EFFECTS OF AIR POLLUTION FROM SHIPS ON HUMAN HEALTH

Bruna Bacalja[1]*, Maja Krčum[1], Matea Videk[2]

[1]University of Split, Faculty of Maritime Studies, Ulica Ruđera Boškovića 37, 21000 Split, Croatia

[2]KBC Split, Spinčićeva 1, 21000 Split, Croatia

Abstract

Air pollution, which has been identified as a global concern, has a significant influence on human health and environment. Human health is affected differently by long and short-term exposure to air pollution causing respiratory and cardiovascular disorders, long-term chronic diseases like cancer and different diseases. Ships emit significant amounts of pollutants into the atmosphere, primarily sulphur (SO_X) and nitrogen oxides (NO_X), as well as particulate matter (PM). Shipping emissions of sulphur and nitrogen oxides have consistently increased over the last thirty years, despite efforts in lowering emissions from land-based sources. As a result, the purpose of this research is to determine main ship air pollutants, their effects on human health and proposing measures of prevention.

Keywords: *air pollution, shipping, health, prevention of diseases*

1. INTRODUCTION

Over the years, there has been an increase in the greenhouse gas concentration in the atmosphere which contributes to global warming and climate change. One of the causes is the burning of fossil fuels due to usage in traffic, which includes shipping. Despite the fact that shipping generates 80 % of global trade by volume and over 70 % by value by providing cost-effective and efficient long-distance transportation, it is facing a number of issues as a result of various severe environmental impacts (Asariotis 2018). Diesel engines are often used as marine propulsion due to their reliability and economy. During the operation of internal combustion in diesel engines, a large amount of fossil fuel is used, which poses a threat to the environment. The purpose of an internal combustion engine is to produce mechanical power from the chemical energy contained in the fuel (Arcoumanis n.d.). In internal combustion engines, energy is released by the combustion of fuel inside the engine. The mixture of fuel and air are the input parameters, and the combustion products are the output parameters (Heywood 2002). The composition of the exhaust gas mixture, liquids, and solids released into the air varies depending on the type of engine, engine power, operating conditions as well as the type of fuel and lubricating oil. While burning high sulfur content fuel oil diesel engines produce sulfur dioxide, nitrogen oxide, and particulate, in addition to carbon monoxide, carbon dioxide, and hydrocarbons. Total shipping (international, domestic, and fishing) has increased its greenhouse gas (GHG) emissions, which include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), expressed in CO_2e, from 977 million tonnes in 2012 to 1,076 million tonnes in 2018. (9.6 percent increase) (MEPC 2020). The above mentioned present a threat globally since air pollution transfers transboundary in the atmosphere (Lonati, Cernuschi & Sidi 2010). NO_X emissions from shipping (2.8 million tons) were equal to 25% of total emissions from the land. Around 30% of these emissions occurred in the EU Member States' Territorial Seas, or within 12 nautical miles of the coast. Emissions from the Exclusive Economic Zones (200 nm) accounted for around 75% of total emissions. Shipping has a significant impact on air pollution in coastal areas. In 2005, international shipping was responsible for 35% of sulfur deposition in coastal areas, which exceeded 0.2 g/m2 per year, with maximum values ranging from 0.5 to 1.0 g/m2 (Campling 2013). In 61% of instances, the risk of mortality from respiratory disorders induced by exposure to all air pollutants is significantly higher than the risk of death from cardiovascular disease, with a 6-10 % greater relative risk on average (Vanos, Hebbern & Cakmak 2014). Individuals with particular health disorders, such as diabetes and cardiovascular disease, hypertension, atrial fibrillation, and cancer, may be vulnerable to the short-term impacts of air pollution (MS 2013). The European Commission has unveiled a comprehensive set of legislative recommendations aimed at reducing greenhouse gas emissions by 55 percent by 2030, with the goal of making the EU climate neutral by 2050 (*European Commission*, n.d.).

In order to attain this objective, greenhouse gas emissions will need to be lowered by at least 55 percent by 2030 compared to 1990 levels. In this regard, a regulation was adopted in 2018, which specifies how much each Member State must reduce greenhouse gas emissions in the areas of road transport, building heating, agriculture, small industrial plants, and waste management in order to drop emissions from these sectors. Under the new proposal for a regulation, the emission reduction target has been increased for all Member States, taking into account the wealth of the Member States. Richer members will need to reduce their emissions significantly more than poorer ones. Bulgaria is required to make the lowest reduction, only 10%. On the other hand, Sweden and Luxembourg have their reduction target increased from the previous 40 to 50%. International Maritime Organisation (IMO) is working to control international maritime emissions. The IMO adopted a new regulatory framework for energy efficiency in 2011. Since then, the IMO developed an initial strategy for reducing greenhouse gas emissions from ships, setting a goal of cutting greenhouse gas emissions by at least half by 2050 compared to 2008 levels, as well as a goal of decarbonizing the industry (MEPC, 2020). It also sets a goal of reducing carbon intensity in international shipping by at least 40% by 2030, with a goal of 70% by 2050, compared to the 2008 results. In this paper, a descriptive research method is used to determine air pollution with the goal of contributing to pollution minimization through the application of technical and medical prevention.

2. AIR POLLUTANTS

2.1. Nitrogen Oxides (NO_X)

Nitrogen (N_2) makes up around 80% of the air humans breathe. The chemical element nitrogen (N) can be reactive and has ionization levels (also known as valence states) ranging from one to five. Nitrogen oxides are nitrogen and oxygen compounds formed as a by-product of fuel burning. As a result, nitrogen can produce a variety of oxides: nitrous oxide (N_2O) nitric oxide (NO) dinitrogen dioxide (N_2O_2) dinitrogen trioxide (N_2O_3) nitrogen dioxide (NO_2) dinitrogen tetroxide (N_2O_4) dinitrogen pentoxide (N_2O_5) (Nitrogen Oxides (NOx), Why and How They Are Controlled 1999). The majority of NO_X emissions from combustion are in the form of NO, which produces the same failure to absorb oxygen into the blood as carbon monoxide (CO). The amount created is proportional to the peak temperature of combustion; the higher the peak temperature, the higher the level generated. As the air mixture is 21 % oxygen and 78% nitrogen, nitrogen reacts with oxygen under certain engine operating conditions to form Nitrogen oxides or NO_X. The combination of high temperatures and pressures in diesel engine cylinders results in relatively large levels of these hazardous gases. NO_X emissions, particularly NO_2, are a known precursor to the development of ozone and secondary aerosols, which contribute significantly to PM_{10} and $PM_{2.5}$. Ozone is particularly harmful to human health since it can induce acute respiratory issues and decrease lung capacity (Lu 2016). As a result, NO_X is not only a pollutant itself, but it also contributes to other pollutants of substantial public health and environmental significance. Furthermore, NO_X can react with volatile organic compounds to produce photochemical smog. Because these gases may easily travel long distances from their source of generation, the pollution they cause (smog, acid rain, etc.) can have an impact many miles away from the source. The shipping industry itself contributes 15% to anthropogenic NO_X emissions (Eyring 2005). As visible from Figure 1, NO_X emission from domestic shipping contribute with 8% and international shipping 27% to all transport NO_X emissions.

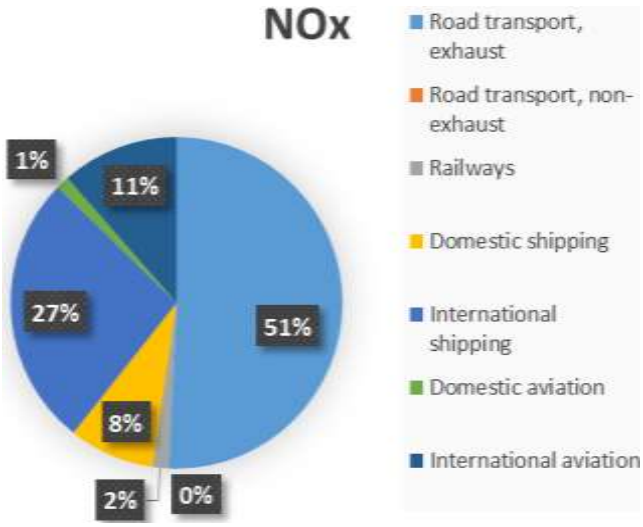


Fig. 1. NOx emissions from transport sector in year 2017

Source: *Emissions of air pollutants from transport — European Environment Agency*

The International Convention for the Prevention of Pollution from Ships (MARPOL) has a major role in regulating air pollution from ships. The MARPOL Annex VI regulates NO_X emissions. Depending on the ship's construction date, several levels (Tiers) of control apply. The Tier I regulation refers to ships built after 1 January, the Tier II regulation refers to ships built after 2011 and the Tier III refers to ships built after 2016. Slow-speed engines (130 rpm), high-speed engines (> 2000 rpm), and intermediate-speed engines (130 < n < 2000 rpm) all have different NO_X emission restrictions (Marpol Convention 1973).

MARPOL Annex 6 Regulation 13 divides marine diesel engines into groups based on their manufacture date and establishes the maximum emissions that can be produced. If the engine was modified, the rebuilt engine must meet the standard that was in place at the time the alteration was made. Technical Code on Control of Nitrogen Oxide Emission from Marine Diesel Engines purpose is defining the requirements for testing, surveying, and certification of marine diesel engines in order to ensure that they meet the nitrogen oxides (NO_X) emission limits outlined in forth in Annex VI regulation 13 (NOX Technical Code 2008).

2.2. Sulfur Oxides (SO_X)

The combustion of fossil fuels emits various sulfur oxides (SO_X). Sulfur oxides (SO_X) are sulfur and oxygen molecular compounds. In the lower atmosphere, sulfur dioxide (SO_2) is the most common type. It's a colorless gas that's detectable by taste and smell. Sulfur dioxide quickly dissolves in water in the atmosphere, forming sulfuric acid (H_2SO_3) (*Sulfur dioxide | SO2 - PubChem* n.d.). Sulfur dioxide, sulfate aerosols, and sulfur dioxide adsorbed onto the particulate matter are all responsible for the health effects attributed to sulfur oxides. Reduced lung function, increased prevalence of respiratory symptoms and disorders, irritation of the eyes, nose, and throat, and early mortality have all been linked to exposure to sulfur dioxide in the ambient air. Children, the elderly, and those who already have respiratory problems, such as asthmatics, are particularly vulnerable. Short exposures to ambient concentrations above 1,000 g/ m3 appear to have health consequences (acute exposures measured over 10 minutes). Sulfur dioxide will dissolve in the watery fluids of the upper respiratory system and be absorbed into the bloodstream if it is consumed alone (Sulfur Oxides n.d.). As reported by several authors, shipping contribute to the overall anthropogenic emission of SO_X from 5 to 8% (Eyring 2005)(Corbett 2007). The percentage of sulfur in fossil fuels can vary, depending on the fuel type. As visible from Figure 2, SO_X emissions from domestic shipping contributes with 10% and international shipping 81% of all transport SO_X emissions.

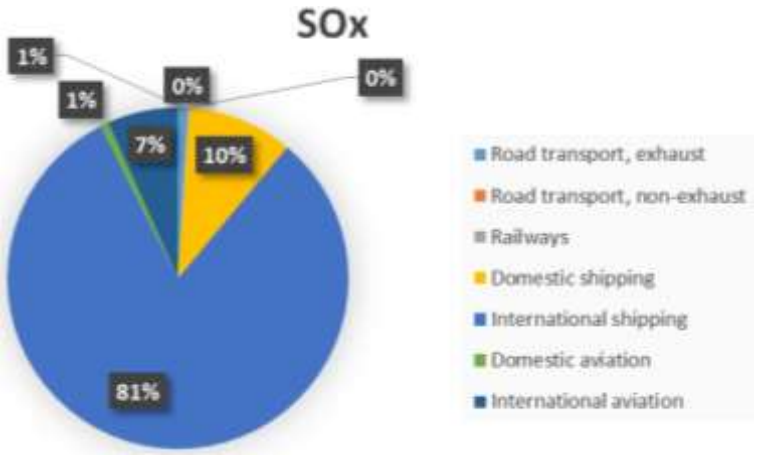


Fig. 2. SO_X emissions from transport sector in year 2017

Source: *Emissions of air pollutants from transport — European Environment Agency*

The International Maritime Organization sets the percentage of sulfur used in marine fossil fuels. Any fuel used onboard must not exceed the following sulfur content limits: 4.50% by weight before 1 January 2012; 3.50% by weight from 1 January 2012 onwards; 0.50% by weight from 1 January 2020 onwards. The International Maritime Organization has imposed an even stricter restriction of 0.10 percent m/m, which is already in application in emission control areas (ECAS) (Marpol Convention 1973). All ships must use fuel with a sulfur level of less than 0.1 by weight while at berths in ports, according to EU Directive 2005/33/EC.

2.3. Particulate Matter (PM)

Soot, ash, and unburned fuel, as well as secondary sulfate and nitrate particles, are classified as particulate matter (PM) and are separated into two classifications based on particle size. PM_{10} are inhalable particles with a diameter larger than 2.5 micrometers and smaller than 10 micrometers and $PM_{2.5}$ are fine particles that are 2.5 micrometers and smaller (Particle Pollution, n. d.).

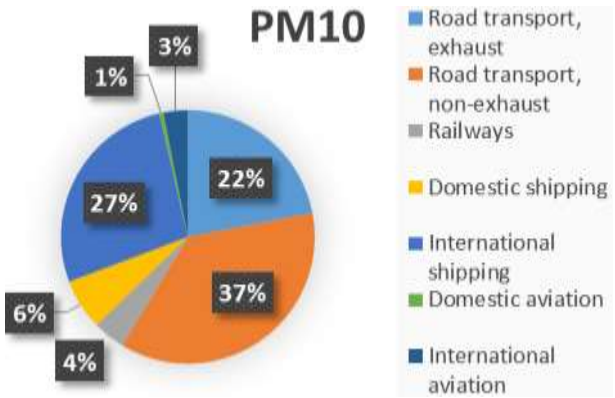


Fig. 3. PM_{10} emissions from transport sector in year 2017

Source: *Emissions of air pollutants from transport — European Environment Agency*

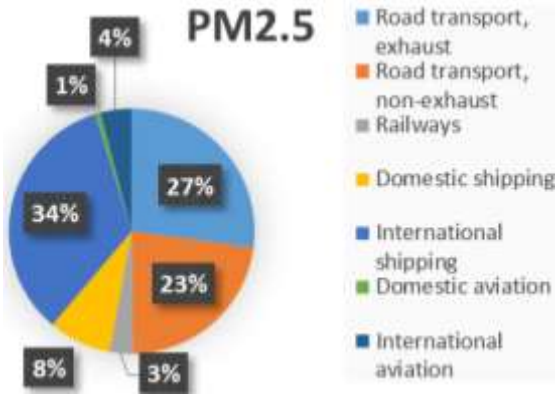


Fig. 4. $PM_{2.5}$ emissions from transport sector in year 2017

Source: *Emissions of air pollutants from transport — European Environment Agency*

All of them have the potential to cause cancer, and the smaller particles, known as $PM_{2.5}$, can be dragged deeper into the bronchial passages, causing asthma, bronchitis, and heart failure. The bigger particles >PM10 are generally deposited close to the source, whereas the lighter and smaller particles can remain airborne for long periods (International Maritime Organization 2015)(Toscano & Murena 2019). According to the European Environment Agency (EEA), $PM_{2.5}$ concentrations caused about 400 000 premature deaths in Europe in 2014 (European Environment Agency 2017). As visible from Figures 3. and 4. PM emissions from domestic shipping contribute with 6-8% and international shipping 27-34% of all transport PM emissions depending on size.

3. TECHNICAL PREVENTION

As a result of the mentioned shipping air emission impacts and requirements for air pollution prevention under Annex VI of the MARPOL Convention, a variety of regional, national, and local authorities have implemented their own restrictions. There are several compliance alternatives available, each with its own set of technical and operational challenges. Exhaust Gas Treatment systems have advanced in response to the growing need in reducing air pollution. Exhaust gas treatment systems can be classified into three categories based on the abatement target: Sulphur Oxide (SO_x), Nitrogen Oxide (NO_x), and Particulate Matter (PM) abatement technologies (Bronsart, Urbanski & Shu 2013).

3.1. Sulfur Oxides reduction

The scrubber technique enables ships the usage of cheaper heavy fuel oil (HFO) while staying under emission control restrictions. The use of sulfur scrubbers in order to minimize SO_2 emissions by a comparable quantity is an alternative to using relatively expensive low sulfur fuels. In the use of wet scrubbers, water is used to wash away the sulfur content of exhaust gas. There are three types of wet scrubbers: Closed Loop Freshwater Scrubber (FWS) system, Open Loop Sea Water Scrubber (SWS) system, and Hybrid Scrubber (HS) system that can work in both open and closed-loop modes (Scrubbers-An economic and ecological assessment n.d.). Depending on the scrubber, either saltwater with natural alkalinity or freshwater dosed with sodium hydroxide (NaOH) is brought into close contact with the exhaust gas and appropriately treated before being discharged to the ocean or flowing back into the system. Unlike the wet scrubbers, Calcium hydroxide in granulate form is used in a dry scrubber to remove sulfur (*Dry scrubber - Energy Education* n.d.). Bosch et al. (2009) present an overview of the costs of new installations and retrofits in terms of both capital and operating costs. The unit SO_2 reduction costs for saltwater scrubbers are substantially cheaper than the expenses of using low sulfur fuels (Bronsart, Urbanski & Shu 2013).

3.2. Nitrogen Oxides reduction

There are two types of NO_X reduction methods: primary and secondary. Primary methods use abatement technology directly to the source of NO_X and limit the creation of NO_X emissions, whereas secondary methods, also known as after treatment, reduce NO_X emissions after they have already been formed. The spray distribution in the combustion chamber can be optimized without affecting temperature and thus engine dependability by replacing traditional fuel valves with sliding low-NO_X fuel valves. By injecting water into the combustion chamber before the combustion process begins, the combustion chamber can be kept cool, reducing NO_X development. The Humid Air Motor (HAM) system reduces NO_X production during the combustion process by mixing heated charge air with water vapor (Riom, Larsson & Hagström 2002). NO_X emissions can be reduced by up to 80% with HAM technology. Exhaust gas recirculation (EGR) technology filters, cleans, cools, and recirculates a fraction of the exhaust gas back into the combustion chamber. Because the specific heat capacities of the main exhaust components are higher than air, less thermal NO_X production can be achieved as a result of the lower combustion temperature (*Exhaust Gas Recirculation - an overview* n.d.). Furthermore, recirculated exhaust gas contains less oxygen, reducing the production of nitrogen oxidation. Exhaust Gas Recirculation (EGR) is a proven technology for diesel engines in land-based applications that recirculates a part of the exhaust gas but it can also be used in marine engines. Selective catalytic reduction is the technique with the greatest ability to reduce NO_X emissions and meet Tier III regulations (Busca n.d.). SCR is an exhaust gas post-treatment system that reduces NO_X emissions by more than 80% (Bronsart, Urbanski & Shu 2013). By the usage of liquid urea, nitrogen oxide (NO_X) is transformed into elemental oxygen (O_2) and nitrogen (N_2), which are no longer harmful to the human body.

3.3. Particulate Matter reduction

Diesel Particulate Filter (DPF) is a standard technology that physically traps particulate matter from a diesel engine's exhaust stream as it passes through a filter. Cordierite, silicon carbide, ceramic fiber, or metal fiber can all be used to make the filter(*Everything You Need to Know About Diesel Particulate Filters*, n.d.). After the PM has been caught, the filter can be regenerated either passively or actively to remove or burn the accumulated soot. Diesel Oxidation Catalyst (DOC) technology, rather than physically trapping PM, uses a chemical reaction to oxidize carbon monoxide, gas-phase hydrocarbons, and the soluble organic fraction of diesel PM (Russell & Epling 2011). The Electrostatic Precipitator (ESP) is an after-treatment system that removes particulate particles from the exhaust stream using induced electrostatic force (*electrostatic precipitator* n.d.). Slow steaming has emerged as an effective method for reducing vessel fuel consumption and emissions in recent years. Reduced sailing speed of marine boats has become an increasingly frequent practice in the sector as a result of the global economic crisis, higher fuel prices, and more available vessel capacity.

3.4. Renewable energy sources in shipping

Wind energy, solar energy, fuel cells and biofuel are some of the alternatives proposed to reduce or replace fossil fuels onboard a ship. They can be utilized on their own or in conjunction making hybrid power systems onboard. Renewables sources of energy in maritime sector can be incorporated into existing fleet as retrofits or new shipbuilding and design. Wind-assisted ship propulsion (WASP) technology, which uses wind to replace some of the propulsive power supplied by fossil fuels, appears to be a promising answer for the shipping industry's decarbonization efforts. The key advantages of deploying wind power aboard ships are the same as they are for the rest of the wind power industry: minimal carbon emissions and less exposure to fossil fuel price volatility. Several projects are in the process of bringing wind power large container ships and even cruise ships. The Neoline, which uses enormous sails claims to minimize carbon dioxide emissions by 90% compared to other roll-on, roll-off ferries (*NEOLINE* n.d.). Solar power is another option for reducing fuel use on board ships. Solar power has become a cost-effective fuel-saving option on pleasure boats, ferries, and tourist vessels, especially for auxiliary engines. Solar panels installed onboard ships are generating electricity, and thus minimizing the amount of power required by diesel generators. Eco Marine Power (EMP) and Hisafuku Kisen K.K. of Onomichi will test the world's first integrated rigid sail and solar power system for ships as part of a new partnership. EnergySails technology, which incorporates solar panels mounted on the covers of big bulk carrier ships, will be combined with energy storage applications managed by a

computer-based monitoring system (*Climate Action* n.d). Hydrogen fuel cells are electrochemical systems that can transform hydrogen's chemical energy into electrical energy, with water as the only by-product. They're similar to batteries, however they're meant to create electricity continually if hydrogen and oxygen are supplied from outside. Hydroville, a 16-passenger shuttle running between Kruibeke and Antwerp, is running on hydrogen fuel (*HYDROVILLE* n.d.). Hydroville, the world's first hydrogen-powered passenger ship, debuted three years ago. It can run on both hydrogen and diesel thanks to its hybrid engine. Biofuels have a very low sulphur content and emit very little CO2, making them a technically viable alternative to low-sulphur fuels. The disadvantages are that the shipping industry has minimal experience with handling and deploying biofuels as a fuel source. Another issue is the volume of biofuels required to serve the shipping industry. The cost of biofuels is higher than the cost of fossil fuels and is expected to remain so (Hsieh & Felby 2017).

4. MEDICAL PREVENTION

The American Organization of Occupational Therapists defines occupational therapy as a profession that helps people perform certain activities by using occupations as therapeutic agents and as such is aimed at disease prevention and health promotion, not just the treatment of pre-existing conditions (Hildenbrand & Lamb 2013). At the center is always the man and his basic needs and all the factors that impair his health at that moment. The most variable factor is a person's reaction to external influences and in the context of disease prevention it is aimed at adopting healthy methods of maintaining health. Disease prevention and health promotion are the first and most important steps in the approach of the holistic view of man as an active and healthy being. Thus, the inclusion of occupational therapy in the prevention of diseases caused by exhaust gases from ships is very effective and expedient. Exhaust gases from ships impair people's health and thus reduce their quality of life. By affecting the respiratory and cardiovascular systems, they affect the quality of performance of everyday life activities. Reduced ability to carry out occupations that are in the interest of the person can disrupt his physical and therefore mental condition. In the prevention of the development of cardiovascular and respiratory difficulties caused by exhaust fumes from ships, occupational therapy intervention is aimed at preserving existing health and improving it. Prevention of cardiovascular diseases is focused on the application of healthy lifestyles, primarily on increased physical activity, but also on the application of healthier lifestyles, which may include smoking cessation, diet regulation, etc. user involvement in occupations aimed at preserving health. Prevention of respiratory difficulties is aimed at the same approach to a healthy lifestyle as in the prevention of cardiovascular disease. According to Barber et al. from 2020, the application of salt rooms, i.e. the application of salt therapy proved to be significant in the fight against chronic respiratory difficulties (Rashleigh, Smith & Roberts 2014). Although there are no official guidelines for the use of salt therapy as a type of treatment, its positive effects can be used in planning disease prevention and maintaining health. Occupational therapy as a client-oriented profession is not only in the service of treating the disease but is also a good tool in preventing the development of pathological conditions. A human being can adapt to new situations, and an imbalance occurs when this possibility is terminated. An imbalance in the distribution of time disturbs the psychophysical state. For sailors, due to long stays outside the home, poor distribution of occupations as well as poor leisure time can cause compensatory methods of using opiates as well as alcohol. Cardiovascular disease affects the seafaring community just as much as the overall population. According to many mortality studies, the percentage of seafarers who die from cardio vascular illnesses is due to a mix of genes, age, smoking, and other factors impacted by conditions aboard such as stress, diet, lack of exercise, and so on. According to a study by Richard Pougnet and colleagues from 2014, 63.1% (range 38.4-96.3%) of sailors smoked tobacco. 14.5% (range 8.8-75%) of seafarers drank alcohol. 3.4% (range 9-45%) had used cannabis during the previous month. The results of the research confirm that a large number of sailors indicate the use of opiates or alcohol that may be associated with impaired daily functioning in everyday occupations. The prevention of addictive behaviors and substitution with healthy patterns of behavior which, in addition to the prevention of addiction, has the function of accepting healthy lifestyles leads to the general improvement of health. Estimating the risk of infectious diseases among seafarers and identifying occupational infectious diseases is of high importance. At each seafarer examination, it is important to provide an intervention plan to prevent the development of disease or

addictive behaviors. The plan of intervention can be summarized as a health protocol and can be actively monitored by each seafarer at intervals of 3-6 months. The protocols would include a plan of healthy behavior patterns and would monitor vital signs such as lung capacity, psychomotor status through addiction prevention testing, and healthy eating plans.

CONCLUSION

The contribution of ships and port operations to air pollution has grown in importance as pollution from road traffic and land-based stationary sources have been rigorously regulated. Air pollution from road traffic, for example, is a topic of public concern and has decreased, whereas most ocean-going ships operate without effective pollution control. The duration of usage of maritime vessels is typically much longer than for road vehicles, and the fuel quality is rarely equivalent to that used in the automotive industry. Because shipping generates the majority of global trade, the environmental policy at the international level is of high importance. International Maritime Organization (IMO) has a major role in the regulation of air pollution. IMO has adopted several measures and is developing further plans in order to reduce air pollution from ships, shipping but due to the numerous parties involved, it takes a lot of time. The first step in preventing and reducing air pollution from ships is to quantify the problem and comprehend the types of air pollutants and their sources. To do so, a program of air quality monitoring should be implemented. Control methods to improve air quality in local areas must incorporate required and executed control measures at the state, regional, and national levels. In general, national government rules have the broadest application, which might help to reduce boundary and economic competition difficulties. Consistent monitoring of air pollution in different ports would enable comparisons to national ambient air quality standards. After the air emissions have been recognized and quantified, steps to prevent emissions from ships can be taken. Besides technical preventions on ships analyzed in this paper, limitation of sulfur content in fuel, financially stimulating ship owners in investing in new vessels or repowering current vessels with lower-emitting engines, and replacing fossil fuels with alternative energies would contribute to air emission reduction. People as living beings who are influenced by purposeful activities can affect their health. To achieve optimal functioning in the activities of everyday life, the distribution of time on the activities of self-care, productivity, and free time has an impact. It is very important that the ratio of participation in individual activities corresponds to the needs of the individual and that no group of activities is burdened or neglected.

REFERENCES

(MEPC), I. M. E. P. C. (2020) ‘4th IMO Greenhouse Gas Study 2020’, *Mepc 75/7/15*, 74.

A European Green Deal | European Commission (no date). Available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (Accessed: 26 July 2021).

Arcoumanis, C. (no date) ‘INTERNAL COMBUSTION ENGINES’, *A-to-Z Guide to Thermodynamics, Heat and Mass Transfer, and Fluids Engineering*. Begellhouse. doi: 10.1615/ATOZ.I.INTERNAL_COMBUSTION_ENGINES.

Asariotis, R. *et al.* (2018) ‘Review of Maritime Transport 2018’, in.

Bronsart, R., Urbanski, T. and Shu, S.-T. (2013) ‘A Life Cycle Cost Analysis of Marine Scrubber Technologies Shih-Tung Shu “EMSHIP” Erasmus Mundus Master Course in “Integrated Advanced Ship Design” “EMSHIP” Erasmus Mundus Master Course, period of study’.

Busca, G. *et al.* (no date) ‘Chemical and mechanistic aspects of the selective catalytic reduction of NO x by ammonia over oxide catalysts: A’.

Campling, P. *et al.* (2013) ‘Specific evaluation of emissions from shipping including assessment for the establishment of possible new emission control areas in European Seas’, (March), p. 84. Available at:

http://www.iiasa.ac.at/web/home/research/researchPrograms/MitigationofAirPollutionandGreenhouse gases/Final_Report_VITO_International_Shipping-main-16042013.pdf.

Convention, M. (1973) 'International Convention for the Prevention of Pollution from Ships', *MARPOL Convention Outline*.

Corbett, J. J. *et al.* (2007) 'Mortality from ship emissions: A global assessment', *Environmental Science and Technology*. doi: 10.1021/es071686z.

Dry scrubber - Energy Education (no date). Available at: https://energyeducation.ca/encyclopedia/Dry_scrubber (Accessed: 27 July 2021).

electrostatic precipitator | Definition, Diagram, Application Of, & Uses | Britannica (no date). Available at: https://www.britannica.com/technology/electrostatic-precipitator (Accessed: 27 July 2021).

European Environment Agency (2017) *Air quality in Europe — 2017, EEA Technical Report*. doi: 10.2800/850018.

Everything You Need to Know About Diesel Particulate Filters (no date). Available at: https://www.uti.edu/blog/diesel/diesel-particulate-filters (Accessed: 22 July 2021).

Exhaust Gas Recirculation - an overview | ScienceDirect Topics (no date). Available at: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/exhaust-gas-recirculation (Accessed: 19 July 2021).

Eyring, V. *et al.* (2005) 'Emissions from international shipping: 1. The last 50 years', *Journal of Geophysical Research D: Atmospheres*, pp. 171–182. doi: 10.1029/2004JD005619.

Heywood, J. (2002) *Internal combustion engine fundamentals, 1988, Environmental Protection*.

Hildenbrand, W. C. and Lamb, A. J. (2013) 'Occupational Therapy in Prevention and Wellness: Retaining Relevance in a New Health Care World', *American Journal of Occupational Therapy*. American Occupational Therapy Association, 67(3), pp. 266–271. doi: 10.5014/AJOT.2013.673001.

Home - NEOLINE Wind powered transatlantic shipping (no date). Available at: https://www.neoline.eu/en/ (Accessed: 13 July 2021).

Hsieh, C.-W. C. and Felby, C. (2017) 'Biofuels for the marine shipping sector: An overview and analysis of sector infrastructure, fuel technologies and regulations', p. 86.

HYDROVILLE | Hydroville (no date). Available at: http://hydroville.be/hydroville/ (Accessed: 24 July 2021).

International maritime organization (2015) 'Study of Emission Control and Energy Efficiency Measures for Ships in the Port Area', *Climate Change 2013 - The Physical Science Basis*, pp. 1–30. doi: 10.1017/CBO9781107415324.004.

Lonati, G., Cernuschi, S. and Sidi, S. (2010) 'Air quality impact assessment of at-berth ship emissions: Case-study for the project of a new freight port', *Science of the Total Environment*. doi: 10.1016/j.scitotenv.2010.08.029.

Lu, X. *et al.* (2016) 'Source apportionment and health effect of NOx over the Pearl River Delta region in southern China'. Available at: http://www.elsevier.com/open-access/userlicense/1.0/ (Accessed: 26 July 2021).

Major shipping company tests solar for cargo ships - Climate Action (no date). Available at: https://www.climateaction.org/news/major-shipping-company-tests-solar-for-cargo-ships (Accessed: 26 July 2021).

MS, G. *et al.* (2013) 'Associations between ambient air pollution and daily mortality among elderly persons in Montreal, Quebec', *The Science of the total environment*. Sci Total Environ, 463–464, pp. 931–942. doi: 10.1016/J.SCITOTENV.2013.06.095.

‘Nitrogen Oxides (NOx), Why and How They Are Controlled’ (1999). Available at: http://www.epa.gov/ttn/catc (Accessed: 26 July 2021).

‘NO x TECHNICAL CODE (2008) Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines’ (no date).

‘Particle Pollution and Your Health What Is Particle Pollution? Are You at Risk? How Can You Protect Yourself? How can the Air Quality Index help?’ (no date). Available at: http://airnow.govhttp//www.scdhec.gov/baq (Accessed: 27 July 2021).

Rashleigh, R., Smith, S. M. S. and Roberts, N. J. (2014) ‘A review of halotherapy for chronic obstructive pulmonary disease’, *International Journal of COPD*. Dove Medical Press Ltd., 9, pp. 239–246. doi: 10.2147/COPD.S57511.

Riom, E., Larsson, L.-O. and Hagström, U. (2002) ‘Reducing NOx emissions using the humid air motor concept’, *MTZ worldwide 2002 63:5*. Springer, 63(5), pp. 10–13. doi: 10.1007/BF03227539.

Russell, A. and Epling, W. S. (2011) ‘Diesel Oxidation Catalysts’, *http://dx.doi.org/10.1080/01614940.2011.596429*. Taylor & Francis Group , 53(4), pp. 337–423. doi: 10.1080/01614940.2011.596429.

‘Scrubbers-An economic and ecological assessment’ (no date). Available at: www.cedelft.eu (Accessed: 19 July 2021).

Sulfur dioxide | SO2 - PubChem (no date). Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Sulfur-dioxide (Accessed: 24 July 2021).

‘Sulfur Oxides’ (no date).

Toscano, D. and Murena, F. (2019) ‘Atmospheric ship emissions in ports: A review. Correlation with data of ship traffic’, *Atmospheric Environment: X*. Elsevier Ltd, 4(October), p. 100050. doi: 10.1016/j.aeaoa.2019.100050.

Vanos, J. K., Hebbern, C. and Cakmak, S. (2014) ‘Risk assessment for cardiovascular and respiratory mortality due to air pollution and synoptic meteorology in 10 Canadian cities’, *Environmental Pollution*. Elsevier, 185, pp. 322–332. doi: 10.1016/J.ENVPOL.2013.11.007.