ICES VIEWPOINT: Scrubber discharge water from ships – risks to the marine environment and recommendations to reduce impacts

Summary

New global standards on sulphur content in marine fuels have led to an increasing number of ships installing exhaust gas cleaning systems, also known as scrubbers, to reduce air emissions of sulphur oxides. Ships equipped with a scrubber can continue to use heavy fuel oil, resulting in significant discharge of acidified water containing several contaminants, such as heavy metals, persistent organic pollutants (POPs; mainly polycyclic aromatic hydrocarbons), and nitrogen compounds. The simplest and most common type of scrubber system, the open-loop scrubber, directly discharges the contaminated water into the sea.

The use of scrubber systems by ships is an emerging global problem and an additional pressure on the marine environment. The substances found in scrubber discharge water can cause acute effects on marine biota and may have further impacts, through bioaccumulation, acidification, and eutrophication, on the structure and functioning of marine ecosystems.

The number of ships with installed scrubber systems is increasing, but legislation on scrubber discharge is lagging, inconsistent between countries, and often insufficient to protect the environment. ICES recommends the use of cleaner low-sulphur fuels, such as marine gas oil, to eliminate scrubber use and associated impacts on the marine environment. Until this is possible, ICES proposes a set of measures to mitigate scrubber impacts.

Recommendations

1. The ideal course of action would be a rapid and complete transition to the use of cleaner low-sulphur fuels, including distilled fuels (e.g. marine gas oil), liquefied natural gas, and biofuels, which can meet sulphur air emission limits without the use of scrubbers.
   If the above recommendation cannot be achieved, it is recommended to apply other mitigation measures. Until the transition to the use of cleaner low-sulphur fuels is completed, discharge of scrubber water to the marine environment should be avoided. This will require significant investment in technological advances and port reception facilities to enable the use of closed-loop scrubber systems with land-based disposal and treatment.

2. Until scrubber water discharge can be avoided:
   a. discharges in specific areas (e.g. Particularly Sensitive Sea Areas and Special Areas, as defined by the IMO) should be banned;
   b. stringent limits for contaminants in discharge water should be set and enforced, and;
   c. further development of standards and protocols for measuring, monitoring, and reporting on scrubber discharge water for contaminants and other parameters should be ensured.

Introduction to the issue

To reduce air pollution, global regulatory limits on maximum allowable sulphur content in marine fuels were implemented as of 1 January 2020 by the International Maritime Organization (IMO, 2016). To comply with the IMO sulphur regulation, ships must switch to a fuel with lower sulphur content or install an exhaust gas cleaning system, also known as a scrubber. Installation of a scrubber allows for continued use of lower cost residual fuels that have higher sulphur content (e.g. heavy fuel oil). Within the scrubber, the exhaust gas passes through a fine spray of alkaline water, which dissolves sulphur oxides so that sulphur levels are sufficiently reduced in air emissions. As a result, sulphur oxides, nitrogen oxides, and numerous other non-target contaminants are transferred to the scrubber discharge water. As of 2020, more than 4000 ships globally have opted to install scrubbers to meet the IMO sulphur regulation (DNV GL, 2020). Contaminant loads from scrubber discharge water exceed those of all other liquid waste streams from ships.

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Discussions within the IMO regarding the use of scrubbers initially stressed the importance of ensuring that air pollution is not simply transferred to the marine environment. Yet, scrubber discharge water is poorly regulated, and relevant guidelines (IMO, 2015) do not adequately address the potential impacts of scrubber discharge water on the marine environment. Of special concern is discharge of scrubber waters in coastal areas with heavy traffic, especially estuaries and semi-enclosed basins, but also in pristine areas (e.g. the Arctic and the Antarctic).

What are the types of scrubber systems?

Scrubbers are classified as open-loop, closed-loop, or hybrid systems. Open-loop scrubbers dominate the current global market (81%), whereas hybrid systems are present in 17% of ships equipped with scrubbers, while closed-loop systems are relatively rare (2%) (DNV GL, 2020). The type of system and its mode of operation affects scrubber discharge volumes and pollutant concentrations as a result of different water processing approaches and methods.

Open-loop systems, also called seawater systems, require large volumes of seawater, relying on its natural alkalinity for removal of sulphur oxides during the scrubbing process. The used seawater is discharged directly back into the sea, rarely with treatment for removal of solids or dilution to reduce acidity. Closed-loop systems, also called freshwater systems, employ freshwater treated with an alkaline substance to adjust the pH level in order to enable effective removal of sulphur oxides. After the washing process in the scrubbing tower, acidification is counteracted through the addition of a base (sodium hydroxide [NaOH]). The water is processed, recirculated, and a small portion is removed from the system and released to the sea, or stored in a holding tank for later discharge into the sea (where currently allowed) or disposed of ashore in port reception facilities (if available). Closed-loop systems produce smaller amounts of discharge water with higher concentration of contaminants than open-loop systems. Hybrid systems can operate either in an open or a closed loop configuration.

What contaminants are present in scrubber discharge water?

The chemical composition of scrubber discharge water depends on several factors, including scrubber design and contaminant removal efficiency, fuel and lube oil composition, and ship operation conditions (such as engine load, ship age and quality of combustion, water treatment installed, etc.).

The process of scrubbing sulphur oxides results in the formation of sulphuric acid, which reduces the pH of the water. In open-loop systems, large volumes (typically 500 $m^3 \times h^{-1}$ for a medium-sized ship) of seawater are acidified (pH range 2.8–5.8) and the alkalinity (or ability to withstand acidification) is significantly reduced.

In addition to sulphur oxides, eleven metals have been recorded in scrubber discharge water: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), vanadium (V), and zinc (Zn), with vanadium, nickel, copper, and zinc showing the highest reported concentrations. Vanadium and nickel originate from, and strongly correlate to, the sulphur content of the fuel, while content of copper and zinc are not related to fuel composition.

Organic substances contained in scrubber discharge water originate from hydrocarbon oil residues and combustion products, and include persistent organic pollutants, mainly polycyclic aromatic hydrocarbons (PAHs).

Scrubber water may also contain variable levels of nitrogen compounds, primarily nitrate, but also nitrite and ammonium. Nitrate concentration in scrubber discharge water is mainly related to nitrogen oxides removed from the exhaust.

What are the contaminant loads to the environment from scrubbers?

Contaminant loading to the environment from the use of scrubbers is significant. Both locally and regionally, contaminant loading will vary depending on ship traffic intensity and scrubber discharge volumes/flow rates, which are in turn influenced by the type of scrubber used and the physico-chemical properties of seawater (in the case of open-loop scrubbers).

Available estimates of scrubber discharge volumes range from 210 to 4500 million tonnes per year in the Baltic Sea and North Sea combined, and 47 million tonnes for 2020 along Canada's Pacific coastline. Estimates of contaminant loads are available for the Baltic and North seas. The annual emission loads from scrubber discharge in these regions have been estimated at ranges of 3–1407 tonnes for vanadium and 1–331 tonnes for nickel. Total yearly emission loads were in the range of 11–1226 tonnes for oil and 0.3–63 tonnes for specific polycyclic aromatic hydrocarbons (PAH_{EPA16}). Less than 2% of ships in the Baltic Sea were equipped with scrubbers in 2018, yet loads of metals and polycyclic aromatic hydrocarbons in scrubber discharge were much higher (i.e. 10- to 100-fold higher) than those of all other shipping waste discharges combined from the Baltic Sea fleet. Estimates of scrubber discharge volumes and contaminant loads in other regions are scarce at present.

What are the consequences and impacts of scrubber discharge water on the environment?

The impacts of scrubber discharge water on the marine environment vary depending on the level of contamination related to shipping intensity and other factors (such as the number of ships equipped with scrubbers, type of operation, and fuel composition), and environmental factors of the receiving environment (like hydrographic conditions, physical and chemical properties of the water, and sensitivity of biota). The impacts may involve both single-dose and cumulative effects.

Contaminants-related impacts

Scrubbers discharge large amounts of metals and polycyclic aromatic hydrocarbons in dissolved, readily bioavailable form. These contaminants may concentrate at ultra-trace levels in the water column and bioaccumulate in plankton, fish, and marine mammals, to levels that may impair vital functions and population productivity. Concentrations of contaminants may be hundreds to million times higher in plankton than in the surrounding seawater.

Scrubber discharge water is toxic to marine biota and has been shown to have lethal and sub-lethal effects on the marine zooplankton community. Effects on copepods include reduced survival, decreased feeding rates, and delayed development and molting. Mortality occurred within minutes of exposure to treatments having 80–100% strength of the scrubber discharge water, and diverse chronic sub-lethal effects occurred within days or weeks of exposure to treatments having 1% concentration. An increase in mortality of marine zooplankton exposed to scrubber discharge water occurs at much lower concentrations of heavy metals and polycyclic aromatic hydrocarbons than observed in single-compound exposures. This indicates synergistic effects of contaminants in scrubber discharge water, which may be enhanced by the acidity of the discharge water (especially for heavy metals).

No comprehensive studies are currently available on the direct effects of scrubber discharge water on fish or marine mammals; however, a number of relevant contamination studies exists. Detrimental effects of the polycyclic aromatic hydrocarbons present in scrubber discharge water have been observed for adult fish, including narcosis, mortality, decreased growth, lower condition factor, edema, cardiac dysfunction, deformities, lesions and tumors of the skin and liver, cataracts, estrogenic effects, damage to the immune system, and compromized immunity. Chronic exposure of early life stages of fish species sensitive to some polycyclic aromatic hydrocarbons may lead to adverse developmental effects, including cardiac dysfunction. The polycyclic aromatic hydrocarbons and metals present in scrubber discharge have been shown to have negative effects on marine mammals at high concentrations (severe and prolonged toxicity), including renal damage and systemic suppression of immune functions, leading to a higher incidence of disease and/or infectious disease outbreaks.

Acidification-related impacts

Seawater is naturally slightly alkaline (around pH 8.1); hence, it easily absorbs sulphur oxides during the scrubbing process. Similarly, the ocean surface readily absorbs carbon dioxide from the atmosphere. When either sulphur dioxide or carbon dioxide are absorbed by seawater, different reactions occur that result in lowering of pH, making the seawater more acidic. Yet, an intrinsinic relation exists between these two chemical species, and due to differences in their chemical characteristics, acidification by sulphur oxide hampers uptake of carbon dioxide in the ocean. It has been estimated that for each tonne of sulphur dioxide discharged by scrubber water, the ocean uptake of atmospheric carbon dioxide is reduced by half a tonne, thereby reducing the ability of the ocean to contribute to offsetting global climate change.

Ocean acidification is already impacting oceanic species, especially shellfish and corals. In areas of intense maritime traffic where scrubber water discharge is permitted, scrubber-related ocean acidification could be similar to that induced by carbon dioxide over several years to decades. This is particularly relevant in semi-enclosed and enclosed seas.

Eutrophication-related impacts

Shipping-related nutrient input to the marine environment is generally dominated (> 99%) by atmospheric deposition of nitrogen. As nitrogen oxides have poor solubility in seawater, it has been assumed that little nitrogen is removed from air emissions during scrubbing, though amounts of nitrogen compounds can be highly variable in scrubber water. Thus, the role of scrubber discharge related to eutrophication is thought to be low. However, scrubber discharge imparts a more localized transfer of nitrogen from ship exhausts to the marine environment compared to deposition of atmospheric emissions and has been demonstrated to stimulate microbial plankton growth in mesocosm experiments.

What actions can be taken?

Use of cleaner low-sulphur fuels

Impacts from scrubber discharge water can be eliminated with the use of cleaner low-sulphur fuels compliant with sulphur air emission regulations, without increasing impacts on the marine environment. This includes distilled fuels (e.g. marine gas oil), liquefied natural gas, and biofuels. Use of cleaner low-sulphur fuels has the added benefit of eliminating the risk of heavy fuel oil spills known to have serious ecological consequences.

Investments and technological advances

Scrubber discharge to the marine environment can be limited through significant technological advances. Large-scale implementation of zero discharge closed-loop scrubber systems, where all residues are left in port reception facilities, needs at least two major investments: (1) expansion of port reception facilities and additional equipment to remove contaminants at the scale of scrubber discharge water production rates; (2) increased operational expenditures to treat scrubber discharge water on land.

Improved regulations, monitoring, and enforcement

If scrubber discharge to the marine environment continues to be permitted, impacts can be reduced by setting and enforcing stringent limits for contaminants in discharge water, and by prohibiting discharges in pristine and sensitive areas.

Additional considerations

Heavy fuel oil consists mainly of residual hydrocarbon products from the refinery of distilled products like gasoline and diesel fuels. Transition to the use of cleaner low-sulphur fuel requires strategies for increasing the supply of low-sulphur products, while minimizing output of high-sulphur products. It is time to find solutions to successfully manage this transition process across multiple sectors.

Caution and additional research is needed regarding the use of new fuel blends (known as hybrid fuels), which are compliant with the IMO sulphur regulation, but may contain higher concentrations of contaminants compared to distilled fuels, and may not be compatible with existing oil spill clean-up equipment.

Direct evidence of the impacts of scrubber discharge water on the marine environment are emerging. Improved *in situ* evaluation and the entire chemical characterization of contaminants and of eutrophying and acidifying substances discharged by scrubbers, together with their impacts, should be continued. The mass balance approach, with mandatory sampling and reporting of chemical characterization of inlet water, scrubber discharge water, fuel and lubricants, along with data on water flows and engine load should be further developed and applied for better quantification of contaminant discharges (Linders *et al*., 2019).

Close collaboration between science, industry, and decision-makers is necessary to achieve sustainable solutions regarding marine pollution, including the definition of acceptable thresholds/limits for scrubber discharge water for contaminants and other parameters that can be realistically implemented, monitored, and enforced. The developed legal base should be flexible to incorporate more environmentally friendly technological developments.

Sources

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