lines with one narrow platform), weak or inappropriately designed ventilation systems (especially in deeper stations), a lack of platform screen doors protecting the commuter from the free ingress of contaminated tunnel air, a topography that involves elevation changes and therefore requires harder braking, and that are old enough to have generated years of particulate pollutants available for repeated resuspension throughout the system.
- In contrast, subway stations with the best air quality are likely to be larger and/or newer, with good air interchange with outdoor street air (although not sourcing from traffic hotspots in the city), with full length screen doors fitted to all platforms, and with a straight, horizontal trajectory that minimises brake and wheel wear.

14 The overall aim of IMPROVE (Implementing Methodologies and Practices to Reduce air pollution Of the subway enVironmEnt, LIFE13 ENV/ES/263)) is to test measures that can reduce PM concentrations in platforms and inside trains, taking into account variations in all the key factors such as station depth, date of construction, station design, type of ventilation, types of brakes used on the trains, train frequency and the presence or absence of platform screen door systems. It also comprises indoor carriage air quality. http://improve-life.eu/


Depending on the materials used in construction, you may breathe different kinds of particles on various platforms worldwide.
London Tube/Wikimedia, © BY-SA

The stations with just a single tunnel with one rail track separated from the platform by glass barrier systems showed on average half the concentration of such particles in comparison with conventional stations, which have no barrier between the platform and tracks. The use of air-conditioning has been shown to produce lower particle-matter concentrations inside carriages. Moreover, subway platform air quality is markedly influenced by the power setting of tunnel ventilation fans and whether or not the platform air is being introduced by impulsion or removed by extraction. Switching from platform impulsion to extraction with higher fan power in the tunnel results immediately in a marked increase in ambient inhalable PM, especially in the number of finest particles (submicron), which are presumably being drawn into the platform from the tunnel.

In trains where it is possible to open the windows, such as in Athens, concentrations can be shown to generally increase inside the train when passing through tunnels and more specifically when the train enters the tunnel at high speed.

Subway commuters are not being exposed to a more toxic atmospheric environment underground than when traveling through the traffic polluted city above

MONITORING STATIONS AND OTHER RECOMMENDATIONS

Although there are no existing legal controls on air quality in the subway environment, research should be moving towards realistic methods of mitigating particle pollution. Our experience in the Barcelona subway system, with its considerable range of different station designs and operating ventilation systems, is that each platform has its own specific atmospheric micro environment.

To design solutions, one will need to take into account the local conditions of each station. Only then researchers can assess the influences of pollution generated from moving train parts. Such research is still growing and will increase as subway operating companies are now more aware of how cleaner air leads directly to better health for city commuters.

These are some important points to consider in order to improve air quality in the subway environment:

- Trace metal components of moving train parts can be recognized in subway air and this prompts the question: are these materials as least toxic as possible? Some of the identified metals, such as manganese, copper, antimony and chromium, are known to produce toxic effects in humans, and so we would urge further research into the toxicity of inhalable friction- generated polymetallic particles, particularly brakes and copper-bearing catenary systems.
- At night, when neither train nor platform ventilation fans are operational, platform air quality improves when tunnel fans are working at lower power, whether or not they are operating on impulsion or extraction. The resulting reduction in air movement from tunnel to platform, due to subdued fan power and no train piston effect, presumably allows particles to settle out of suspension. Slowing down the speed of trains in places on lines where there are sharp curves and high gradients should reduce the emissions of iron-rich particles.
- Controlling the exchange between the outdoor and underground air masses using intelligent ventilation systems, avoiding sourcing from traffic hotspots in the city by careful selection and design of outdoor ventilation grill locations: impulsion of outdoor air at platforms during metro hours; Ventilation on platforms at frequencies higher than 25 Hz; Forced extraction of outdoor air at tunnel during operating hours; Air conditioning systems inside trains.
- The use of air purifiers: their effect is dependent on the distance to the passenger and the flow rate.
- Platform screen doors: modern subway lines are being fitted with platform screen doors, primarily for passenger safety reasons. The additional benefit to passenger health is their efficiency in reducing the ingress of contaminated tunnel air into the platform, especially of relatively coarse inhalable particles.
- Night maintenance: some good practices must be taken into account to ensure dust emission reduction such as conducting the cleaning as early in the night as possible and using dust suppressant (water and/or antiresupension polymer) when laying ballast.