Topic C7: Transport cabin environments

INDOOR ENVIRONMENT ON-BOARD THE SWEDISH ICEBREAKER ODEN

Sarka LANGER[1,*], Jana MOLDANOVÁ[1], Erica BLOOM[2] and Cecilia ÖSTERMAN[3]

[1]IVL Swedish Environmental Research Institute Ltd., Gothenburg, Sweden
[2] IVL Swedish Environmental Research Institute Ltd., Stockholm, Sweden
[3] Kalmar Maritime Academy, Linnaeus University, Kalmar, Sweden

[*]*Corresponding email: sarka.langer@ivl.se*

Keywords: Indoor air quality, ship, gaseous and particulate air pollutants

SUMMARY

The indoor air quality (IAQ) on-board the Swedish icebreaker Oden was examined during two field campaigns, in winter and in summer 2013. The measured parameters were temperature, relative humidity, air exchange rate and concentration of CO, CO_2, NO, NO_2, ozone, SO_2, volatile organic compounds (VOC), formaldehyde, PAH, PM_{10}, $PM_{2.5}$ and submicron and ultrafine particles. Several indoor spaces of both living and working environments were investigated from the top to the bottom of the ship and outdoor air reference samples were collected at the same time. The results show in general that the IAQ on the ship is good with respect to the existing, recommended indoor air guideline values and occupational limit values. Concentrations in the living spaces were comparable with those in Swedish homes. The majority of the indoor air pollutants on the ship originated from the ship fuel evaporative emissions and operation of the main and auxiliary engines and boilers.

INTRODUCTION

Indoor air quality on ships has not received much attention in spite of the crews' experience of indoor related health symptoms and sailors' elevated cancer morbidity. The indoor environment on ships is a combined working and living environment. Good indoor air quality is important for the crews' health, work efficiency and well-being.

Surprisingly few studies on the indoor environmental quality on ships have been published in the open literature. The indoor thermal environment was assessed on Chinese air-conditioned ships. Questionnaires to appraise the thermal sensation were collected and they were evaluated together with field measurements performed (Liu et al., 2011). Another study presents results from the measurements of temperature and relative humidity in the engine room and the engine control room on-board a merchant ship (Oroa and Oliveira, 2010). The indoor air quality was investigated with respect to the volatile organic compounds, formaldehyde, CO, CO_2 and PM_{10} on-board a newly launched passenger ship and a cargo ship. The temperature and relative humidity were found acceptable and the concentrations of the air pollutants were lower then the levels recommended in international and national standards in the accommodation spaces (Kim et al., 2010). Indoor environmental parameters were investigated on-board of a Swedish submarine equipped with independent propulsion during more than one week of continuous submerged operation (Persson et al., 2006). The number of measured parameters was representative for a thorough indoor study and they were pressure, temperature, relative humidity, oxygen, hydrogen, CO_2, formaldehyde, volatile organic compounds, ozone, NO_2, particulate matter and microbiological contaminants. The

concentration of the pollutants from the study did not indicate any build-up of hazardous compounds during the operation.

The work environment on ships in Sweden is regulated by the Swedish Transport Agency's regulations and general advice about working on ships (Transportstyrelese, 2009). This regulation also puts the occupational exposure limits in force (Arbetsmiljöverket, 2011). The indoor air quality on-board a ship in the personal spaces may be assessed from the existing recommended guideline values provided by WHO (2010).

The aim of the work was to investigate quality of the indoor environment on-board a ship through comprehensive detailed measurements of an extensive number of parameters relevant for indoor air.

METHODOLOGIES

The actual measurements on the ship were performed on the Swedish icebreaker Oden during two field campaigns. The first one was in winter between February 28 – March 11, 2013, during the icebreaking operations in the Gulf of Botnia. The second one was on the overpass from the coastal city of Landskrona in south-western Sweden to Longyearbyen at Svalbard. The selected sampling site were: boiler room, purifier room and engine control room in the engine space and engine office, mass, galley, cabin, bridge as representatives for the personal spaces. Outdoor samples were collected in the bow at fourth deck approximately 20 meter above the sea level and in aft at the main deck of the ship.

The icebreaker Oden is 108 m long and has displacement 13 000 t. The ship is powered by 4 Sulzer ZA40S main engines with total power of 24 500 hp and has 4 Sulzer AT 25H diesel generators, 1200 kW each. During the campaign the main engines were fuelled with heavy fuel oil (HFO) and the auxiliary engines with marine gas oil (MGO). The crew is normally approximately 20 persons. The ship is intended for the icebreaking operations during the winter seasons in the Baltic Sea and in the summers, it often serves as a base for arctic polar expeditions.

The measured parameters were concentrations of gaseous and particulate air pollutants as well as temperature (T), relative humidity (RH) and air exchange rate (AER). Temperature and relative humidity were monitored by HOBO U12-012 data loggers (Onset Computer Corp., USA). CARBOCAP®CO_2 monitors (GMW22, Vaisala, Finland) were used to measure the CO_2 concentration and the data were logged using the HOBO logger. AER were measured using inert gas (CO_2) injection and following its concentration decay in time. CO was monitored using ToxiRae Pro (Rae System, Inc., San Jose, CA, USA) personal wireless monitor. Concentrations of ozone, NO and NO_2 (NO_x) and SO_2 were measured using IVL passive samplers (Ferm and Rodhe, 1997). The formaldehyde samplers were DSD-DNPH Aldehyde Diffusive sampling Device (Supelco, Bellefonte, PA) and for VOC, Tenax adsorbent tubes (Perkin-Elmer) were used. Polycyclic aromatic hydrocarbons (PAH) were collected by pumping the air sample through tandem-coupled PTFE filter sampler for collection of the particulate phase followed by a polyurethane foam sampler sampling the gaseous phase.

Particles PM_{10} and $PM_{2.5}$ were sampled on PTFE and quartz filters using impactors that separated the particles of the required size. Additionally, particles in the size range of 0.3 – 20 µm were continuously monitored by Grimm Portable Dust Monitor model 1.108 (Grimm

Aerosol Technik GmbH & Co) and particles in the size range of 5 – 560 nm by an Engine Exhaust Particle Sizer (TSI Inc. Model 3090) with time resolution of 1 minute.

The concentrations of ozone, NO_x and SO_2 were analyzed by wet chemical techniques. Formaldehyde was analyzed, after eluting from the sampler, by liquid chromatography/UV detection. VOCs were thermally desorbed from the solid adsorbent and analyzed by gas chromatography/mass spectrometry and quantified as Total Volatile Organic Compounds (TVOC) in toluene equivalents. PAH samples were extracted to organic solvent, the gaseous and the particulate phases separately, and analyzed by liquid chromatography with fluorescent detection. The method detects 16 EPA (US Environmental Protection Agency) PAH species.

The particle mass concentration was determined from sample weights and sampled volumes. Elemental composition of the particles from PTFE filters (elements with atomic number between Si and U) was determined by Energy Dispersive X-ray Fluorescence. Samples collected on the quartz filters were analyzed with respect to elemental and organic carbon (EC/OC) with thermal optical method as described in the American standard method NIOSH 5040.

RESULTS AND DISCUSSION

The results presented below represents a selection from the large amount of collected data. Here we show comparison of parameters observed on the ship with the parameters measured in a survey of indoor air quality in the Swedish housing stock as presented by Langer and Bekö (2013). These are temperature, relative humidity, air exchange rate, and concentrations of NO_2, formaldehyde and VOC. The reason of such a comparison is to give an idea for the crew about the indoor air quality onboard the ship in relation to an average Swedish residence.

The average temperature and relative humidity in the engine room were (35 ± 3) ^oC and (19 ± 8) %, respectively. The average temperature and relative humidity in the personal spaces were (23 ± 3) ^oC and (34 ± 14) %, respectively. The engine room represents working environment and the working schedule and conditions are regulated. The indoor climate in the personal spaces is within the comfort zones and similar to the Swedish residences with median T = (22 ± 1) ^oC and RH = (33 ± 1) %, respectively.

The AER in the engine room were 83 h^{-1} and 42 h^{-1} in the boiler room and the purifier room. The high air exchanges in the engine room are designed and maintained for the operation of the engines. The average AER in the personal spaces (4.4 ± 2.0) h^{-1}; this is well above the requirement for the residences of 0.5 h^{-1} as specified by the Swedish building code (Boverket, 2009).

Figures 1 – 3 show the measured concentrations of NO_2, formaldehyde and TVOC. These indoor air pollutants were measured and evaluated in the survey of the Swedish housing stock for single family houses and apartment in multi-storey houses. The concentration of NO_2 (Figure 1) was below the Swedish Transport Agency's regulations on working environment onboard of ships of 100 µg/m^3. The values were higher than the median values found in the single-family houses and apartments of the Swedish housing stock of 6 µg/m^3 and 10 µg/m^3, respectively. They were also relatively high with respect to the typical marine boundary layer concentrations in the region which are 0.4 – 3 µg/m^3 (EMEP 2011, EMEP data 2013). The recommended indoor air guideline value for NO_2 is 40 µg/m^3 as an annual average (WHO, 2010.

Recommended indoor air guideline value for formaldehyde is 100 µg/m^3 as a 30-minute average (WHO, 2010). The concentration derived from the regulations for indoor environment on ships by the Swedish Transport Agency is 19 µg/m^3. Figure 2 shows the results. The very low concentrations of formaldehyde found onboard the icebreaker are due to small indoor sources (furnishings) and low content of formaldehyde in ship exhaust combined with the large air exchange rates. Typical formaldehyde concentrations in clean background air are around 1.5 µg/m^3 in summer and 0.8 µg/m^3 in winter (Solberg et al., 2013).

The TVOC results are shown in Figure 3. The concentration of TVOC were high in the engine room. This is due to evaporation of the ship's fuel HFO and MGO. The average TVOC concentration in the personal spaces was (290 ± 60) µg/m^3, just below the hygienically safe level proposed by the Federal Environment Agency of Germany (UBA). It should be noted the average outdoor air TVOC concentration was (430 ± 240) µg/m^3, even higher than in the indoor air. The composition of the individual indoor and outdoor VOC found in the sample chromatograms was mainly made by aromatic compounds (benzene, toluene, xylenes, higher substituted benzenes) and long-chain aliphatic hydrocarbons, originating from the ship's fuels (HFO and MGO). Non-Methane Hydrocarbons in the marin boundary layer are typically 0.5-1 µgC/m^3 in summer and 1.5-2 µgC/m^3 in winter (EMEP, 2011).

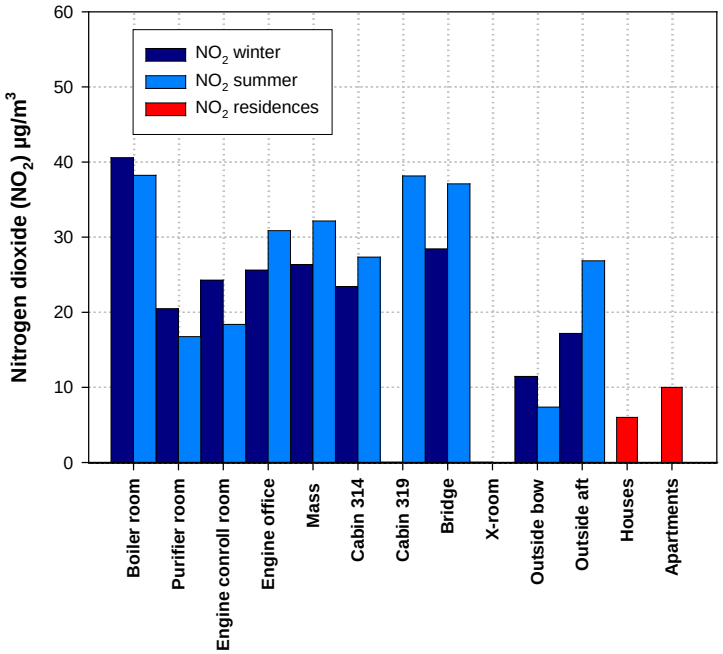

Figure 1. Concentration of NO_2 in the various spaces onboard the icebreaker Oden. The information from Swedish residences is added for comparison.

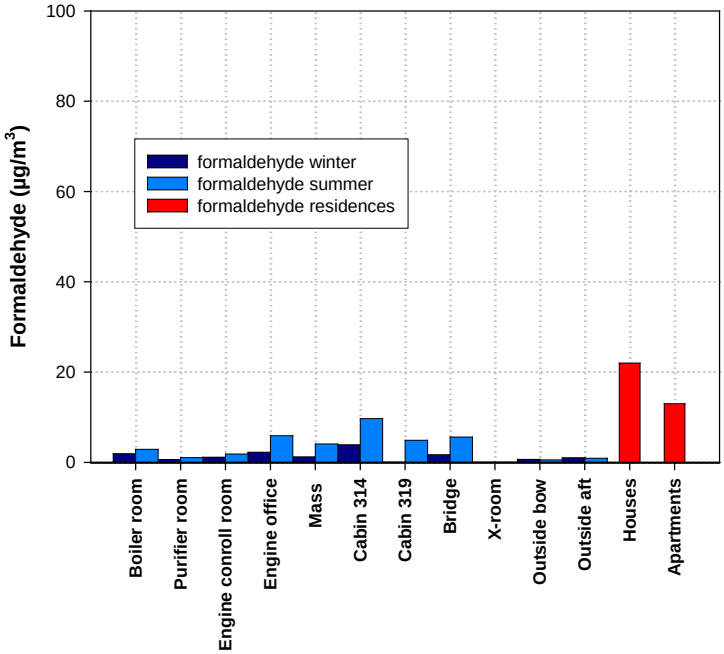

Figure 2. Concentration of formaldehyde in the various spaces onboard the icebreaker Oden. The information from Swedish residences is added for comparison.

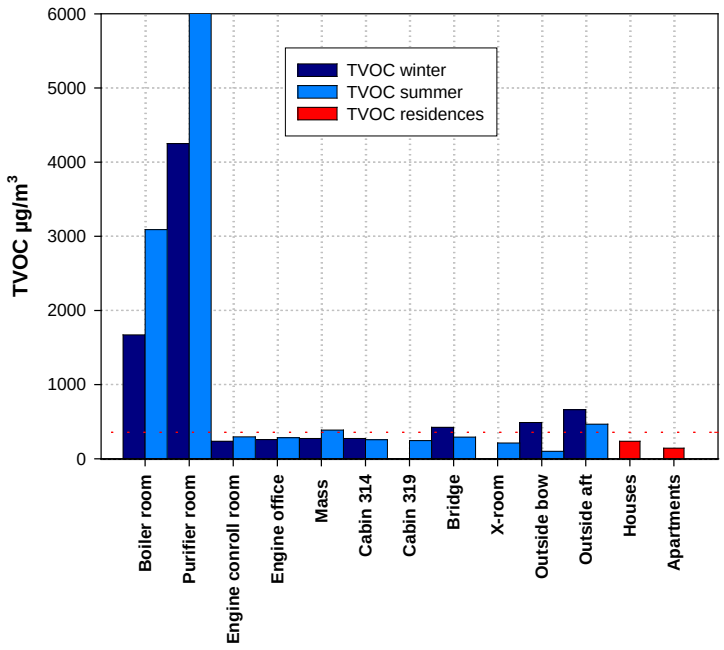

Figure 3. Concentration of TVOC in the various spaces onboard the icebreaker Oden. The information from Swedish residences is added for comparison. The dashed line represents the hygienically safe level of 300 µg/m^3 as specified by the Federal Environment Agency of Germany (UBA).

The average mass concentration for both winter and summer of PM_{10} and $PM_{2.5}$ in the perosnal spaces were 8 and 6 µg/m^3, respectively. The corresponding outdoor values were 13 and 5 µg/m^3, respectively. PM_{10} measurements at EMEP background station Palas during the winter and summer measurement campaigns showed concentrations 2.9 and 3.6 µg/m^3, respectively, confirming the finding based on VOC data that the outdoor air is affected by the ship. Thus the particulate matter in the indoor and outdoor air on the ship is of similar origin, partly from atmospheric background particles and partly from exhaust emission and fuel evaporation. High concentration of particles were found in engine and purifier rooms with the highest koncentrations in the purifier room (average values of 95 and 45 µg/m^3, respectively, for PM_{10} and $PM_{2.5}$). As an example from all the other data available from the measurements, Figure 4 shows the particle total number concentration, PM_{10} and $PM_{2.5}$ as measured by the optical counter (Grimm Dust monitor) and EEPS as a function of the ship's operation mode (main engine off and on). It is not surprising that most particles are produced when the main engines are operating.

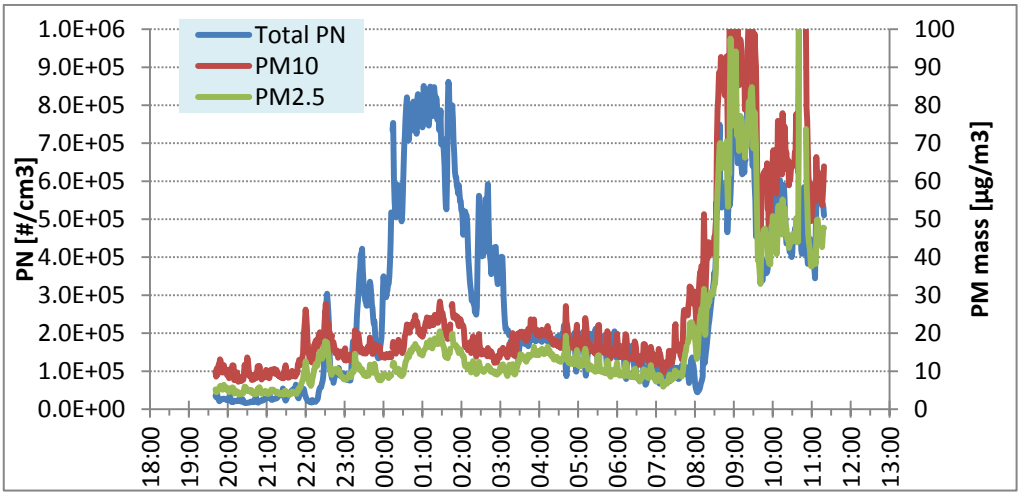

Figure 4. Particle concentration as a function of the operation mode of the main engines (ME): total number concentration (Total PN) and PM_{10} and $PM_{2.5}$ mass concentrations as continuously measured by optical particle counter. 8 – 22 ME off, 22 – 03 ME on, 03 – 7:45 ME off 7:45 – 11:30 ME on.

CONCLUSIONS

The indoor environment on the icebreaker Oden is good with respect to the existing indoor air quality guideline values and indoor comfort. This is valid for the personal spaces. The working environment (engine room, galley) has higher temperature, lower relative humidity, high air exchange rate and elevated concentrations of both the gaseous and the particulate air pollutants. Even though, the values found in this study are well below the occupational limit values (Arbetsmiljöverket, 2011; Transportsyrelsen, 2009). The indoor air quality in personal spaces of the icebreaker Oden is comparable to normal Swedish residences.

The high concentrations of the volatile organic compounds and particles found in the engine room, and especially in the purifier room, requires taking some measures to decrease them or to aim at limiting the time the staff spends in these areas.

The source of the air pollutants are evaporative and combustion emissions from operation of the main and auxiliary engines and boilers of the ship. The operation of the ventilation system with the relatively large flows brings the majority of the air pollutants from the outdoors to the indoor spaces which can lead to recirculation of the ship's emissions. This fact puts requirements on the design and placement of the intake of supply air in a way that infiltration of exhaust from the airing devices from the fuel tanks and from purifier room and from the chimney are minimized.

ACKNOWLEDGEMENT

AFA Insurance is acknowledged for financial support of this project through contract 120063. We would to thank the captain and the crew of the icebreaker Oden for their help an hospitality during our stay on-board.

REFERENCES

Arbetsmiljöverket (2011). The Swedish Work Environment Authority's Regulations and General Advice on occupational exposure limits. Stockholm, Sweden (in Swedish).

Boverket (2009) BBR 18: Rules for building. BSF 1993:57. Boverket - the Swedish National Board of Housing, Building and Planning (in Swedish).

EMEP (2011) Transboundary acidification, eutrophication and ground level ozone in Europe in 2009. EMEP Report 1/2011, www.emep.int.

Ferm M and Rodhe H (1997). Measurements of air concentrations of SO_2, NO_2 and NH_3 at rural and remote sites in Asia. *Journal of Atmospheric Chemistry*, **27**, 1, 17-29.

Kim SS and Lee YG (2010) Field measurements of indoor air pollutant concentrations on two new ships. *Building and Environment*, **45**, 2141-2147.

Langer S and Bekö G (2013) Indoor air quality in the Swedish housing stock and its dependence on building characteristics. *Building and Environment*, **69**, 44-54.

Liu H, Ni J, Xing N et al (2011) An investigation and analysis of indoor environment in air-conditioned Chinese ship vessel cabins. *Indoor and Built Environment*, **20**, 377-385.

Orosa JA and Oliveira AC (2010 Assessment of work-related risk criteria onboard a ship as an aid to designing its onboard environment. *Journal of Marine Science & Technology*, **15**, 16-22

Persson O, Östberg C, Pagels J et al (2006) Air contaminants in a submarine equipped with air independent propulsion. *Journal of Environmental Monitoring*, 8**,** 1111-1121.

Solberg S. (2013) VOC measurements 2011. EMEP/CCC-Report 5/2013, www.emep.int.

Transportstyrelsen (2009) The Swedish Transport Agency's Regulations and General Advice on the working environment on ships. Norrköping, Sweden (in Swedish).

UBA Federal Environment Agency of Germany. Health and Environmental Hygiene. Guide values for indoor air quality. http://www.umweltbundesamt.de/en/ad-hoc-working-group-for-indoor-air-guide-values-0

WHO (2010) World Health Organization. Selected pollutants. WHO indoor air quality guidelines. Copenhagen: WHO Regional Office for Europe, pp. 1-454.