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CHEMICAL CONTAMINATION OF POTABLE WATER IN SHIP TANKS

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ABSTRACT

Introduction Unpleasant odour from drinking water in newly built ships is increasingly documented by the German Port Health Authority during sanitary inspections. Chemical contaminations are assumed to originate from washed off solvents of tank coatings due to the non-maintenance of required drying periods. The aim of this study was to explore the frequency of drinking water contamination by chemicals in a selected sample of vessels and to assess the usefulness of recommended control measures.

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Methods The available analyses of chemicals in drinking water from container ships which were taken by the Port Health Officers of the Hamburg Port Health Center in the last three years were summarized and analysed. Each analysis was initiated due to aromatic odour. The analysis spectrum comprised 22 different volatile halogenated hydrocarbons and solvents.

Results Drinking water analyses of 21 container ships with a maximal age of one year were available. The guideline value (GV) of chemical substances in drinking water was exceeded on five different ships (23.8 %) (ship no 1: xylene 770 µg/l (GV 500 µg/l), ethyl benzene 590 µg/l (GV 300 µg/l), vinyl chloride 0.6 µg/l (GV 0.5 µg/l); ship no 2: xylene 510 µg/l, ethyl benzene 400 µg/l; ship no 3: xylene 860 µg/l; ship no 4: xylene 540 µg/l; ship no 5: benzene 1.0 µg/l (GV 1.0 µg/l)). In 70% of ships with follow-up analyses, the chemical concentrations in potable water decreased as consequence of appropriate intervention measures (complete discharge and ventilation of the tanks for at least 14 days).

Conclusions The study shows that an aromatic odour on newly built ships indicates a potential hazard to human health due to chemical solvents. In order to control possible adverse health effects to seafarer suitable codes of practice in the handling of coatings need to be observed by manufacturers. Public Health Officers, ship masters and other persons responsible for health and safety on board have to be aware of the problem and to initiate surveillance and control measures. Recommended measures include the complete emptying of potable water tanks, the accelerated drying of tank coatings by means of ventilators for at least 14-21 days and the thorough cleaning of tanks with acetic acid.

Keywords: chemicals, coating, potable water, contamination

INTRODUCTION

According to the German Decree on Potable Water, drinking water should be germ-free, suitable for consumption and clean (1). With regard to bacteriological contamination annual analysis of potable water systems on ships are mandatory. Chemical analyses of potable water are initiated by our Port Health Officers of the Hamburg Port Health Center in case of chemical odour or taste perception.

The chemical contaminations in shipboard potable water are likely caused by solvent-based tank coatings (intended to protect against corrosion) due to the non-observance of required specifications, especially the drying periods, as it has been already described by our working group (2). In a recent study, several samples of an ocean-going vessel's water supply were taken and the highest concentration of chemicals was observed in the fresh water tank (3).

For potable water supply only such materials in newly built or maintained constructions are to be used that do not

a) release substances after contact with water exceeding a level being higher than unavoidable considering the generally accepted technical rules
b) impair human health
c) cause unpleasant odour or taste of drinking water (1).

The health risks associated with chemical constituents of drinking water differ from those of microbial contamination and arise primarily from the ability of chemical constituents to cause adverse effects after prolonged periods of exposure. Therefore, the chemical concentrations in drinking water have to be below a harmful guideline value (GV) listed in national and international guidelines, respectively (1, 4). There is a broad spectrum of possible chemicals in potable water (especially volatile halogenated hydrocarbons and solvents), and consequently a wide range of chemicals are included in routine screening tests by our Port Health Inspectors. If water samples show the presence of chemical solvents the Public Health Officers often face the difficulty to assess the risk to human health associated with the findings and to recommend the appropriate control measures because of a lack of GV in national and international recommendations for many substances. The aim of this study was to explore the frequency of drinking water contamination by chemicals in a selected sample of vessels and to assess the effect of specific interventions to reduce these concentrations.

METHODS

All drinking water samples were taken by the Port Health Officers of the Hamburg Port Health Center and immediately analyzed by the Hamburg Institute of Hygiene and Environment according to DIN EN ISO 10301 F4 (1997) (5). Inspections were done at the time of the scheduled arrival of the vessels at Hamburg port. At that time, the inspectors interviewed the shipmasters about operation duration and climatic conditions when the chemical odour of potable water was recognized. The answers were documented to be available for subsequent evaluation. The analysis spectrum comprised 22 different volatile halogenated hydrocarbons routinely checked in Hamburg when chemical analyses of drinking water have been ordered.

It was not possible to receive detailed information about the coatings' ingredients. We assumed that the 22 halogenated hydrocarbons we tested as a standard test battery were released into the water as a consequence of insufficiently dried coatings. Each of the chemical analyses was initiated between 2004 and July 2007 on account of aromatic odours of the shipboard potable water. Drinking water results of 21 vessels were available. The coating of each tank consisted of epoxy resin (average recommended drying period at 20° C was 16 hours for dry hard and 7 days for fully cured).

Dependent on the accessibility of the shipboard water supply system, the potable water samples were taken from the tanks (70.6%) or the galley (29.4%). Repeated measurements of chemical concentrations in potable water were conducted on 17 ships after 1 to 19 months depending on the time of the return visit of the vessel to the port of Hamburg. In nine vessels (42.9%), the chemical concentration was measured in portside as well as in starboard tanks at the same time in order to explore differences of the chemical load in water supply systems. Chemical analyses of ten vessels (47.6%) were performed in follow-up investigations to assess concentrations after interventions to reduce the chemical load. In total, more than 1,500 measurement values were obtained and included in the analysis.

For the interpretation of the results the GVs listed in the German Decree on Potable Water were applied. In case of missing national GV references, the corresponding WHO GV was referred to (Table 1). Chemical concentrations above the German and WHO GV, respectively, were regarded as elevated.

Table 1 also displays the published chemical odour thresholds.

Table 1 Guideline values (GVs) of chemicals significant to shipboard in drinking water

	CAS No	German GV	WHO GV	Odour threshold
Ethyl benzene	100-41-4		300 µg/l	2-130 µg/l [1]
Vinyl chloride	71-55-6	0.5 µg/l	0.3 µg/l	
Mixed xylenes ('1,2+1,3/1,4)			500 µg/l	
o-Xylene	95-47-6		500 µg/l	Xylenes 20-1,800 µg/l [1]
m-Xylene p-Xylene	108-38-3 106-42-3		500 µg/l	
Benzene	71-43-2	1 µg/l	10 µg/l	
Toluene	108-88-3		700 µg/l	24-170 µg/l [1]
Dichloromethane	75-09-2		20 µg/l	
Chloroform	67-66-3	50 µg/l	300 µg/l	7,500 µg/l [3]
Carbon tetrachloride	56-23-5	30 µg/l		520 µg/l [4]
Trihalomethanes		50 µg/l	200 µg/l	
1,1-Dichloroethane	75-34-3	no GV available		
1,2-Dichloroethane	107-06-2	3 µg/l	30 µg/l	20,000 µg/l [2]
1,1,1-Trichloroethane	71-55-6		2,000 µg/l	
1,1,2-Trichloroethane	79-00-5		2,000 µg/l	
Tribromomethane	75-25-2	10 µg/l		
Bromodichloromethane	75-27-4	50 µg/l	60 µg/l	
Dibromochloromethane	124-48-1	50 µg/l	100 µg/l	
Vinylidene chloride	75-35-4	no GV available		
cis-1,2-Dichloroethylene	156-59-2		50 µg/l	
trans-1,2-Dichloroethylene	156-60-5		50 µg/l	
Trichloroethylene	79-01-6	10 µg /l	20 µg/l	
Tetrachloroethylene	127-18-4	10 µg/l	40 µg/l	
Methyl tert-butyl ether	1634-04-4		50 µg/l guideline value in California	15 µg/l [3]
Naphthalene	91-20-3	no GV available		2.5 µg/l [3]
1-Methylnaphthalene	90-12-0	no GV available		
2-Methylnaphthalene	91-57-6	no GV available		

GVs used for data interpretation in this study are given in bold type.

[1] WHO 2006 (4)

[2] Agency for Toxic Substances and Disease Registry (ATSDR) (6)

[3] Young et al. 1996 (7)

[4] IPCS: International Programme on Chemical Safety (8)

RESULTS

Available drinking water analyses derived from 21 container ships bigger than 10,000 gross register tons and manufactured in South Korean shipyards. The mean age of the vessels at the time of the first chemical analysis was 12 months (range 2 to 24 months). Unpleasant odours were always perceived, mostly at the beginning or within a few weeks after the initial operation. They often increased during stays in warmer climatic zones. In none of the explored ships, a microbiological concentration above the guideline values of the German Decree on Potable Water was found.

Concentrations of chemicals in potable water on board

The GVs of chemical substances in drinking water were exceeded on five ships (23.8 %) (ship no 1: xylene 770 µg/l, ethyl benzene 590 µg/l; vinyl chloride 0.6 µg/l; ship no 2: xylene 510 µg/l, ethyl benzene 400 µg/l; ship no 3: xylene 860 µg/l; ship no 4: xylene 540 µg/l; ship no 5: benzene 1.0 µg/l). The highest chemical concentration in ship tanks was observed within the first 12 months after initial operation.

Most of the other investigated chemicals were below the respective detection limit in potable water. Only in seven vessels the concentration of the following chemicals was above detection limits (and considerably below the GV): chloroform (0.7 to 26 µg/l), tribromomethane (0.5 to 2.4 µg/l), bromodichloromethane (0.1 to 13.0 µg/l), dibromochloromethane (0.6 to 5.9 µg/l). The last mentioned three chemicals did only occur simultaneously.

Results of parallel measurements in different areas of the water supply system

The chemical load in potable water of nine vessels was simultaneously controlled from samples taken from portside and starboard tanks. These are normally not connected to each other. Three of these vessel samples showed comparable chemical concentrations in both tanks. The load of xylene and ethyl benzene differed considerably between the tanks of six vessels. Higher chemical concentrations were found twice in starboard and 4 times in portside tanks.

Effect of interventions to reduce the chemical concentration in potable water

In case of suspected chemical contamination in potable water, the Port Health Authority advised the ship management to completely empty the potable water tanks and to ventilate the tanks in order to promote the hardening of the coating for at least 10 days 3).

A continuous decrease of xylene and ethyl benzene was observed due to ventilation and rinsing the tanks (Table 2) in seven out of ten vessels (ships 1 – 7) with available data on chemical concentrations in follow-up examinations. However, the chemical load in three vessels developed discontinuously in follow-up analyses in spite of interventions.

Table 2 Interventions to reduce the chemical concentrations in the potable water of 10 vessels

	1. investigation	1. intervention measures	2. investigation	2. intervention measures	3. investigation	change of chemical concentration+ (%)
Ship No 1 (portside tank: 170 tons)						
Months after 1. invest.	0	Complete discharge , ventilation for 14 days, use of a ventilator	1	Complete discharge , ventilation for 14 days	5	
Mixed xylenes	134		96		<0.2	Below detectio n limit
Ethyl benzene	19		18		<0.1	
Ship No 2 (portside tank: 100 tons)						
Months after 1. invest.	0	Complete discharge, ventilation for 8 days	19			
Mixed xylenes	540		7.8			-98.6%
Ethyl benzene	48		3.3			-93.1%
Ship No 3 (starboard tank: 170 tons)						
Months after 1. invest.	0	Complete discharge, ventilation for 14 days, use of 1 ventilator	3		4	
Mixed xylenes	82		<0.2		<0.2	Below detectio n limit
Ethyl benzene	4.8		<0.1		<0.1	
Ship No 4 (portside tank: 120 tons)						
Months after 1. invest.	0	Cleaning of the tanks, ventilation for a few days	1			
Mixed xylenes	269		86			-68.0%
Ethyl benzene	6.7		10.8			+61.2%
Ship No 5 (galley)						

Months after 1. invest.	0	Complete discharge; high pressure cleaning; ventilation for 5 days; use of 1 ventilator	2	Complete discharge; high pressure cleaning; ventilation for 5 days; use of 1 ventilator		
Mixed xylenes	254		85			-66.5%
Ethyl benzene	38		6.5			-82.9%
Ship No 6 (galley)						
Months after 1. invest.	0	Discharge as complete as possible; periodical ventilation every 30 days for approx. 4 weeks; use of a ventilator	2	Discharge as complete as possible; periodical ventilation every 30 days for approx. 4 weeks; use of a ventilator		
Mixed xylenes	31		11			-64.5%
Ethyl benzene	4.7		2.3			-51.1 %
Ship No 7 (galley)						
Months after 1. invest.	0	Complete discharge; high pressure cleaning; ventilation for 3 days; use of 1 ventilator	2	Complete discharge; high pressure cleaning; ventilation for 3 days; use of 1 ventilator		
Mixed xylenes	333		256			-23.1%
Ethyl benzene	63.0		18.0			-71.4%
Ship No 8 (starboard tank: 170 tons)						
Months after 1. invest.	0	Complete discharge; ventilation for 14 days; use of 1 ventilator	4	Complete discharge; ventilation for 14 days; use of 1 ventilator	5	
Mixed xylenes	25		36		35	+40.0%
Ethyl benzene	4.5		4.5		3.4	-24.4%
Ship No 9* (starboard tank: 170 tons)						
Months after 1. invest.	0	Complete discharge; ventilation for 14 days; use of 1 ventilator	4	Complete discharge; ventilation for 14 days; use of 1 ventilator	6	
Mixed xylenes	12		8.7		13	+8.3%
Ethyl benzene	2.1		1.7		3	+42.9%
Ship No 10 - portside tank (170 tons)						
Months after 1. invest.	0	Complete discharge; ventilation for 14 days; use of 1 ventilator	2	Complete discharge; ventilation for 14 days; use of 1 ventilator	5	
Mixed xylenes	74		8.1		<0.2	Below detection limit
Ethyl benzene	6.5		1.7		<0.1	
- starboard tank (170 tons)						
Months after 1. invest.	0		4		8	
Mixed xylenes	66		34		53	-19.7%
Ethyl benzene	11		17		3.8	-65.5%

Discontinuous developing of chemical concentrations in follow-up examination is given in bold type.

+ change (decrease or increase in %) of chemical concentrations after last intervention compared with first measured chemical concentrations

* 8 months after first chemical investigation, the concentrations of mixed xylenes and ethyl benzene were 0.5 and 0.2 µg/l, respectively

DISCUSSION

The observation of the Public Health Officers from the Hamburg Port Health Center and the chemical analysis performed in this study show that an aromatic odour on newly built ships indicates a potential hazard to seafarer's health due to chemical solvents. A probable cause of this hazard is a non-maintenance of the recommendations of the tank manufacturers in the product-specific handling of coatings.

In our study, all of the potable water samples with a typically chemical odour derived from new container ships manufactured in South Korean shipyards indicating a problem connected to the production process. It should be noted that the available chemical analyses of shipboard potable water revealed elevated concentrations of xylene and/ or ethyl benzene in 23.8%. Out of the broad spectrum of analysed chemicals, these two substances seem to play a major role in the chemical contamination of shipboard drinking water.

There are certain limitations which need to be mentioned in the interpretation of results:

First the sample of ships in this study is not representative of all cargo vessels, since chemical analyses were taken only in ships under German flag which underwent routine drinking water analysis. No chemical analysis was done in newly built vessel where an odour was not present. Also, variability of measurement results may be assumed to a ray of physical parameters, like amount of water in tanks and climate. Ships regularly sailing in tropical zones show tank temperatures up to 40 °C. These conditions can enhance the wash-out effect of chemicals into the potable water and may lead to an increase of chemical odours in warmer regions. Therefore, the conditions of drinking water tanks on board and ashore differ considerably.

The differences of chemical loads between portside and starboard tanks are likely attributable to different hardening times during the manufacture. Furthermore, the investigated tanks sometimes had slightly different water levels leading to the dilution of chemical concentrations. This may also partly explain the differences in the chemical load of tanks.

Taking under consideration the above mentioned limitations in interpreting the values, follow-up analyses suggest decreasing concentrations of chemicals in 70% of ships as consequence of appropriate intervention measures (mostly complete tank discharge and ventilation for at least 14 days). The remaining ship tanks (ship No 8-10) revealed stable or increasing concentrations despite control measures indicating a persistent wash-out process of chemicals and requiring intensified interventions (e. g. extended ventilation time; see below).

We were not able to determine a single cause of the persistently elevated load of chemicals in the three ships. It is hypothesized that these ships had different coatings with a considerable higher proportion of ethyl benzene and xylene. As the chemical release mainly depends on the duration of the drying period in shipyards it is also possible that these drying periods of shipboard water tanks were shorter than those of the other ships. It is assumed that the prolongation of ventilation time leads to a more effective evaporation of solvents and minimizes their concentration to a level without health risk. The persistently raised level of chemicals on these three ships may allow the conclusion that a ventilation period of two weeks is not appropriate for an effective reduction of potable water contamination.

Ship tank coating before initial operation

Tank coating is a matter of specialists and should only be performed by well-trained and experienced personnel. Currently, epoxy coatings are mostly used based on different chemical compounds: rheological additives (resins and accelerator, e. g. phthalates, polyacrylates, bisphenol A-diglycidether, isocyanates), pigments and fillers, organic substances, solvents, and auxiliary products (9). The coatings often include solvents reducing their viscosity. A thickness of more than 2,000 µm is obtainable by solvent-free coatings whereas solvent-based coatings have to be applied as a thin film in order to enable their evaporation through the hardening resin layer. Diluters in solvent-free coatings are not permitted.

Coating requires to strictly comply with the manufacturers' recommendations comprising among others the mixing ratio of components, the thickness of each coating layer, the recoating intervals, the use of additives or thinners, the surface temperature and the hardening period. Especially the complete hardening of the coatings is important. It depends further on environmental factors such as ventilation, humidity and temperature. Thus, coating during winter time requires longer hardening periods and the use of heater blowers is often necessary. Based on our findings, we generally recommend the shipyards to extend the hardening time of coatings, e. g. by an earlier manufacture of tanks complete with coating.

Dry, fresh air to remove all solvent vapours is important in enclosed areas. Since most solvent vapours are heavier than air, ventilation ducts should reach the lowest parts of enclosed areas as well as structural pockets. Moreover, ventilation should be provided throughout the curing period to ensure that the solvents are removed from the coating.

To our knowledge, exclusively new vessels (younger than 3 years) are affected by chemical contamination of potable water. Thus, the concentration of chemicals in drinking water should generally be measured in new ships by construction inspectors and should be a criterion for the acceptance of new ships.

Measures to decrease the chemical load in shipboard drinking water tanks

Our data show that a persistent evaporation of solvents is possible over years if the coating is not completely hardened before the first operation. In our follow-up measurements, an increase of the chemical load in potable water was observed in some vessels indicating a persistent solvent evaporation. The inspectors of the Port Health Authority are aware that the continuous wash-out process can occur over a long period of time.

Even though this observational study does not allow to prove the effectiveness of the intervention due to the study design and the above mentioned limitations our experience suggests that the following procedure may be useful in reducing the chemical contamination:

1) completely discharge the potable water tanks
2) clean the tanks thoroughly e. g. with acetic acid and subsequent rinse with fresh water
3) dry the tanks by the means of ventilators or heaters introduced in the tanks in order to promote the hardening of the coating for at least 14-21 days
4) chemical disinfection of potable water
5) refil with potable water (a disinfection with chlorine may be applied before usage of tanks).

Early and careful interventions will have the best success to reduce chemical concentrations in potable water.

Further studies are needed in this area. It is current practice of our Port Health Authority to recheck chemical load in potable water approx. three months later, if feasible.

If the unpleasant odour and/ or the high concentrations of chemicals persist we do recommend to extent the ventilation time to 4, 5, 6 weeks and so on after each subsequent unsuccessful control. In order to assess the success of the intervention in hardening the coating the public health officers of our center advise to use a simple so called “finger nail test” (scratching with fingernails does not cause marks on the coating).

Health risks due to potable water contamination by chemicals

Although slightly increased chemical concentrations above the respective GV do not often elicit symptoms, health-adverse effects such as gastrointestinal diseases, disorders of the liver or of the central nervous system due to the accumulation of chemicals cannot be excluded. Long-time exposure to mixed xylene can lead to CNS symptoms, i.e. to anxiety, forgetfulness, dizziness as well as to eye and nasal irritation and sore throats (10). Ethyl benzene can cause irritation of airways, skin and eyes as well as central nervous disorders. Unfortunately, no data on the health status of the controlled vessels’ crews were available.

The vessels of this study were investigated due to chemical odours of potable water. It may be possible that water contamination by chemicals also occurs in other ships with concentrations below odour thresholds but above GVs (see Table 1). This means that crews may be exposed to elevated chemical concentrations over an extended period of time without their knowledge.

The crews on ships with potable water contamination above guideline values (GV) were advised to only use the tap water for personal hygiene. This water has to be regarded as non-potable until the chemical concentration decreases below the respective GV. In the meantime, the crew should only consume bottled mineral water.

CONCLUSIONS

The results of this study raise the awareness to a health concern associated with chemical constituents of drinking water in newly built cargo vessels mainly from South Korea. As water samples had only been taken from ships in which an unpleasant odour of potable water was present, it is not possible to generally assess the contamination by chemicals in shipboard drinking water. Also, health status of seafarers being exposed to the contaminated water was not assessed. Further studies are needed to quantify the size of the problem to the health of the seafarers. Despite the limitation in the data it is prudent to recommend routine control measures in new ships. In order to control possible adverse health effects to seafarer suitable codes of practice in the application of coatings need to be observed by producers. Public Health officers, ship masters and other persons responsible for health and safety on board have to be aware of the problem and to initiate appropriate surveillance and control measures.

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