Effects of VOC Emissions on Health and Safety of Ship Personnel in Crude Oil Tankers: Risks and Protective Measures

Hazal Kahraman [1], Turgay Battal [2]

[1] *Iskenderun Technical University Graduate Education Institute, Turkey. Email: hazal.kahraman.lee21@iste.edu.tr*
[2] *Iskenderun Technical University Department of Maritime Transportation Engineering, Turkey. Email: turgay.battal@iste.edu.tr*

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ABSTRACT
This article discusses the effects of emitted VOCs on health safety of shipboard personnel in crude oil tankers considers some protective measures that may be used to mitigate the risks. The term VOC defines any chemical compound that is volatile at typical environmental conditions and can be emitted into the atmosphere during a specific source activity. For example, transportation of crude oil can generate many serious hazards because of either the fire hazard or the toxic nature of VOCs. Health effects of VOCs on crew range from short-long-term diseases, mainly pointing to respiratory diseases disorders of the nervous system. Simultaneously, emissions of VOC enhance fire and explosion hazards, hence becoming one of the serious safety concerns for ships. The paper will present an assessment of different technical and operational strategies for mitigation of those risks, which include the use of vapor recovery units, personal protective equipment, risk assessment methodologies such as HAZOP and LOPA. It also addresses negative effects on the marine ecosystem, as well as other environmental hazards, due to VOCs especially around sensitive areas. Generally, this requirement is a holistic approach to reduce adverse effects on crew health safety of ships due to the emanation of VOCs.

1. Introduction

The cargo transported in crude oil tankers contains VOCs, which are highly hazardous to the environment and the personnel on board the ships. The term VOC defines any chemical compound that is volatile at typical environmental conditions and can be emitted into the atmosphere during specific source activity. The volatility and toxicity of VOCs make them one of the major threats to ship in the operations (Pandey and Yadav, 2018; Baalisampang *et al.*, 2018; Baur *et al.*, 2015). In particular, the vapors generated during the loading and unloading and storage of crude oil are the main sources of VOC emissions. These emissions have been seriously harmful not only to the marine ecosystem but also to the health and operational safety of ship personnel (Ancione et al., 2021). The most obvious effect of VOC emissions is that they have a very harmful effect on seafarers' health. The short-term inhalation of these compounds can cause headaches, dizziness, and respiratory problems exposure can result in permanently damage to the nervous system. Chronic VOC exposure threatens the general health of the crew and reduces work efficiency.

Moreover, the flammability properties of VOCs also increase the risk of fire and explosion in tankers, which is considered a major problem from the perspective of ship safety. Elidolu *et al.* (2022) and Boviatsis et al. (2022) argued that VOC emissions from crude oil tankers are considered a critical area of research with regard to crew health safety and environmental impacts. VOCs are emitted during loading, unloading, and transit operations during the transport of crude oil. According to Hu et al., significant VOC emissions at the oil terminals come from the storage tanks and tanker operations; thus, effective monitoring and reduction strategies should be realized, which Hu et al. pointed out in the work dated 2020. Tamaddoni et al. (2014) also provided experimental data on VOC emissions, particularly from crude oil tankers, highlighting the hazardous nature of these emissions and the potential health risks for crew members (Tamaddoni et al., 2014). The health effects of VOC exposure are well documented, and some VOCs are recognized as carcinogenic and toxic. Gao et al. (2020) discussed the health risks associated with various VOCs, such as benzene and ethylbenzene, which prevail in emissions from industrial activities and crude oil tankers (Gao et al., 2020). Their cumulative exposure may raise significant health concerns for the crew members, thus safety and monitoring systems should thus be robust (Fetisov et al., 2023). Mitigation strategies are essential to reduce VOC emissions and protect crew health. Lee et al. propose multi-objective optimization techniques for the recovery and reuse of VOCs during crude oil loading, which can significantly minimize emissions (Lee et al., 2013). In addition, Karbasian et al. (2017) presented a novel method aimed at reducing VOC formation during the crude oil loading process, highlighting the potential for technological advances to address this issue (Karbasian et al., 2017). These strategies are crucial not only for compliance with environmental regulations but also for protecting the health and safety of personnel working on tankers.

Furthermore, the regulatory environment surrounding VOC emissions in the oil and gas industries is evolving. Fetisov et al. (2023) discussed the increased focus on regulating VOC emissions as part of broader climate change mitigation efforts, which reflects the increasing recognition of the environmental and health impacts of these compounds (Fetisov et al., 2023). This regulatory review is likely to stimulate further research and the development of effective abatement technologies. Thus, the assessment of VOC emission risks to crude oil tankers has becomes a complex issue of health, safety, and environmental concern. The literature identifies that there is still a need for continuous research on sources of emissions, health effects, and novel mitigation measures to safeguard crew members and meet regulatory standards. Although there is an important volume of literature on the consequences of VOC emissions the environment and crew health, there is a lack of research on how these risks become dynamic under ever-changing operational conditions. A comprehensive overview of the extent of VOC exposure during different operational stages, particularly during loading, unloading, and underway, and the long-term health effects associated with such exposure are lacking. Furthermore, few studies have assessed the efficiency of the existing technologies applied to reduce such emissions and newer, more innovative approaches. This situation focuses on the need for more detailed research in both directions: the health and safety risks of the ship crew and their effective management. This study analyzed the impact of VOC emissions on crude oil tankers, with particular emphasis on crew health and ship safety management. This research will scrutinize the adequacy and efficiency of the safety management systems and procedures concerning VOCs from the perspective of international standards: The Oil Companies International Marine Forum (OCIMF), International Safety Guide for Oil Tankers and Terminals (ISGOTT), The International Safety Management (ISM) and Tanker Management Self Assessment (TMSA), and how these systems minimize VOC exposure risks during tanker operations. The following are the research questions addressed in this thesis will address:

- How well are VOC management systems integrated into the safety protocols for crude oil tankers?
- What are the main problems and deficiencies that tanker personnel perceive in the current VOC safety management practices?
- In what respects might current training, reporting and risk management practices be improved to enhance on-board VOC safety?

2. Literature Review

Volatile Organic Compounds emitted from oil tanker transportation pose immense health hazards for seafarers. Emissions occurring mainly during loading, unloading and transit contribute to air pollution, affecting the crew and nearby populations. Studies have shown that VOC exposure leads to adverse health effects ranging from respiratory problems to neurological effects and increased cancer risk. The safety culture and organizational factors in the maritime sector are crucial for reducing these risks.

Lee and Chang(2014) emphasize that VOCs can pose significant environmental hazards owing to their high global warming potential and toxicity. Emissions from oil terminals and tankers particularly affect workers directly involved in operations and nearby populations (Cipolla et al., 2016). Hu et al. (2020) confirmed that storage tanks and tanker operations are the main VOC emission sources, leading to increased exposure to seafarers (Hu et al., 2020).

2.1 Health Effects of VOC Emissions

VOCs emitted into crude oil tankers pose significant health risks to a ship's crew through respiration, causing acute symptoms short-term and chronic health problems in long-term. Johnson et al. (2023) found that occupational VOC exposure can lead to a risk of genotoxicity. Long-term exposure increases the risk of respiratory diseases such as asthma and bronchitis. Some VOCs, particularly benzene, are carcinogenic properties. Extended exposure can also trigger mental health issues including depression and anxiety.

2.1.1 Short-Term Effects

Short-term VOC effects tend to result in acute health issues characterized by their quick onset following initial exposure to such substances. Upon the direct exposure of ship personnel to these gases during the handling, loading, and unloading operations of crude oil, they may show physical reactions that can be visibly noticed after a relatively short period. Symptoms such as dizziness, headache, difficulty breathing, and irritation of the eyes, nose and throat are common among the short-term effects caused by inhalation of VOCs. These symptoms can negatively affect the working conditions of the crew, reduce work efficiency and cause personnel to feel unsafe (Başaran, 2009). In cases where VOC concentrations are high in closed areas, personnel may face a risk of acute poisoning. Especially in an oxygen-depleted environment, the concentration of VOC vapors can have serious effects on employees, including loss of consciousness and respiratory arrest. In addition, some of these compounds also cause skin problems such as dermatitis and skin irritation upon contact with the skin. Although these symptoms usually improve in a short time after the VOC exposure ends, they can become more permanent health problems after long-term and high-dose exposures. Personnel exposed to VOCs may experience a lack of concentration owing to these symptoms, which can endanger the safety of ship operations (Weiss et al. 2024). Distraction and fatigue are contributing factors to occupational accidents, especially for crew members responsible for sensitive tasks. It is of great importance to quickly identify any short-term effects and fit the crew with protective equipment against VOC exposure. Relating to this subject, Erik (2015) studied the effects of oil tankers' accidents on the environment. In this study, environmental pollution cases caused by accidents involving oil tankers and the negative effects of these pollutatns on ecosystems are discussed. Marine pollution and damage to marine life are very important, and some measures to avoid tanker accidents have been suggested.

2.1.2 Long Term Effects

Long-term VOC exposure may result in severe and irreversible health consequences for on board personnel. Unlike in the case of short-term exposure, the effects of related to continuous contact with volatile organic compounds can lead to more complex health problems that progress over time. The toxic structure of these compounds damages a variety of organ systems, seriously affecting the quality of life and work performance of the crew (Engel, 2023; Knave et al., 1978; Kleinbeck & Wolkoff, 2024). The most common long-term effects of VOCs are respiratory diseases. Especially in closed and poorly ventilated environments where ship personnel are constantly exposed to VOC vapors, the risk of developing chronic respiratory diseases, asthma, and bronchitis increases.

2.2 Ships Safety Effects by VOC Emissions

The impacts of VOC on ship safety includes comprise environmental, health and operational aspects. They are flammable and explosive, posing multiple operational hazards. Emission control is vital to safety. VOCs have a very low flash point and are thus highly flammable. Vapor recovery systems are used to reduce emissions but they need to be properly maintained to avoid potential hazards.

Explosions can occur because of pressure buildup or the leakage in the system. Safe conduct requires a detailed risk assessment and crew training.

Recent studies have highlighted the increase in VOC emissions from ships, particularly in coastal areas where maritime shipping activities are prevalent. For example, Gao discussed the potential of emissions from land-based activities in the maritime shipping sector to control VOC emissions in coastal areas, arguing that current regulations primarily focus on sulfur dioxide and particulate matter and neglect VOCs (Gao, 2024). This observation is critical because VOCs can lead to the formation of secondary organic aerosols (SOA) and ozone, which are harmful to both human health and the environment (Tong, 2024). The contribution of ship emissions to the VOC levels has been the subject of several studies. For example, Huang et al. (2018) found that moderate levels of volatile organic compounds (IVOCs) in ship exhaust were significant, which could have serious consequences for air quality and maritime safety (Huang et al., 2018).

2.3 Precautions and Strategies to Reduce Risk

This was achieved through the use of HAZOP and LOPA risk assessment methods aimed at minimizing the risk of VOC emissions. Such systematic approaches allow early hazard detection and protective measures. Gas detectors and warning systems should be used to continuously monitor for VOC build-up and provide an early warning for action. This includes risk mitigation strategies that include regular inspections and effective control procedures associated with different operational processes.

2.4 Vapor Recovery Units

VRUs are an important technology for controlling volatile organic compound (VOC) emissions from crude oil tankers. They capture, retain and recover vapors that are emitted during loading/unloading, thus minimizing environmental pollution and safety hazards. VRUs absorb and re-liquefy vapors to prevent VOCs from escaping into the atmosphere while allowing their recycling. Regular maintenance and inspections are critical not only for operational efficiency but also for safety.

The operating principle of a Vapor Recovery Unit is based on the absorption of VOC vapors emitted from tanks during the loading and unloading process, and their re-liquefaction within the system. In this way, the release of VOCs into the atmosphere is prevented, while at the same time the recovered vapors are recycled back into crude oil (Kaptı and Ayrımış, 2016). This process provides both economic and environmental benefits, significantly reducing air pollution caused by VOC emissions. In relation to this process, Dev et al., (2021) analyzed this process using simulation models to control and reduce VOC emissions. In this study, the effect of different operational conditions on VOC emissions in the crude oil-loading process was evaluated, and the possible effects of these emissions on the environment and human health were discussed. Methods for reducing of VOC emissions have also been suggested. In addition, the vapor recovery units applied should be supported by regular maintenance and inspections with regards to safety and operational effectiveness

2.5 Ship Security Risk Assessment Methodologies (HAZOP + LOPA)

HAZOP identifies possible design and operations deviations that result in hazardous situations and is a structured way of identifying hazards in processes and operations. As highlighted by Animah and Shafiee, HAZOP is an effective method for identifying the risks in ship-to-ship transfer systems. It is particularly helpful to fire, explosion, and toxic exposure perils from VOC emissions replicated during cargo operations.

The LOPA is used to evaluate whether a protection layer is adequate against a specific hazard. Recent studies have reported its efficiency when used together with a Fault Tree Analysis. Fan et al. highlighted the importance of safety culture and the potential adverse effects of humans on maritime accidents, correlating them with HAZOP's human interactions. Such methods are constantly evolving to address the growing complexity of maritime operations.

2.6 2.6. Environmental Effects due to VOC Emissions

VOC emissions are of great concern to ship personnel and the environment. This practice produces compounds that contribute to air pollution and participate in reactions that lead to global warming and ecosystem disruption. Environmental impacts are most extreme in sensitive regions such as the Arctic, where VOCs can erode the ozone layer and expose the Earth to elevated levels of damaging UV radiation. In marine environments, certain VOCs transform into more toxic compounds upon contact with seawater, accumulating on the surface of water and contribute to pollution.

2.7 Market and Logistics Impacts

VOC emissions affect both the mechanisms of the oil market and the logistics processes. The state of oil demand is higher so tankers work harder to load/unload which increases the emission risk during the operation. It must consider weather conditions, environmental regulations, and local emission limits. Some of the ports may also have different regulations for VOC emissions which could affect the time of operation and/or cost. Emission management technologies such as recovery systems raises operational expenses but are critical for meeting regulation and reducing risks.

Furthermore, emission management should also be considered in the planning of tanker stopover points and loading-unloading ports. The ports where loading and unloading are carried out may have different regulations related to VOC emissions, which may affect the operational times and logistics costs of tankers. In relation to this problem, Keskin (2006) focused on the control and management of waste originating from ships in his thesis. In the presented study, how the waste reception facility in Ambarlı Port manages ship waste and the environmental impacts of these processes are addressed.

3. Methods

As such, the study evaluated the literature regarding the effects of VOC emissions on the health and safety of crew members on crude oil tankers. The review examined scientific studies and industry reports related to operational, environmental and health effects of emissions.

3.1 Resource Selection and Screening

Publications were identified using sources such as Scopus, Web of science and ScienceDirect targeting peer-reviewed literature as well as industry reports. Some of these included "VOC emissions", "ship safety", "marine industry", "vapor recovery units", "crew health", and "fire and explosion risk".

3.2 Data Analysis

The selected sources were reviewed for the impacts of VOC emissions on human health, operation risk, and mitigation[13–16]. The effects of emissions on crew health and risk management approaches have been compared across studies.

4. Findings

A literature review found extensive data regarding the effects of VOC emissions on crew health, ship safety, and the environment for crude oil tankers. The results showed serious health impacts, increased in safety risks and risks to the environment. Exposure to VOC in the short term resulted in symptoms such as headaches and respiratory issues, but long-term exposure over a long time resulted in chronic ailments, especially respiratory illness as well as potential carcinogenic effects.

Vapor recovery units were found to be effective in regulating emissions, although they required regular maintenance. Environmental impacts are especially pressing in sensitive zones, those with notable marine ecosystems, and in areas that experience air pollution. VOCs lead to ground-level ozone, contributing to air pollution and affecting human health and vegetation.

5. Discussion

This review highlights the major threats to crew health, safety and the environment from VOC emissions and further calls attention to the immediate need for better management practices. They can exert different health effects, ranging from acute symptoms to serious chronic diseases, and there are particularly serious concerns regarding chronic respiratory diseases and neurological disorders from long-term exposures to particulate matter (Baur et al. 2015).

The low flash points of VOCs pose major safety challenges in terms of fire and explosion hazards. Although the VRU is a valuable tool for reducing potential risk, it must still be both properly maintained and operated by a well-trained crew. Operational testing and correct installation are critical for ensuring system safety (Tugyi et al. 2024; Doh et al. 2019).

This may correspond to particularly severe environmental impacts in sensitive regions, such as the Arctic, ecosystems, and as a contributor to the depletion of one of the most important greenhouse gases, ozone. Existing laws must be tightened and expanded to regulate emissions in sensitive areas (Can and Yay, 2014).

Emissions management is greatly affected by logistics and market factors, for route planning, environmental regulations must be balanced with operational efficiency. Although costly to operate, emission control technologies, offer long-term environmental and economic benefits.

VOC emissions from crude oil tankers significantly impact crew health, ship safety, and environmental protection. Based on the literature review, several key recommendations have emerged:

- Strengthen health monitoring systems for crew members, including regular health checks and early detection protocols.
- Enhance VRU maintenance and inspection protocols to ensure consistent effectiveness.
- Implementation comprehensive crew training on emission control technologies and emergency procedures.
- Develop stricter emission control measures for environmentally sensitive areas.
- Optimize tanker routes and port operations to minimize emission exposure.
- Update international regulations to reflect current environmental and safety concerns.

Effective VOC management requires balancing technological solutions with operational efficiency while prioritizing crew safety and environmental protection.

6. Conclusion and Recommendations

This study considers the adverse effects of the VOC emissions that occur in crude oil tankers with respect to their health relevance for the ship's personnel, ship safety and the environment, and the potential steps that can be implemented to mitigate such hazards. Research results based on the literature review showed that VOC emissions which in the short and long term are problematic for human health, increase the potential for fire and explosion in tanker operations and are a serious threat to ecosystems and the atmosphere. The maintenance of VOC emissions is a very important issue when it comes to all ship operations; it is required not only in the context of protection against adverse health effects for the personnel and to ensure the safety of vessels, but also in terms of environmental protection and the compliance with international regulations. An effective solution for minimizing risks is provided by such Technologies such as vapor recovery units, which control VOC emissions. In addition, ship operational phases require continuous assessment and periodic inspection of VOCs emissions. Using VOC detectors effectively and ensuring that emission levels are within international limits is an essential step towards protecting the health of ship personnel and the environment.

It is important to train ship personnel on VOC emissions and the measures to be taken against them. This also includes spreading awareness among the personnel on the use of technologies for emission control such as a vapor recovery system and the safety measures to be adopted during emergencies for safe operations.

Existing Vapor Recovery Units and other emission control Technologies require refined screening, and technological developments followed up for the safer and more efficient operation of these systems. Innovative emission reduction technologies are critical for minimizing emissions and cutting costs.

The current VOC emission-based international regulations need to be updated to achieve higher goals for both environmental and vessel safety; this also needs more scrutinized control of implementation. Emission must be under much stricter control in highly environmentally sensitive areas, among other aspects.

Health monitoring programs should be developed in order to monitor the health status of the crew regularly and enable the early detection of possible health problems related to the exposure to VOCs. These should include periodic health checks to reduce the health risks of personnel when exposed for long periods.

For operations with intense VOC emissions, the routes for tankers and port operations should be planned more carefully. Long stays in ports can increase emissions; therefore, optimizing operation times and avoiding emission-intensive areas will be useful in managing risks.

In general, the VOC management process is important for safe, efficient, and environmentally sustainable ship operations. Therefore, close monitoring of technological development, along with crew training and adherence to international regulations, will effectively minimize the health and safety risks caused by VOC emission.

References

[1] Ancione, G., Lisi, R., & Milazzo, M. F. (2021). Human health risk associated with emissions of volatile organic compounds due to the ship-loading of hydrocarbons in refineries. Atmospheric Pollution Research, 12(2), 432-442. https://doi.org/ 10.1016/j.apr.2021.01.002

[2] Animah, I., & Shafiee, M. (2020). Application of risk analysis in the liquefied natural gas (lng) sector: an overview. Journal of Loss Prevention in the Process Industries, 63, 103980. https://doi.org/10.1016/j.jlp.2019.103980

[3] Baalisampang, T., Abbassi, R., Garaniya, V., Khan, F., & Dadashzadeh, M. (2018). Review and analysis of fire and explosion accidents in maritime transportation. Ocean Engineering, 158, 350-366. https://doi.org/10.1016/j.oceaneng.
2018.04.022

[4] Baur, X., Budnik, L.T., Zhao, Z., Btaveit, M., Djuhuus, R., Verschoor, L., Rubino, F., M., Colosio, C. & Jepsen, J., R. (2015). Health risks in international container and bulk cargo transport due to volatile toxic compounds. J Occupational Medicine nad Toxicolgy, 10, 19. https://doi.org/10.1186/s12995-015-0059-4

[5] Chen, S., Lu, C., Shang, K., Guo, J., & Pan, J. (2021). Enablers of safety citizenship behaviors of seafarers: leader-member exchange, team-member exchange, and safety climate. Maritime Policy & Management, 50(1), 81-96. https://doi.org/ 10.1080/03088839.2021.1959077

[6] Cheng, Q., Wang, X., Chen, D., Ma, Y., Zhao, Y., Hao, J., & Zhou, Y. (2023). Impact of ship emissions on air quality in the Guangdong-Hong Kong-Macao Greater Bay Area. Sustainability, 15(11), 8820. https://doi.org/10.3390/su15118820

[7] Dev, A., Virdi, S. S., Li, C., & Lee, Y. L. (2021). Simulation of VOC emission during loading operations in a crude oil tanker. The International Journal of Maritime Engineering, 163(A1), 1-16. https://doi.org/10.3940/rina.ijme.2021.a1.615

[8] Doh, DH., Chun, K.W., Ninomiya, N. et al. A swirl static mixer with diluent for reducing the flammable extent of venting gases in a low-flashpoint fueled vessel. J Mech Sci Technol 33, 3311–

3321 (2019). https://doi.org/10.1007/s12206-019-0626-1

[9] Dong, B., Carrera, M., Baumler, R., & Tang, C. (2023). The relationship between work-induced sexual abstinence and psychological health of Chinese male seafarers. Inquiry: The Journal of Health Care Organization, Provision, and Financing, 60, 1-9. https://doi.org/10.1177/00469580231186230

[10] Elidolu, G., Uflaz, E., Aydin, M., Celik, E., Akyuz, E., & Arslan, O. (2022). Numerical risk analysis of gas freeing process in oil/chemical tanker ships. Ocean Engineering, 266, 113082. https://doi.org/10.1016/j.oceaneng.2022.113082

[11] Engel, L., S. (2023). Exposure to volatile hydrocarbons and neurologic function among oil spill workers up to 6 years after the Deepwater Horizon disaster. Environmental research, 231:116069-116069. doi: 10.1016/j.envres.2023.116069

[12] Erik, Y.N. (2015). Petrol Tankeri Kazaları ve Neden Olduğu Çevre Kirliligi. Mavi Gezgin, No 20, 1-11.

[13] Fan, S., Blanco-Davis, E., Yang, Z., Zhang, J., & Yan, X. (2020). Incorporation of human factors into maritime accident analysis using a data-driven Bayesian network. Reliability Engineering & System Safety, 203, 107070. https://doi.org/10.1016/j.ress.2020.107070

[14] Fetisov, V., Gonopolsky, A. M., Davardoost, H., Ghanbari, A. R., & Mohammadi, A. H. (2023). Regulation and impact of VOC and CO2 emissions on low-carbon energy systems resilient to climate change: A case study. Energy Science & Engineering, 11(4), 1516-1535. https://doi.org/10.1002/ese3.1271

[15] Gao, Y. (2024). A newly discovered ozone formation mechanism observed in a coastal island of east China. ACS EST Air, 1(8), 935-945. https://doi.org/10.1021/acsestair.4c00082

[16] Hu, G., Butler, J., Littlejohns, J., Wang, Q., & Li, G. (2020). Simulation of cargo VOC emissions from petroleum tankers in transit in Canadian waters. Environmental Science & Technology, 54(15), 9240-9249. https://doi.org/10.1021/acs.est.0c01090

[17] Huang, C., Hu, Q., Li, Y., Tian, J., Ma, Y., & Zhao, Y. (2020). Intermediate volatility organic compound emissions from a large cargo vessel operated under real-world conditions. Environmental Science & Technology, 54(21), 12934-12942. https://doi.org/10.1021/acs.est.8b04418

[18] Huerte, M. (2023). Health risk classification patterns among Filipino seafarers. International Maritime Health, 74(3), 143-152. https://doi.org/10.5603/IMH.2023.0018

[19] Johnson P, Sekhar L, Santhanam D, Venugopal, V. (2023). O-227 Effect of occupational exposure to volatile organic compounds and inorganic dusts on respiratory health. Occupational and Environmental Medicine 80: A23. doi: 10.1136/oem-2023-epicoh.54

[20] Karbasian, H., Kim, D., Yoon, S., Ahn, J., & Kim, K. (2017). A new method for reducing VOCs formation during crude oil loading process. Journal of Mechanical Science and Technology, 31(6), 2839-2845. https://doi.org/10.1007/s12206-017-0528-z

[21] Kleinbeck, S. & Wolkoff, P. (2024). Exposure limits for indoor volatile substances concerning the general population: The role of population-based differences in sensory irritation of the eyes and airways for assessment factors. Archives of Toxicology, doi: 10.1007/s00204-023-03642-w

[22] Knave, B., Olson, B. A., Elofsson, S., Gamberale, F., Isaksson, A., Mindus, P., Persson, H. E., Struwe, G., Wennerg, A., & Westerholm, P. (1978). Long-term exposure to jet fuel: II. A cross-sectional epidemiologic investigation on occupationally exposed industrial workers with special reference to the nervous system. Scandinavian Journal of Work, Environment & Health, 4(1), 19–45. http://www.jstor.org/stable/40964689

[23] Lan, H. (2024). Risk evolution analysis of seafarers' unsafe acts in maritime accidents. Applied Sciences, 14(6), 2595. https://doi.org/10.3390/app14062595

[24] Lee, S., & Chang, D. (2014). Safety systems design of VOC recovery process based on HAZOP and LOPA. Process Safety Progress, 33(4), 339-344. https://doi.org/10.1002/prs.11662

[25] Martens, M. O., Oldervik, O., Neeraas, O. B., & Strom, T. (2023). Control of VOC emission from crude oil tankers. International Conference on Marine Engineering Systems (ICMES), 1-12. https://doi.org/10.5957/ICMES.2023.001

[26] Ng, K. (2023). Organizational factors and safety culture maturity among seafarers: towards maritime safety. Journal of Undergraduate Research, 5(3), 9-26. https://doi.org/10.46754/umtjur.v5i3.351

[27] Pike, K., Wadsworth, E., Honebon, S., & Broadhurst, E. (2021). Gender in the maritime space: experiences of women seafarers. Journal of Navigation, 74(6), 1238-1251. https://doi.org/10.1017/S0373463321000473

[28] Rajabi, H., Mosleh, M. H., Mandal, P., & Lea-Langton, A. (2020). Emissions of volatile organic compounds from crude oil processing: Global emission inventory and environmental release. Science of The Total Environment, 727, 138654. https://doi.org/10.1016/j.scitotenv.2020.138654

[29] Shehu, H., Okon, E., & Gobina, E. (2020). Separation of methane from shuttle tanker vents gases by adsorption. Key Engineering Materials, 733, 42-46. https://doi.org/10.4028/www.scientific.net/KEM.733.42

[30] Szafran-Dobrowolska, J., & Grubman-Nowak, M. (2023). The psychosocial burden and stress coping strategies among seafarers. International Maritime Health, 74(2), 122-128. https://doi.org/10.5603/IMH.2023.0018

[31] Tamaddoni, M., Sotudeh-Gharebagh, R., & Nario, S. (2021). Experimental study of the VOC emitted from crude oil tankers. Process Safety and Environmental Protection, 147, 755-766. https://doi.org/10.1016/j.psep.2021.01.015

[32] Thompson, T., Shepherd, D., Stacy, A., & Barna, M. (2017). Modeling to evaluate contribution of oil and gas emissions to air pollution. Journal of the Air & Waste Management Association, 67(4), 445-461.https://doi.org/10.1080/10962247.
2016.1251508

[33] Tong, M. (2024). Contribution of ship emission to volatile organic compounds based on one-year monitoring at a coastal site in the Pearl River Delta region. Journal of Geophysical Research: Atmospheres, 129(2), e2023JD039999. https://doi.org/10.1029/2023JD039999

[34] Wang, L., Zhang, K., Chen, R., & Yang, S. (2023). VOC emissions control technologies in marine vessels: A comprehensive review. Journal of Marine Science and Engineering, 11(4), 789-812. https://doi.org/10.3390/jmse11040789

[35] Wu, Z., Zhang, Y., He, J., Chen, H., Huang, X., Wang, Y., & Wang, X. (2020). Dramatic increase in reactive volatile organic compound emissions from ships at berth after implementing the fuel switch policy in the Pearl River Delta Emission Control Area. Atmospheric Chemistry and Physics, 20(4), 1887-1900. https://doi.org/10.5194/acp-20-1887-2020

[36] Tugyi, L., Siménfalvi, Z., & Szepesi, G. L. (2024). Determination of Flash Points of Flammable Mixtures for Explosion Protection. In Solid State Phenomena (Vol. 363, pp. 81–86). Trans Tech Publications, Ltd. https://doi.org/10.4028/p-tky3si

[37] Yang, X. (2023). Integrating software FMEA and STPA to develop a Bayesian network-based software risk model for autonomous ships. Journal of Marine Science and Engineering, 12(1), 4. https://doi.org/10.3390/jmse12010004

[38] Wang, L., Zhang, K., Chen, R., & Yang, S. (2023). VOC emissions control technologies in marine

vessels: A comprehensive review. Journal of Marine Science and Engineering, 11(4), 789-812. https://doi.org/10.3390/jmse11040789

[39] Weiss, T., Koslitz, S., Nöllenheidt, C, Caumanns, C., Hedtmann, J., Käfferlein, H., U., & Brüning, T. (2024). Biomonitoring of volatile organic compounds and organophosphorus flame retardands in commercial aircrews after "fume and smell events". International Journal of Hygiene and Environmental Health, 259:114381-114381. doi: 10.1016/ j.ijheh.2024.114381

[40] Wu, Z., Zhang, Y., He, J., Chen, H., Huang, X., Wang, Y., & Wang, X. (2020). Dramatic increase in reactive volatile organic compound emissions from ships at berth after implementing the fuel switch policy in the Pearl River Delta Emission Control Area. Atmospheric Chemistry and Physics, 20(4), 1887-1900. https://doi.org/10.5194/acp-20-1887-2020

[41] Yang, X. (2023). Integrating software FMEA and STPA to develop a Bayesian network-based software risk model for autonomous ships. Journal of Marine Science and Engineering, 12(1), 4. https://doi.org/10.3390/jmse12010004

[42] Yazdi, M., Mohammadpour, J., Li, H., & Huang, H. (2023). Fault tree analysis improvements: A bibliometric analysis and literature review. Quality and Reliability Engineering International, 39(5), 1639-1659. https://doi.org/10.1002/qre.3271

[43] Xiao, Q., Li, M., Liu, H., Fu, M., & Deng, F. (2020). Characteristics of marine shipping emissions at berth: Profiles for particulate matter and volatile organic compounds. Atmospheric Chemistry and Physics,18(13),9527-9545.https://doi. org/10.5194/acp-18-9527-2018

[44] Yilmaz, F. (2022). Green-eco port approach and maritime industry: Comparative analysis of Turkey and EU applications. Journal of Transportation and Logistics, 4(2), 65-78. https://doi.org/10.26650/JTL.2019.04.02.02

[45] Zhang, H., Liu, Y., Wang, J., & Wu, X. (2024). Health impacts of occupational VOC exposure in maritime industry: A systematic review and meta-analysis. International Journal of Environmental Research and Public Health, 21(2), 567. https://doi.org/10.3390/ijerph21020567