Academic Article

Propagation of tracer gas in a subway station controlled by natural ventilation

Jonathan Spiegel*[1] Markus Brüne*[1] Nils Dering*[1] Andreas Pflitsch*[1] Zi Qian*[2]
Brian Agnew*[2] Roberto Paliacin*[2] Malcolm Irving*[3]

*[1] Department of Geography, Ruhr-University Bochum, Germany
*[2] NewRail, School of Mechanical and Systems Engineering, Newcastle University, UK
*[3] Nexus, Newcastle upon Tyne, UK

Corresponding author: Jonathan Spiegel, jonathan.spiegel@rub.de

ABSTRACT

To minimize risk from passengers and emergency rescue teams in occurrence of an event of the release of toxic agents or a fire scenario, an understanding of the dispersion process inside subway systems is valuable information. To gather knowledge about the airflow conditions in the subway system of the Tyne and Wear Metro in the centre of Newcastle upon Tyne, air velocity and tracer gas dispersion were obtained during a nightly experiment in the absence of train movement. Results indicate that dispersion ways and passenger routes often overlap.

Key Words : natural airflow, tracer gas experiment, chimney effect, subway station, sensor platform

1. Introduction

Recent research focusses on the effect of the piston wind as a passive way to ventilate subway systems. But this is only one part of the complex system of air currents in the underground. Beside the piston effect and an active ventilation, a natural ventilation based on background airflows occurs in subway systems (Pflitsch et al., 2002). The understanding of this natural background airflow is helpful to obtain a pleasant environment for passengers and is highly important to identify the dispersion paths of smoke and other toxic agents. Insufficient understanding of the variable background airflow can hinder effective rescue of passengers and endanger the life of emergency response teams.

In the past it was assumed, that air currents in the underground only come about the movement of trains. These currents were described as unsteady, alternating and decisive for airflows inside subways stations. For some time the existence of a natural background airflow, which is independent of train movement and ventilation, was observed in several subway systems. (Pflitsch 2001). This background airflow is a highly complex system of air currents with spatial and temporal variation, which can be defined as an independent airflow system. It is always present but mainly masked by the movement of trains. Short time after termination of traffic (about 1-3 minutes) it occurs noticeable (Pflitsch et al., 2011).

The complex system of air currents is influenced by a variety of factors. Mainly by the outside weather conditions. This weather-related influence is in complete contradiction to the conventional method of applying a permanent uniform airflow to the boundaries of numerical simulations.

Temperature differences within the subway system and between subway and outside atmosphere have a strong influence on underground air currents. High temperature gradients usually lead to stronger and more stable airflows in the tunnel system. This effect can be observed especially in winter months when the temperature inside the system lags behind the changing of the outside temperature. Large temperature differences between inside and outside, preferably during periods of extreme cold or heat leads to strong compensating airflows between inside and outside (Pflitsch et al., 2013). During cold weather conditions, when the outside air is a much colder than the air in the subway, strong chimney effects can be found at connections to the surface or at vertical structures within a subway station. (Spiegel et al., 2014)

2. Case study Monument Station, Newcastle upon Tyne

This paper examines the Monument station of the Tyne and Wear Metro in Newcastle upon Tyne, a light rail system in North

East England and only one of four underground metro systems in the UK.

The underground area of the subway system is located entirely within the city centre of Newcastle upon Tyne. It consists of a north-south running line with tunnel openings north of Jesmond Station and south of Central Station with opening to the Tyne Bridge. The east-west running line has tunnel openings after Manners Station and St. James. All these stations are each adjacent to Monument station, which is the main interchange station. The underground area is a total of 4km long and consists of six stations.

The Experimental setting was intended to examine air flow and tracer gas dispersion in the Monument station. Monument station is the most complex station within the system, consisting of two platform levels and a main concourse with connections to the surface. The north-south line (platforms 1 and 2) is at the lowest level (see Fig. 1). Both platforms are connected with the station concourse and with a direct connection that allow changing platforms without moving through the main concourse. Unlike previous studies in which air samples were taken with syringes (Pflitsch et al., 2013), which were afterwards analysed in a laboratory, this experiment was accomplished with a new measuring system. The new sensor platforms were part of the research project "Measuring system for the determination of the

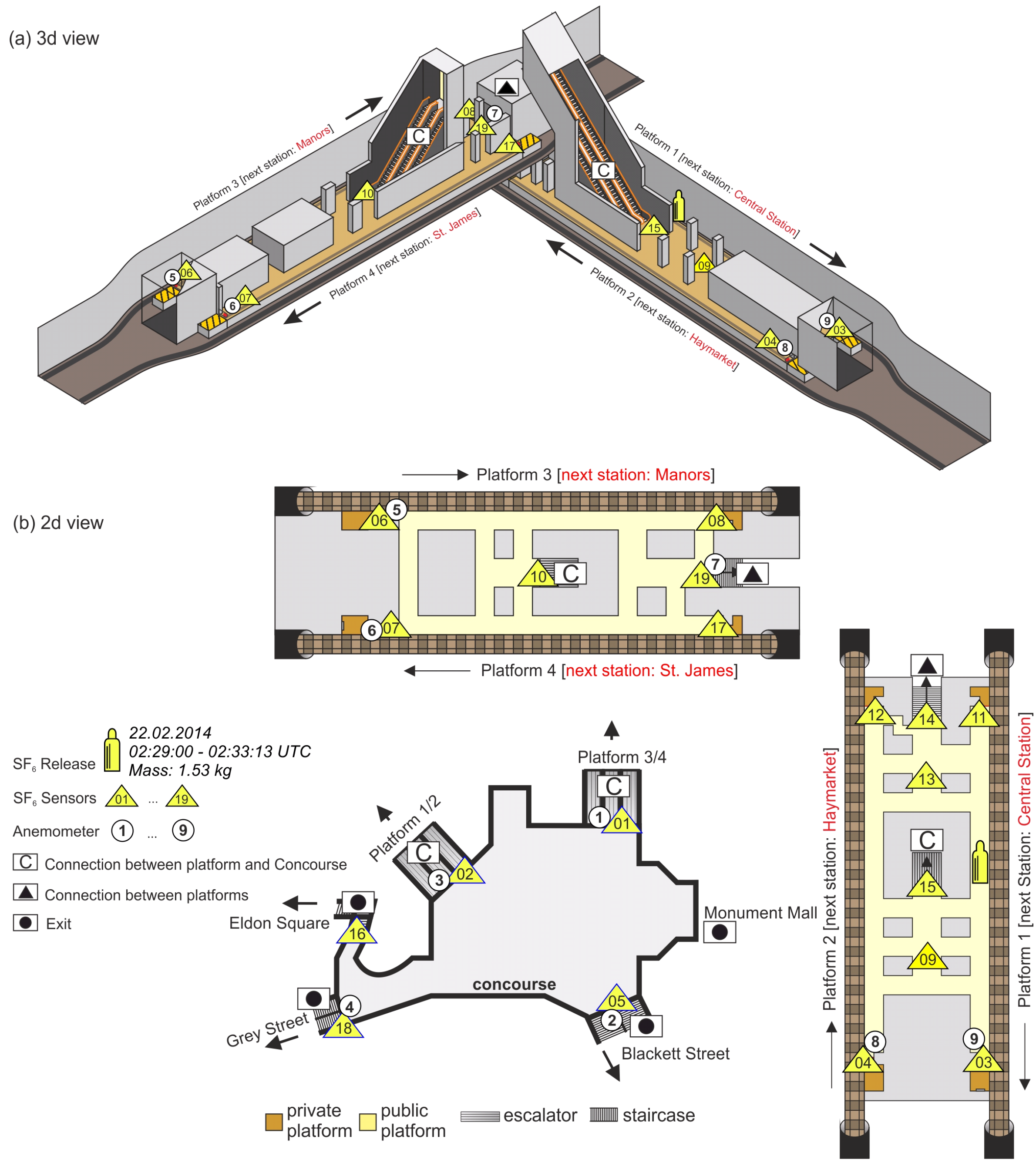

Fig. 1 Experiment setting, (a) 3d view, (b) 2d view of Monument Station

propagation of hazardous materials in critical infrastructures and complex buildings for the prevention of civil disasters" funded by the German Federal Ministry of Education and Research (BMBF, Grant number 13N11673) and were able to measure concentrations of 0.05 ppm to 50 ppm (optical measurement range) of the tracer gas sulfur hexafluoride (SF_6). (Potje-Kamloth, 2014).

All measurements were taken during operational break in the night between 21st and 22nd February 2014. The release of tracer gas started at 2:29 (UTC) and ended at 2:33. In total 1.53kg SF_6 was released. The measurement lasted till 3:10. The time slot was chosen as not to disrupt the normal operation of the train service and examine the propagation based on the natural background airflow. All instruments were placed on temporary stands at different locations (see Fig. 1) on all platforms and the main concourse.

The Release Point of the tracer gas was at the lowest level in the middle of platform 1. A gas sensor was placed at every in- and outlet of the tunnel, at the connections to the main concourse and the other platform level and at two places in the middle of the level. As on the other level, platform 3/4 was equipped with gas sensors at each in- and outlet. The position of the velocity sensors can be seen in Figure 1.

The goal of the experiment was to examine, how fast dispersion

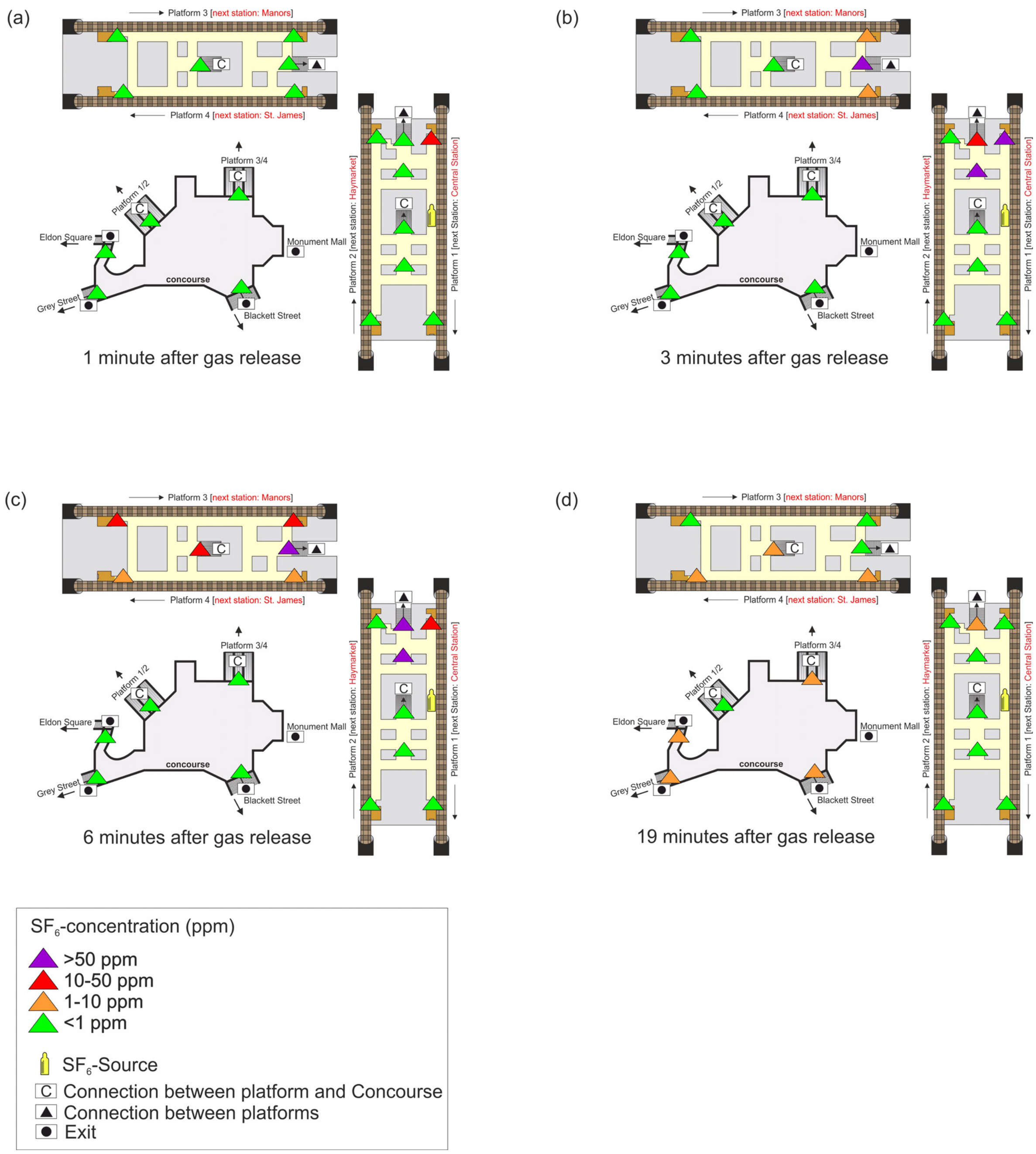

Fig. 2 Temporal development of tracer gas concentrations at 19 different locations inside Monument station during tracer gas experiment. Night from 21th to 22th February 2014

of hazardous substances will contaminate a whole subway station and which parts of the station were affected and which parts stay free of contamination. Similar experiments in other subway systems showed, that within 5 minutes nearly most evacuation routes were contaminated.

3. Results

Figure 2a-d show the temporal development of tracer gas dispersal during the experiment. The tracer gas was emitted on the lower platform in the middle of track 1, from where it spread within the first minute to the adjacent tunnel of track 1. The other parts of the station were not affected at this time. After three minutes the gas spread via the stairway, connecting the two platforms, with a very high concentration over 50 ppm. Up to this time, only the parts near this stairway and the adjacent area to the northward tunnel were involved.

After six minutes only the northern area of the lowest level was affected, while the remaining parts stay free of concentration. The upper level is now completely filled with tracer gas while the concourse stays clear.

After 19 minutes, the concentration has almost completely disappeared from the lower level. The upper level is still partially affected but with a rather low concentration. However, the tracer gas has moved from the upper level via the central stairway to the concourse and contaminated a large area. All three exits to the surface show a medium concentration of SF_6.

Remarkable is that the central stairway from the lower level to the concourse, despite the short distance to the release point, stays free over the entire period. In an emergency, this would be the ideal escape route from the lower level through the concourse, which shows no contamination until 10 minutes after gas release, to the surface. An important result shows the contamination of the stairway connection between the two platforms. This stairway would have been uncertain from the beginning.

The main reason for the rapid propagation to the upper level can be found in chimney effects supported by a clear inflow of warm air from the southward tunnel at the lower level. Figure 3 shows a steady inflow of approx. 1 m/s for the ultrasonic anemometer 8 and a smaller inflow of 0.25 m/s at ultrasonic 9 on the lower level. A negative value always means air is flowing towards the ultrasonic, while positive means a flow in opposite direction of the ultrasonic. The upper level shows a small but steady outflow of 0.4 m/s in direction of St. James. The ultrasonic placed in front of the stairway between upper and lower level shows a strong airflow of 1.25 m/s from the lower to the upper level. The exit Blackett Street in the concourse demonstrates a strong airflow to the surface with 1.5 m/s, interrupted by various dips of cold air. The connection between concourse and the two platform levels shows different airflow patterns. The connection from the concourse to platform 1/2 shows a steady flow with 1

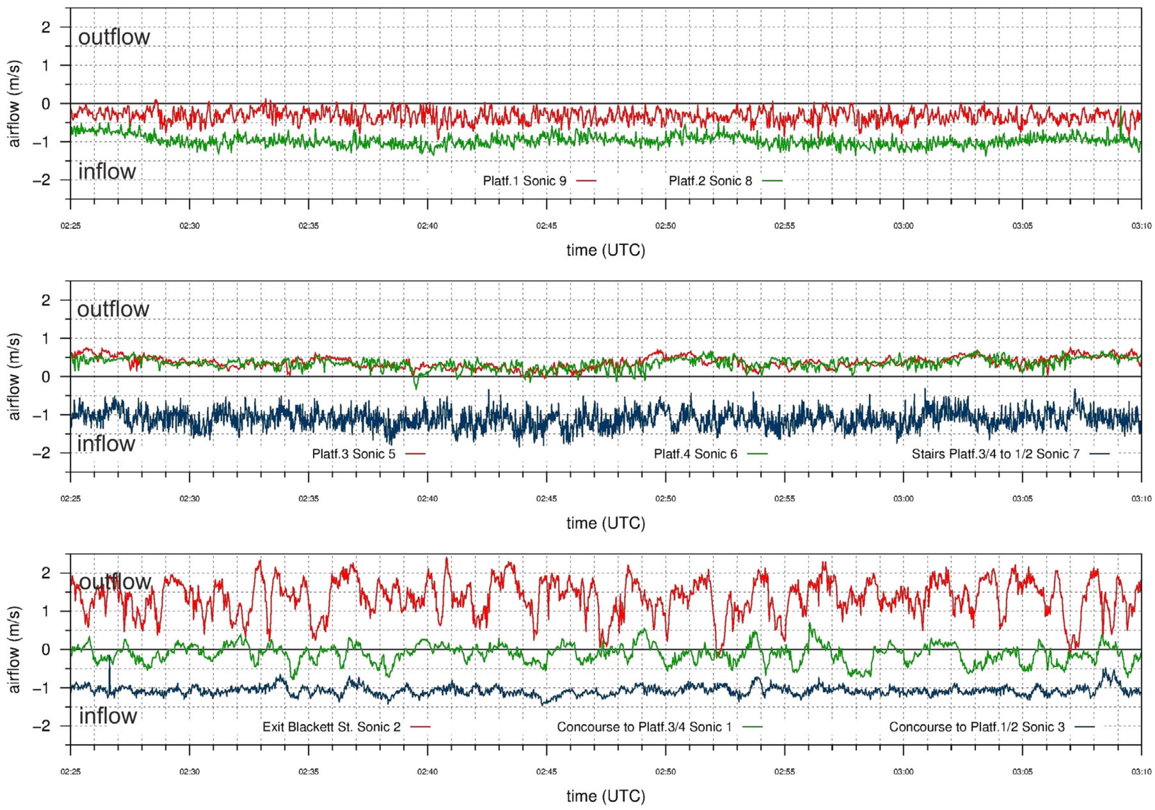

Fig. 3 Variation of Air Velocity at the Monument Station

m/s from the lowest level to the concourse while the other connection is alternating with slightly more movement from the upper level to the concourse (see Fig. 3). The concourse level with connected shops is relatively over warmed to the rest of the station and therefore pulls air out of the lower parts, which results in chimney effects.

Beside chimney effects within the station, the stable wind conditions on the lower level can be explained by the tunnel geometry. Northwards the tunnel rises up to the station after the next at approx. 25m. The relatively light warm air within the tunnel system is moved up to a chimney effect through the rising tunnel. The same situation occurs on the upper level, where the next station St. James is about 10m higher than Monument station.

4. Conclusion and further work

Previous measurements inside the tunnels have shown the presence of a strong background airflow that is driven by a chimney effect based on the inclination of the tunnel (Pflitsch et. al., 2011). This background airflow was also responsible for the dispersion of the tracer gas experiment.

The influence of the tunnel geometry and chimney effects within the subway station on the propagation paths could be clarified. Knowledge of these processes shows how wrong it may be to expel static escape routes. A system that identifies escape routes dynamically and assigns the safest way out of the compound, may save lives in fire or disaster.

The use of new measurement technology significantly expands the possibilities for the implementation of tracer gas experiments. Due to a limited number of syringes that can be analysed in a laboratory, air samples could yet only be taken every minute over a time period of 20-40 minutes. With the new automatic sensor technique it is now possible to take samples with a temporal resolution of 1-2 seconds, when the time period is only limited by the battery service life of approx. 10 hours. This allows completely different experiments, such as the spread of tracer gas from one station to the neighbouring stations or the outlet of tracer gas inside a moving train to investigate the spreading from the train into the approached stations. Such experiments could be accomplished yet and will be published in near future.

The tracer gas experiment in this station has shown a clear situation of tracer gas contaminated and free areas.

References

(1) Pflitsch, M. Brüne and H. Küsel, Spatial variability and Dynamic changes in air temperature distribution within different subway stations, 15th Conf. on Biometeorology/Aerobiology and 16th International Congress of Biometeorology (2002).

(2) A. Pflitsch, Investigations on air currents in underground public transportation systems, in Meteorologische Zeitschrift 10 (4) (2001).

(3) A. Pflitsch, M. Brüne, B. Steiling, M. Killing-Heinze, B. Agnew, M. Irving and J. Lockhart, Air flow measurements in the underground section of a UK light rail system, in: Applied Thermal Engineering 32, 22–30 (2011).

(4) A. Pflitsch, M. Brüne, M. Killing-Heinze, J. Ringeis, B. Agnew, and B. Steiling, Natural Ventilation as a Factor Controlling the Dispersal of Airborne Toxins in Subway Systems in a Disaster Situation, Journal of Transportation Safety & Security 5(1), 78-92 (2013).

(5) J. Spiegel, M. Letzel, T. Flassak and A. Pflitsch, Dispersion of Airborne Toxins in a highly complex Subway Station, in Proceedings of the 6th International Symposium on Tunnel Safety and Security 2014, 255-263 (2014).

(6) Potje-Kamloth, K. (2014): Finding the ideal escape and emergency route, http://www.imm.fraunhofer.de/content/dam/imm/de/documents/pdfs/PD_MAusKat_final.pdf (December 11, 2014).

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