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Commuter exposure to black carbon, carbon monoxide, and noise in the mass transport *khlong* boats of Bangkok, Thailand

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ABSTRACT

This work quantifies commuter exposure to black carbon, CO and noise when waiting for and travelling in the mass transport *khlong* (canal) boats in Bangkok, Thailand. Exposure to toxic pollutants and acute noise is similar or worse than for other transportation modes. Mean black carbon concentrations observed at one busy pier and along the main canal were much higher than ambient concentrations at sites impacted by vehicular traffic. Concentrations of CO were similar to those reported for roadside areas of Bangkok. The equivalent continuous sound levels registered at the landing pier were similar to those reported for roadsides, but values recorded inside the boats were significantly higher.

1. Introduction

Many cities in developing countries lack efficient mass transport systems. Bangkok, the capital of Thailand, is an example. Increased economic growth has led to rapid urbanization, but the development of mass transport systems has not kept pace. The daily commute for thousands of residents often involves long journeys in over-crowded, uncomfortable, unsafe, polluting and noisy vehicles (Bae and Suthiranart, 2003). *Khlong* (canal) boats in Bangkok are a mass transport alternative, providing service to over 100,000 people daily. Running along the Chao Phraya river and some inner canals, which work as exclusive transit-ways, they provide a faster alternative to navigate the city. The boat services are in considerable demand despite perceptions of being unreliable and unsafe. With the exception of Ongwandee and Chavalparit (2010) on exposure to BTEX hydrocarbons (benzene, toluene, ethylbenzene and the xylene isomers), no data are available to assess the public health risk of the *khlong* boats. Here we measure black carbon (BC) and carbon monoxide (CO) concentrations, and noise level related to the *khlong* boats. The measurements were conducted at one of the busiest piers and within boats during commutes. Our study addresses some aspects of pollution related to this popular mode of public transportation.

2. Methods

Khlong boats are traditional long-tailed boats powered by one large diesel engine with an exhaust tailpipe at the rear. The boats investigated in this study have engines located behind the middle passenger section. Passengers sit in 11–15 rows in front of the engine, and in five behind. Some space around the engine allows passengers to stand. The boats have capacity to transport about 90 passengers. Roofs are constructed from canvas sheets and the sides are open to provide ventilation. Side curtains installed to reduce splashes and wake spray are often ineffective. The boats operate from 5:30 to 20:30 departing from main passenger piers approximately every 3–6 min.

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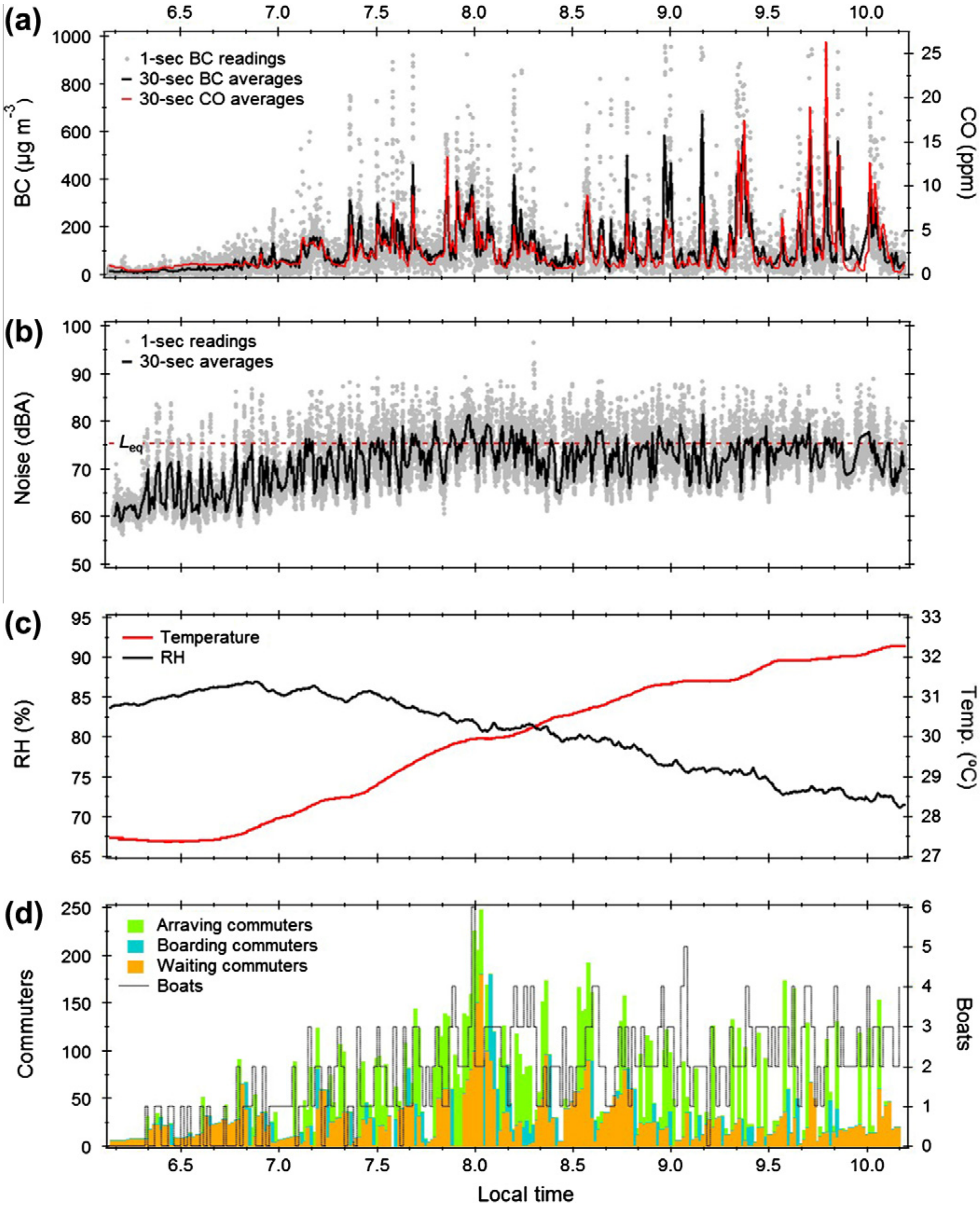

Fig. 1. Pollution, noise, temperature and humidity to which commuters are exposed at Pratunam pier during a typical weekday morning (18-May-2012).

Passenger exposure while waiting for and travelling in the boats was evaluated by fix measurements at the Pratunam pier and along the eastern line of the Saen Saeb canal, an artery passing through the heart of Bangkok. Measurements along the canal covered a route of 13.3 km in both directions between Pratunam and Wat Sriboonreuny piers. The study was conducted during 6 days in the months of May and June 2012. None of the sampling periods were affected by rain. The majority of measurements at the Pratunam pier were made during the morning rush hour (7:00–9:00). Measurements along the canal were made during the late morning and early afternoon.

Instruments measuring black carbon (micro-aethalometer AE51, AethLabs), CO (T15n, Langan), noise (TES-1353, TES), temperature and relative humidity (HOBO Pro v2, Onset) were hand carried near breathing height during measurements. They were synchronized and programmed for 1 s readings. Previous studies have reported that micro-aethalometer readings are sensitive to mechanical shock or vibrations (Apte et al., 2011). To counter this, in this analysis, we ignore both negative concentrations and positive spikes over 200 μg m^{-3} not correlated with CO spikes. The BC data required an additional adjustment to account for the instrument sensitivity associated with the filter load. Briefly, because BC concentration is measured by changes in light attenuation on a disposable filter through which sample air is drawn at 50 cm^3 min^{-1}, concentrations were adjusted using the empirical relationship of Kirchstetter and Novakov (2007) based on the instrument-reported attenuation coefficient.

3. Results

Observed BC and CO concentrations were highly variable as a consequence of individual boat state of repair, operator skill, and irregular timing of arrival and departure. Weather conditions were hot and humid during all measurements; small variations did not influence the BC and CO concentrations. Mean concentrations of BC ranged from 74 to 136 $\mu g\ m^{-3}$ at Pratunam pier; 15–411 $\mu g\ m^{-3}$ from inside the boats. Similarly, the mean concentrations of CO ranged from 2.5 to 3.6 ppm and 0.3 to 8.3 ppm at the pier and on the boats. The exposure inside the boats depended on the engine conditions, driving style and passenger seat location. For example, passengers seated in the rows behind the engine were exposed to higher concentrations of BC and CO with frequent short-lived (about seconds) fumes exceeding 1000 $\mu g\ m^{-3}$ and 30 ppm. BC fumes over 200 $\mu g\ m^{-3}$ were observed, however, with frequencies of 2–10 min in many other locations in the boat. These fumes occurred when the boat approached passenger piers, as fumes concentrated in the passengers seating area as the boats decelerated. In contrast, the boundary layer generated around the boat during fast movement prevented the incursion of pollutants inside the boat.[1]

The BC and CO concentrations at the Pratunam pier were higher (in terms of a normal distribution) than those recorded inside the boats during commuting trips. Plumes over 1000 $\mu g\ m^{-3}$ were observed about every 15 min. The incidence of plumes over 200 $\mu g\ m^{-3}$ was similar to that observed when travelling in the boats. The duration of these high-concentration periods ranged from 3 s to 3.5 min. Longer periods of high concentrations occurred when two or more boats approached or departed from the pier simultaneously, a situation that was common during peak commuter periods.

The BC concentrations at the pier and along the canal were higher than the maximum hourly mean concentration of 28 $\mu g\ m^{-3}$ reported by Sahu et al. (2011) for an urban site of Bangkok impacted by a busy highway. Kim Oanh et al. (2010) found that 68% of the fine aerosols ($PM_{2.5}$) emitted by diesel vehicles in Bangkok corresponded with BC. If we use the same ratio for the *khlong* boats, the mean concentrations of $PM_{2.5}$ at the Pratunam pier range from 110 to 200 $\mu g\ m^{-3}$. Similarly, the BC spikes over 200 and 1000 $\mu g\ m^{-3}$ represent $PM_{2.5}$ spikes over 295 and 1470 $\mu g\ m^{-3}$. In contrast, all mean concentrations of CO in the pier and inside the boats were similar to the concentrations reported in roadside areas of Bangkok (<10 ppm). These concentrations were within the 1-h standard of 30 ppm for Thailand (Pollution Control Department, 2012).

Because BC and CO are products of incomplete combustion, the slope of the BC–CO correlation is a useful parameter for characterizing emission sources. Here the slopes of 24 and 25 $\mu g\ m^{-3}\ ppm^{-1}$ were obtained using regression analysis based on 30-s average concentrations. The correlation coefficients were 0.71 and 0.64, inside the boats and on the pier, that can be compared with Sahu et al. (2011) estimate of about 10 $\mu g\ m^{-3}\ ppm^{-1}$ for Bangkok vehicular traffic, composed of gasoline- and diesel-powered vehicles, and within the range found by Verma et al. (2010) for diesel vehicles.

The highest noise levels were recorded while travelling along the canal, and occurred at maximum speeds of 30–40 $km\ h^{-1}$; the mean speed along route was 20 $km\ h^{-1}$. The equivalent continuous sound level (L_{eq}) ranged from 83 to 98 dBA inside the boats and 70–78 dBA at Pratunam pier. Instantaneous noise levels over 100 dBA occurred in sectors when boats reached maximum speeds; this was at the "extremely annoying" noise level for commuters (Ouis, 2001).[2] The L_{eq} values recorded at Pratunam pier were similar to those at roadsides in Bangkok; between 61 and 86 dBA over 24 h (Pollution Control Department, 2012).

BC and CO concentrations and noise level increase with the number of commuters and boats during the morning of a typical weekday (Fig. 1). The low frequency of boats before 6:30 hold pollutants and noise levels down, but during the peak morning rush hour (8:00–9:00), pollutant concentrations and noise level rose. After 9:00 the frequency of boats decrease as the number of commuters fell, with the remaining boats idling and keeping pollutants and noise levels high.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jrp.2013.02.005.

[1] The same type of boundary layer effect was found by Ongwandee and Chavalparit (2010).

[2] The World Health Organization recommends a 24-h L_{eq} <70 dBA, with occasional noises <110 dBA, to avoid hearing impairment in traffic areas (Berglund et al., 1999).

References

Apte, J.S., Kirchstetter, T.W., Reich, A.H., Deshpande, S.J., Kaushik, G., Chel, A., Marshall, J.D., Nazaroff, W.W., 2011. Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India. Atmospheric Environment 45, 4470–4480.

Bae, C.H.C., Suthiranart, Y., 2003. Policy options towards a sustainable urban transportation strategy for Bangkok. International Development Planning Review 25, 31–51.

Berglund, B., Lindvall, T., Schwela, D.H. (Eds.), 1999. Guidelines for Community Noise, World Health Organization. Geneva, Switzerland.

Kim Oanh, N.T., Thiansathit, W., Bond, T.C., Subramanian, R., Winijkul, E., Paw-Armart, I., 2010. Compositional characterization of $PM_{2.5}$ emitted from in-use diesel vehicles. Atmospheric Environment 44, 15–22.

Kirchstetter, T.W., Novakov, T., 2007. Controlled generation of black carbon particles from a diffusion flame and application in evaluating black carbon measurement methods. Atmospheric Environment 41, 1874–1888.

Ongwandee, M., Chavalparit, O., 2010. Commuter exposure to BTEX in public transportation modes in Bangkok, Thailand. Journal of Environmental Sciences 22, 397–404.

Ouis, D., 2001. Annoyance from road traffic noise: a review. Journal of Environmental Psychology 21, 101–120.

Pollution Control Department, 2012. Thailand State of Pollution. Report 2010. Ministry of Natural Resources and Environment, Bangkok.

Sahu, L.K., Kondo, Y., Miyazaki, Y., Pongkiatkull, P., Kim Oanh, N.T., 2011. Seasonal and diurnal variations of black carbon and organic carbon aerosols in Bangkok. Journal of Geophysical Research 116, D15302. http://dx.doi.org/10.1029/2010JD015563.

Verma, R.L., Sahu, L.K., Kondo, Y., Takegawa, N., Han, S., Jung, J.S., Kim, Y.J., Fan, S., Sugimoto, N., Shammaa, M.H., Zhang, Y.H., Zhao, Y., 2010. Temporal variations of black carbon in Guangzhou, China, in summer 2006. Atmospheric Chemistry and Physics 10, 6471–6485.