Personal exposure of seafarers to air pollutants and perceived indoor air quality on a passenger ferry

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SUMMARY

The purpose of this study is to examine crew members' personal exposure and perceived air quality on board a Swedish passenger ferry before and after a change of fuel type. Personal exposure was measured in the breathing zone of 20 crew members and quantified in terms of concentrations of nitrogen dioxide (NO_2) and total volatile organic compounds (TVOC) with focus on benzene. Measured concentrations are compared with international indoor air quality guidelines and occupational exposure limit values. The perceived indoor air quality was assessed through a self-reporting questionnaire. The results show that the measured personal exposure was largely below Swedish occupational exposure limit values and international guideline values. Elevated levels were found especially in the engine crew samples. The subjective assessment of the air quality showed the air to be perceived as just acceptable with a slight odour, and a sense of the air being dry and stuffy.

PRACTICAL IMPLICATIONS

Indoor air quality and personal exposure to harmful pollutants on board merchant vessels has not received much attention. Increased knowledge of type of pollutants and its concentrations is valuable when deciding on appropriate measures to further reduce health risks and also to mitigate worries among seafarers.

KEYWORDS

Indoor air quality, ship, fuel change, gaseous air pollutants, work environment.

1 INTRODUCTION

The purpose of the study presented in this paper is to examine crew members' personal exposure to some harmful air pollutants on board a Swedish passenger ferry, before and after a change of fuel type, and how the crew perceives the indoor air quality.

Despite substantial development of working conditions on board contemporary merchant vessels, towards more sedentary monitoring and administrative work, the shipping industry still suffers from a high level of occupational accidents, and mortality and morbidity rates for seafarers remain among the highest for all occupations (Ellis, Sampson, & Wadsworth, 2011; Oldenburg, Baur, & Schlaich, 2010). The high incidence of work-related ill-health and disorders means that many individuals are afflicted with aches, pains and sometimes lifelong disability and relegation from the labour market. It also means disruptions of output and heavy expense to businesses and community (Österman, 2012).

Notably, a vessel is both a working, living and recreational environment, where the seafaring crew may spend prolonged periods of time on board, with small opportunities to change or influence the indoor environment. Indoor air may contain about 6 000 compounds. These compounds can cause negative sensory effects on humans, and as a consequence, people staying indoors are known to complain of poor air quality (Wargocki, 2004). Yet, the shipboard indoor air quality has received little attention and not much work has investigated seafarers' personal exposure to toxic air pollutants on board.

There are some studies on exposure to benzene and carcinogenic agents on oil and chemical tankers (e.g. Jacobs et al., 2011; Kirkeleit, Riise, Bråtveit, & Moen, 2006; Moen et al., 1995). On other type of vessels, previous research has demonstrated that the indoor air pollution on board is largely dominated by the evaporative emissions from the vessel's own bunker fuel and emissions originating from the running of main and auxiliary engines and boilers (Langer et al., 2014). In an older study by Kim and Lee (2010), the indoor air quality on board two newly built vessels, a large passenger ship and an oil tanker, was investigated. The results showed elevated levels of CO and CO_2 on both ships as a result of the combustion sources present in the living quarters. More knowledge is however needed on the personal exposure to pollutants present in the indoor environment on board and its potential health effects.

2 METHODS FOR DATA COLLECTION AND ANALYSIS

Measurements were performed on two occasions on board a Swedish passenger ferry during a cruise in the Baltic Sea. The ferry has a capacity for 1 800 passengers and does not carry any other type of cargo. It is operated by approximately 150 persons during peak season (about 100 persons during the measuring campaigns), has a gross tonnage of 35 000 tons, is 177 meters long and 28 meters wide. The ferry is powered by four Wärtsilä 6L46 diesel main engines with total power of 23 400kW. The first measuring campaign took place in November, 2014. During this voyage, the main engines were fuelled with heavy fuel oil (HFO) with 1% sulphur content. The second campaign took place in April 2015, with the engines operating on a hybrid ultra-low sulphur fuel oil with 0.1% sulphur.

In addition to the personal exposure measurements reported in this paper, the indoor air quality was examined on multiple locations on board the ship through a comprehensive measuring of temperature, relative humidity, concentration of CO, CO_2, NO, NO_2, ozone, SO_2, VOC, formaldehyde, PAH, $PM_{2.5}$, submicron and ultrafine particles. The results of these measurements are presented in Langer et al. (2016). At the same time, outdoor air reference samples were collected on upper deck, approximately 20 meters above sea level.

Sampling and analysis of personal exposure

During both campaigns, personal exposure was measured using passive diffusive samplers in the breathing zone of ten crew members from the deck, engine and catering departments. In total, 20 persons carried the samplers during their ordinary work for about 48 hours.

Concentrations of NO_2 were sampled using IVL passive samplers (Ferm & Rodhe, 1997) and analysed by wet chemical techniques. Sampling of VOC was done by Tenax® adsorbent tubes (Perkin-Elmer) (Uhde, 1999). After exposure, the tubes were thermally desorbed from the solid adsorbent and analysed by gas chromatography/mass spectrometry (GC/MS) and quantified as Total Volatile Organic Compounds (TVOC) in toluene equivalents.

Self-reporting questionnaire

Subjective assessments on the perceived indoor air quality were collected by a self-reporting questionnaire that was distributed to all crew members during the voyage. The questionnaire included three questions, which were asked on one page for the work place, and on the second page for the cabin. In the first question, the respondent was asked to assess the acceptability of the air quality in general, by marking on a continuous acceptability scale with the two extreme ends labelled '*Clearly unacceptable*' and '*Clearly acceptable*' (as illustrated in Figure 1a). This kind of scale is recommended for use by untrained respondents that are not used to observe and assess indoor air quality. Coding on a scale from -1 to 1 with the split junction coded as 0 is made after the assessments are completed (Wargocki, 2004).

In the second and third questions, the respondent is asked to assess odour intensity and the perceived air quality in non-technical terms, describing the air as fresh or stuffy, dry or humid, dusty or not dusty and mouldy or not mouldy. This assessment is done by marking on horizontal visual analogue scales (Figure 1b), and coding is made after the assessment on a scale from 0 to 10 (Wargocki et al., 1999).

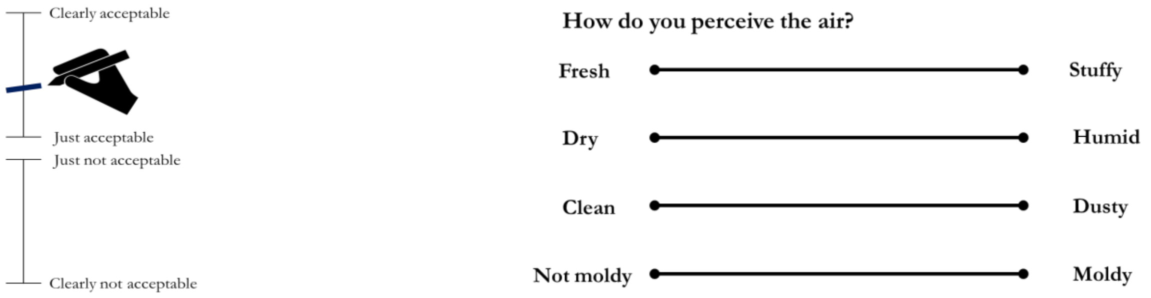

Figure 1. (a) Continuous acceptability scale, and (b) horizontal visual analogue scale.

3 RESULTS AND ANALYSIS

The results presented and discussed below are a selection of a vast collection of data. Measured concentrations of NO_2, benzene and TVOC are compared to the occupational exposure limits that apply for all Swedish flagged ships in the Swedish Transport Agency's regulations and general advice about work environment on ships (TSFS, 2009:119). Acknowledging the ships as a living environment as well as a working environment, the parameters are also compared to recommended guideline values for indoor air quality provided by the World Health Organization (WHO, 2010).

Personal exposure measurements

Figure 2 displays the measured concentrations of NO_2 for the different individuals.

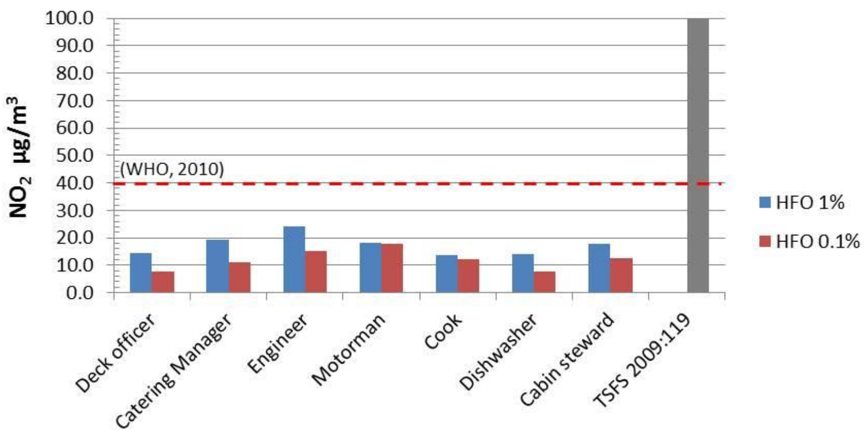

Figure 2. Personal exposure to concentrations of NO_2 compared to Swedish occupational exposure limit (TSFS 2009:119) and the WHO recommended guideline value.

NO_2 originates from combustion processes and is commonly used as an indicator for diesel engine exhaust emissions. All NO_2 concentrations were well below the Swedish occupational exposure limit of 100 µg/m^3 (set in 1990), and the recommended guideline value for NO_2 of 40 µg/m^3 as an annual average, illustrated with the red dashed line (WHO, 2010).

Figure 3 displays measured personal concentrations of benzene before and after the fuel change. The occupational exposure limit for benzene onboard Swedish ships 1 500 µg/m^3 for an 8 hour period was prescribed in 1990 and has not been revised since. For comparison, although without any legal value, the Swedish health based long-term average recommendation for the general population of 1,3 µg/m^3 (Victorin, 1998) is illustrated with a red dashed line in the figure. All samples were well below the occupational exposure limit value. During both campaigns, the highest concentrations were found in the samples carried by the motorman (3.9 µg/m^3 and 2.3 µg/m^3).

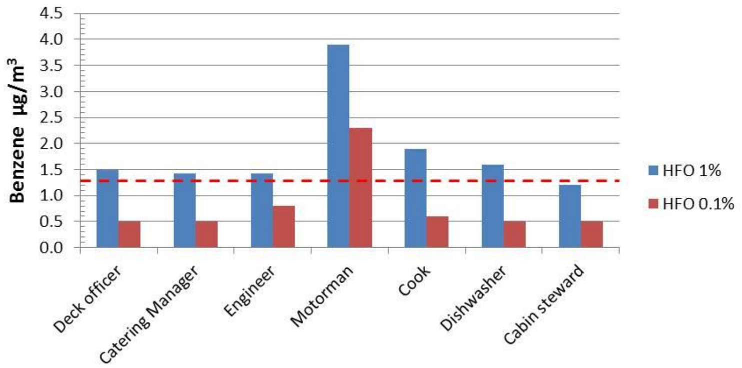

Figure 3. Personal exposures to concentrations of benzene. The Swedish health based recommended guideline value of 1.3 µg/m^3 is showed as a red dashed line for comparison.

Elevated levels of TVOC were found especially in the samples carried by the engine and deck crew, but also in the sample carries carried by the cook and a cabin steward (Figure 4). The motorman was exposed to very high concentrations (2 840 µg/m^3 and 2 566 µg/m^3) due to the cleaning and service work that was carried out during the measurements on one of the ship's heavy fuel oil purifiers. Work tasks included cleaning parts with diesel oil, water and compressed air in a cleaning room. During the first campaign, the sample from the bosun (a foreman for the deck crew) also showed elevated levels, 1 001 µg/m^3.

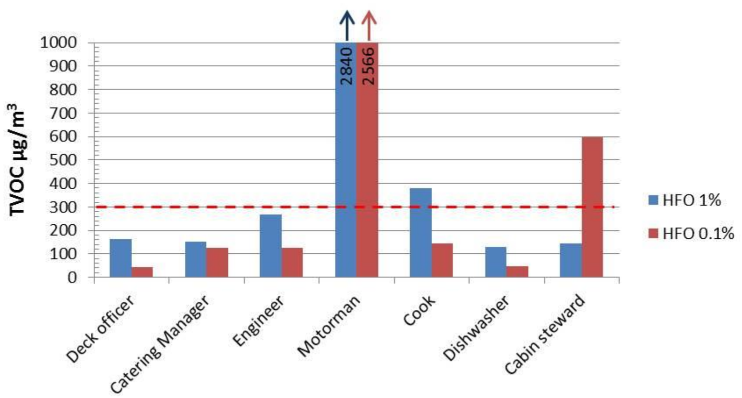

Figure 4. Personal exposure to TVOC concentrations compared to the 'acceptable' value, marked by the red dashed line.

Since a TVOC value is not simply the sum of the volatile organic compounds detected in an analysis, but expressed as toluene equivalents, it is necessary to identify the individual compounds in the air. Hence, there is no specific exposure limit for TVOC. However, scientific literature on the topic generally seems to agree that < 300 µg/m^3 represents an 'acceptable' TVOC level (e.g. Ayoko & Wang, 2014).

As an example, the chromatograms in Figure 5 show the differences in chemical composition of the organic air pollutants for the two crew members with the highest level of TVOC during the first campaign, the motorman (a) and the bosun (b). The sample from the motorman contains long-chained aliphatic hydrocarbons (C_6-C_{20} n-alkanes), and BTEX aromatics (benzene, toluene, ethylbenzene, xylenes and higher substituted benzenes), clearly originating from the ship's fuel oil and corresponds well to the work tasks performed during the measurements. The sample from the bosun contains glycol ethers, a group of solvents commonly used in paints and cleaners.

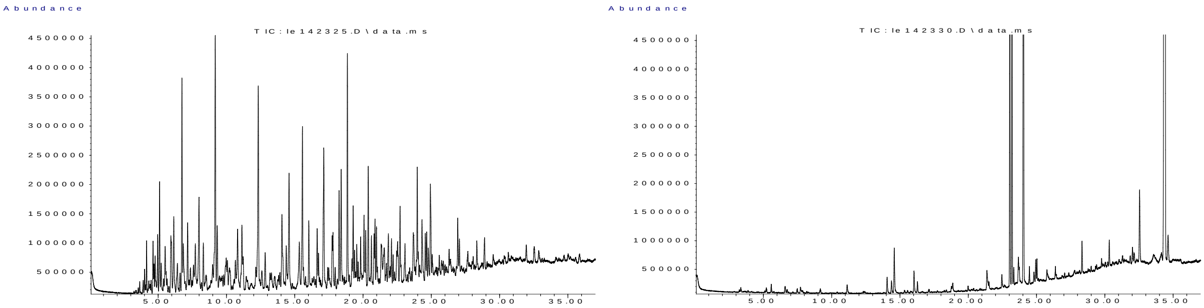

Figure 5. Chromatograms of the HFO 1%samples from the a) motorman and b) the bosun.

Self-reported questionnaires

The questionnaire was answered by 31 respondents during the first campaign and 67 during the second, corresponding to a rather low response rate of about 35% and 74% respectively. Figure 6a presents the subjective assessment of the acceptability of the air quality in general, at the work place and in the cabin, before and after the fuel change.

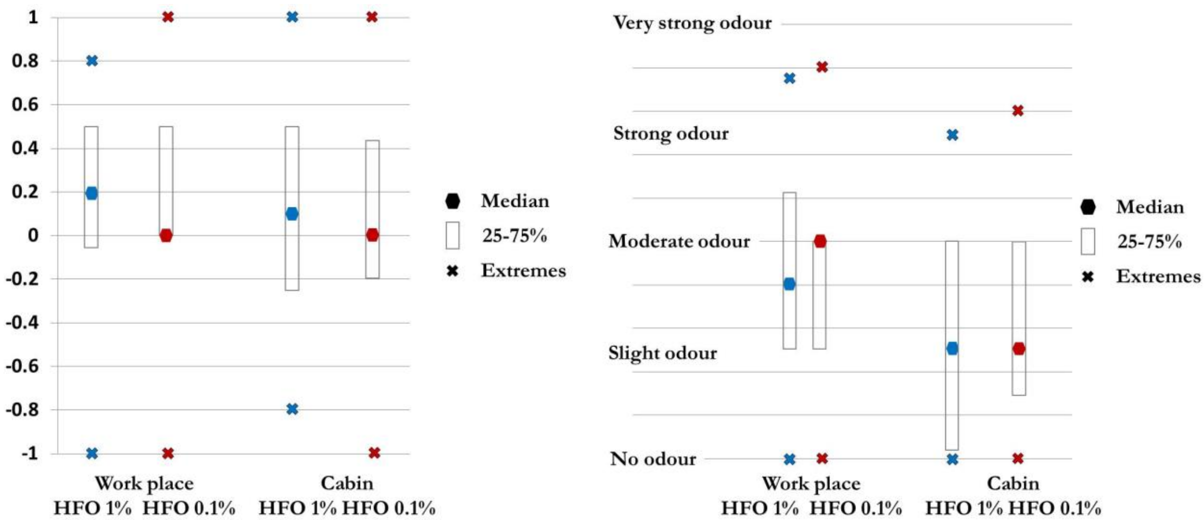

Figure 6. Subjective assessment before and after the fuel change of (a) general air quality acceptability at the work place and in the cabin, and (b) the odour intensity at the work place and in the cabin.

Overall, the respondents find the air quality just acceptable. Before the fuel change, the median value is 0.2 for workplace and 0.1 for cabin. After the fuel change, the median value is 0 for both work place and cabin. As shown in Figure 6b, respondents perceive a light to moderate odour at the work place and a slight odour in the cabin. When controlling for work place, it is the crew working in the restaurants that perceive the highest odour intensity at work.

Figure 7 shows the median and distribution of the subjective assessment of the air quality for the work place and cabin before the fuel change, and Figure 8 after the fuel change. The response patterns are similar for the work place and the cabin. The air on board is generally being perceived as rather stuffy, dry, somewhat dusty, and not mouldy. As with the reported odour intensity, the restaurant crew also perceives the air at the work place as being 'mouldy' to a higher degree than respondents from other departments.

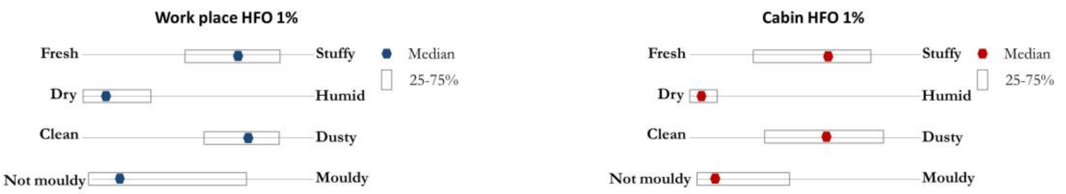

Figure 7. Subjective assessment of the air quality in the work place and cabin before the fuel change (HFO 1% sulphur).

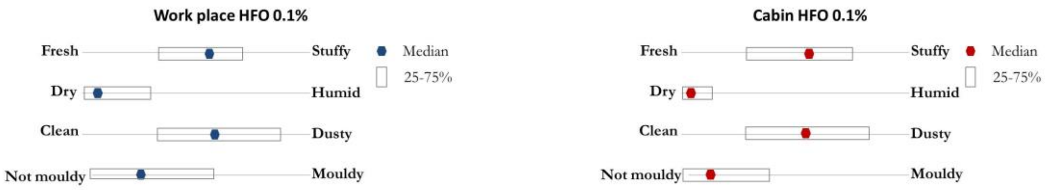

Figure 8. Subjective assessment of the air quality in the work place and cabin after the fuel change (HFO 0.1% sulphur).

Despite the assessment of the air being perceived as dry, the average temperature (T) and relative humidity (RH) in the personal spaces were measured during the campaign and found to be (23 ± 2)°C and (38 ± 4) %, respectively. This is within the comfort zone and similar to the Swedish residences with mean of T = (22 ± 2)°C and RH = (33 ± 6)%, respectively (Langer & Bekö, 2013).

5 DISCUSSION

In sum, the personal exposure samples show that the general indoor air quality on board the ferry is good, when comparing to occupational exposure limits and recommended guideline values. One should however note that the occupational exposure limits does not take into account that seafarers spend longer time on board in a rather confined space than a worker on a shore based work place would generally do. From the measurements, it is not possible to ascertain any significant differences before and after the measurements. More studies are needed in this respect, for example measuring particular matters.

Elevated levels of benzene could be found in some samples. Human exposure to benzene has been associated with a range of acute and long-term adverse health effects and diseases, including cancer. It is added on the WHO list of compounds with recommended guideline values in indoor air, but since no safe level of exposure can be recommended no numeric value is given. Instead, WHO suggests that concentrations should be kept as low as possible. The lower concentrations in the sample carried by the engineer can largely be explained by the differences in work tasks carried out between engine officers and engine ratings, despite belonging to the same department. During the measurements, the engineer spend more time with supervising and monitoring work in the engine control room than the engine ratings who spend more time working in the engine and purifier rooms.

It is clear that certain work tasks are associated with exposure to hazardous air pollutants. To minimize occupational health risks, these tasks must be carefully planned and performed. Preferably already at the design stage when building new ships to make sure that cleaning and maintenance can be done in well-ventilated spaces.

The subjective assessment of the air quality showed the air to be perceived as just acceptable with a slight odour and a sense of the air being dry and stuffy. Previous studies have shown that perceived air quality is strongly influenced by the humidity and temperature of the inhaled air (e.g. Toftum, Jørgensen, & Fanger, 1998), implying that the perception of air quality does not exclusively depend on the chemical composition of the air but on the combined response of our responses (Wargocki, 2004).

6 CONCLUSION

The results of this study as it was designed show that the personal exposure to NO_2 as an indicator for diesel engine exhaust emissions are well below the occupational exposure limit values and the WHO recommended guideline values. Elevated levels of TVOC and benzene concentrations were identified in the samples from the engine crew especially, suggesting that critical work tasks needs to be identified and measures taken to reduce exposure during these tasks, preferably already at the design stage of a ship.

The subjective assessment of the air quality showed the air to be perceived as just acceptable with a slight odour and a sense of the air being dry and stuffy.

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