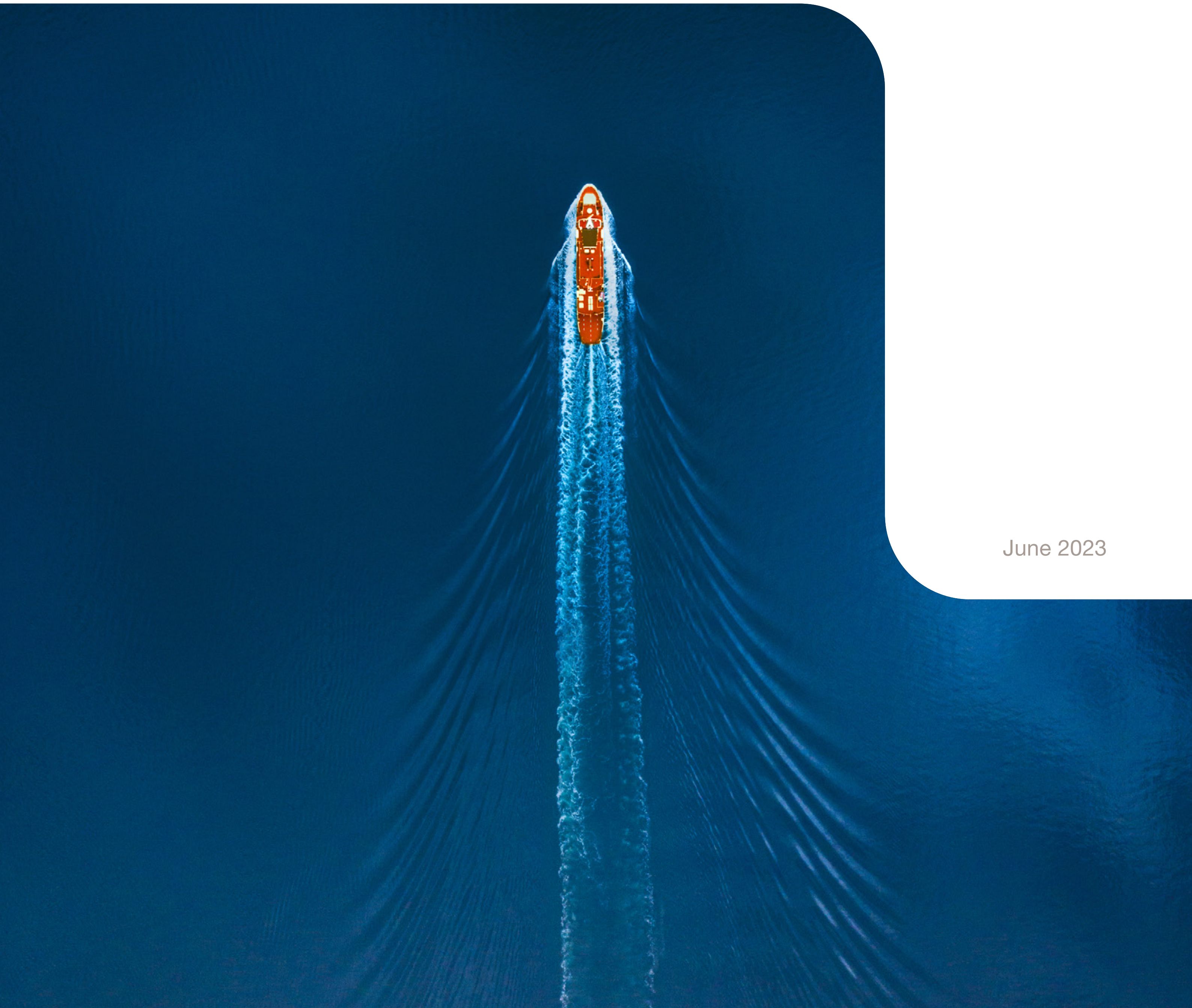
WHITE PAPER

Smart preparation for closed-loop scrubbing

What to consider when choosing a closed-loop or hybrid scrubber system

June 2023



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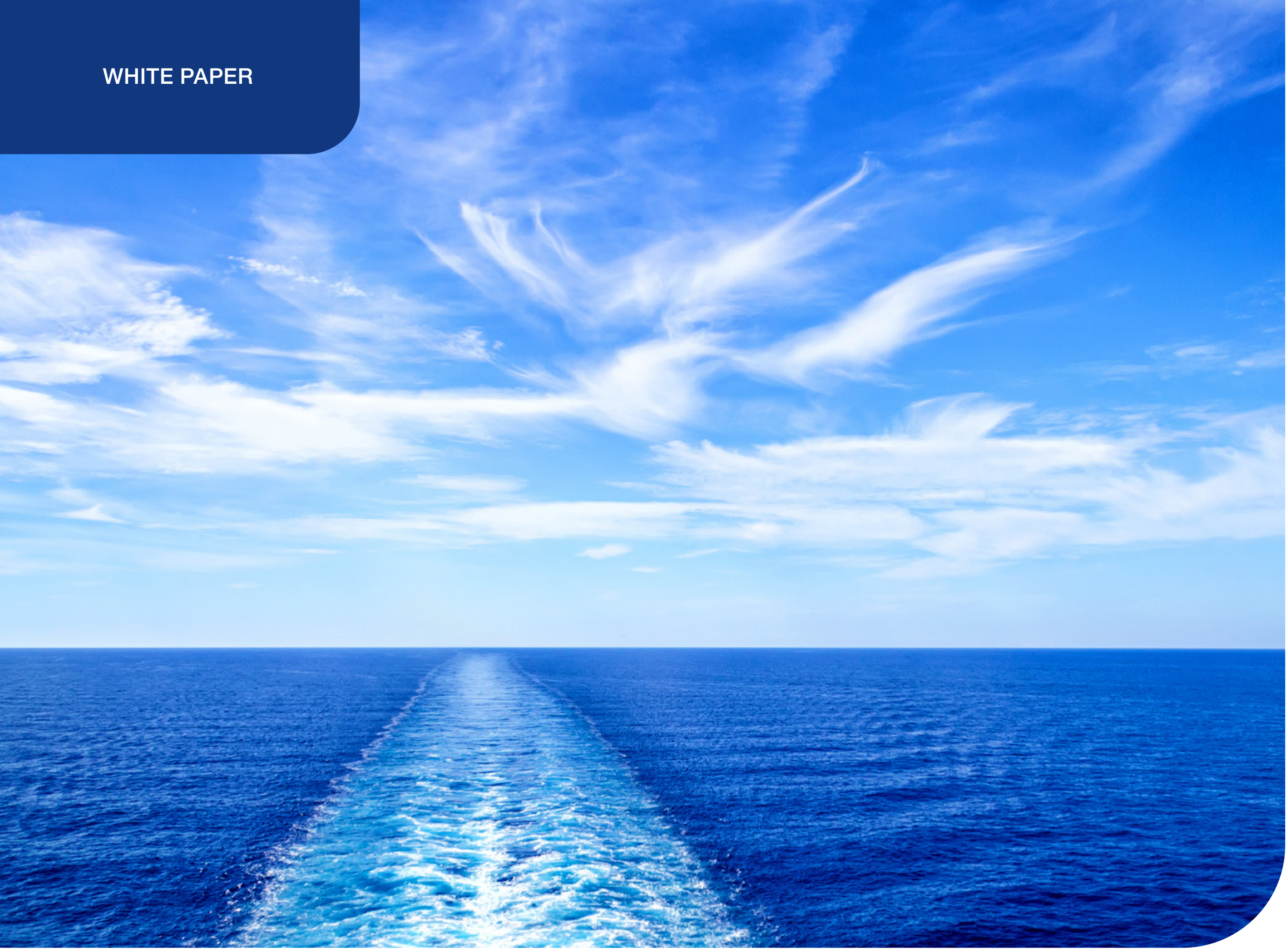

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1. Introduction

Marine SOx scrubbers, formally referred to as exhaust gas cleaning systems (EGCS), have shown their effectiveness in cleaning air emissions. By allowing shipowners to take advantage of the price difference between low-sulphur and high-sulphur fuels, they also continue to provide good return on investment.

Up to now, open-loop scrubbers have been most common – a situation that will likely continue so long as water discharge regulations remain as they are. However, increasing focus on water emissions and the possibility of additional bans on open-loop scrubbing are leading more shipowners to explore the possibility of closed-loop operation.

When considering closed-loop options, it is important to understand the rules that govern water discharge. Likewise, it is necessary to account for a range of factors when designing a closed-loop or hybrid system to match the ship and its sailing profile. This paper explores both aspects.

2. Water discharge regulations

Scrubbers use seawater or fresh water to clean exhaust gas and remove the SOx compounds it contains. In open-loop scrubber systems, the water is discharged directly overboard. In closed-loop scrubber systems, the water is recirculated and only a small amount of bleed-off water is discharged after cleaning. Hybrid scrubber systems are capable of both open-loop and closed-loop operation.

Regardless of the scrubber system type, the water discharged overboard is subject to the same strict MEPC regulation.

2.1 Global discharge water criteria

IMO sets global criteria for scrubber discharge water, three of which (pH, PAH and turbidity) are monitored continuously. The measured values must be recorded and immediately retrievable from the control and monitoring system for a period of 18 months, and Port State authorities may check these records. Breaches of the global criteria can lead to fines from local authorities.

- **pH**
  The reaction of SOx with seawater during scrubbing forms sulphuric acid, which reduces the water's pH. When it comes to pH, the discharge water should meet one of the following requirements:
  - The pH value should be no lower than 6.5 when measured at the ship's overboard discharge point.
  - The pH value should be no lower than 6.5 at a distance of four metres from the ship's discharge point. Since this cannot be measured directly, it needs to be calculated using a computational-based methodology and approved by the administration.
- **Turbidity**
  The turbidity criterion reflects particle/soot content in the discharge water. As with pH in port areas, the measurement is based on the difference in turbidity between inlet and outlet.

  The turbidity limit has both a time-dependent allowance area and a do-not-exceed level. The increase in turbidity between inlet and outlet should be below 25 nephelometric turbidity units (NTU) or formazin attenuation units (FAU) but this may be exceeded by 20% (i.e. up to 30 NTU or FAU) for a combined total of 15 minutes over a rolling period of 12 hours. The turbidity difference must never exceed 30 NTU or FAU.
- **PAH**
  Polycyclic aromatic hydrocarbons (PAH) indicate oily content in the water. Similar to the turbidity criterion, the PAH criterion is based on the increase in PAH over the background level. However, the PAH level measured at the inlet will be zero.

  The PAH limit is variable and dependent upon the scrubber system's water load compared with the load on the engine. As with turbidity, there is a time-dependent allowance area and a do-not-exceed level. For 15 minutes over a rolling period of 12 hours, the PAH limit may be exceeded by up to 50%. However, the PAH level must never go beyond the additional 50%. (Keep in mind that the PAH limit is variable, which means the allowance area and do-not-exceed level also vary.)
- **Nitrates**
  Nitrates arise when NOx formed through fuel combustion reacts with seawater during scrubbing. When measured through discharge water sampling, the captured amount should not exceed 60 mg/l, which corresponds to removal of around 12% of the exhaust gas NOx. Currently, no wet scrubber system captures this amount of NOx.

  Nitrate measurement is required after the installation of the scrubber system and prior to renewal surveys. Alternatively, with the agreement of the administration, compliance can be proven through engineering analysis. In this case, the scrubber's design is compared to similar designs whose compliance has already been demonstrated.

2.2 Local water discharge prohibitions

While IMO sets the global criteria for scrubber discharge water, local authorities can impose additional restrictions that govern its discharge.

- **Zero-discharge areas**
  Local regulations can prohibit the discharge of water from scrubber systems entirely. Areas with such regulations are called zero-discharge areas.

  In closed-loop operation, scrubber systems discharge significantly less water due to the operation of the water cleaning system. The by-products of the water cleaning system are scrubber residue (i.e. sludge) and cleaned bleed-off water that meets MEPC rules. Because the bleed-off water cannot be discharged within a zero-discharge area, it must be stored on board temporarily, which is manageable due to the small volume.

  When the ship exits the zero-discharge area, the cleaned bleed-off water can be discharged from the storage tank so long as it complies with the previously described MEPC criteria for pH, PAH and turbidity.

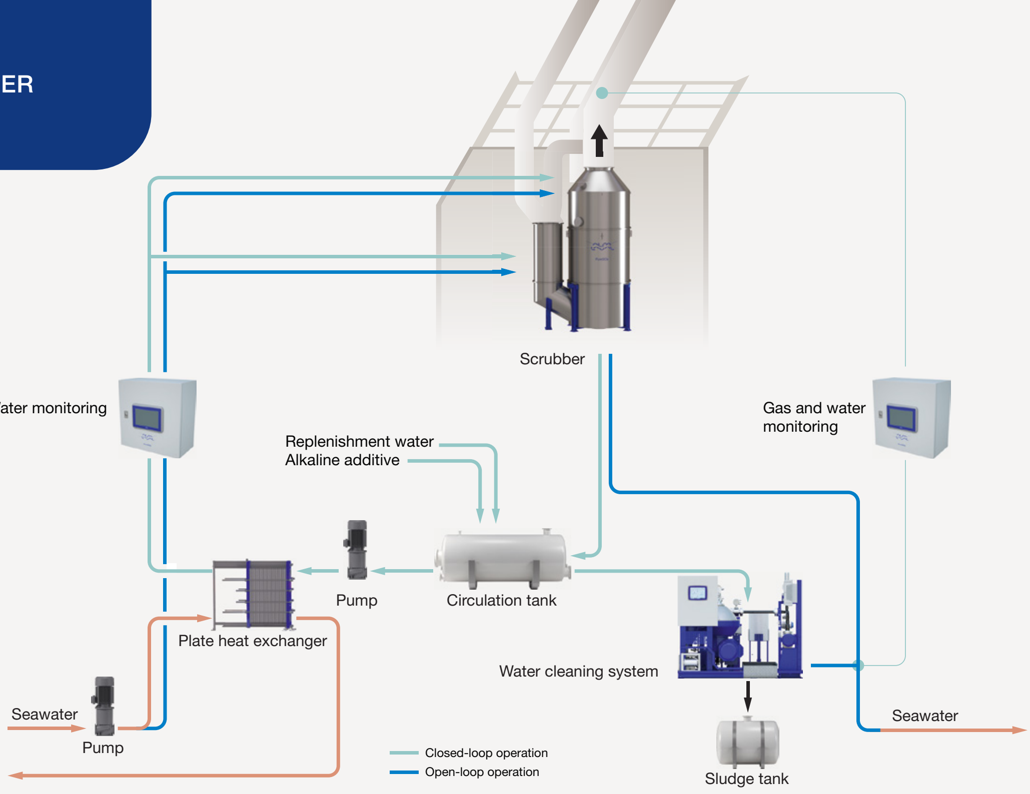
- **Open-loop scrubber bans**
  Some areas have open-loop scrubber bans. In these areas, discharge of bleed-off water from closed-loop operation is allowed, whereas discharge from open-loop operation is prohibited.

  In theory, open-loop scrubbers can work in either a zero-discharge area or an area with an open-loop scrubber ban, so long as all the water is stored on board. In practice, the large quantities of water involved make onboard storage impossible. For a ship with an open-loop scrubber, the only practical solution in these areas is to switch to a sulphur-compliant fuel.

Water cleaning in open loop?

Today there are shipowners who demand any possible form of water cleaning in open-loop operation. Some scrubber manufacturers have responded by saying that they can remove harmful pollutants from open-loop discharge water.

In fact, the treatment of open-loop discharge water would be either insignificantly effective or unreasonably expensive. Because the pollutant concentrations in open-loop discharge water are extremely low, the capacity of an open-loop water cleaning system would need to be around 100 times larger than that of an equivalent closed-loop water cleaning system. Likewise, it would require large volumes of supporting chemicals, which would ultimately increase polluting emissions.



3. Effective design for closed-loop operation

When considering a closed-loop or hybrid scrubber system, effectiveness is not the only concern. Cost efficiency is also in focus, and there are a number of key considerations that can influence both CAPEX and OPEX.

3.1 Equipment placement

Sub-optimal system configuration or placement of the closed-loop components can lead to oversized equipment and excessive energy consumption in closed-loop operation. For this reason, the scrubber supplier should always be consulted to ensure that the system design is optimal.

The pumps are among the key considerations. Hybrid scrubber systems are typically equipped with large seawater pumps installed for open-loop operation, which are then used in closed-loop operation as well. Depending on the ship's layout and the available space on board, the pump setup can be tailored for CAPEX and OPEX savings.

- **Hybrid systems with circulation pumps**
  Most commonly, hybrid systems are equipped with dedicated circulation pumps. In open-loop mode, the feed pumps deliver water to the scrubber sprayers. In closed-loop mode, the circulation pumps deliver water to the scrubber sprayers while the feed pumps deliver cooling water to the plate heat exchanger (PHE). When designed well, this setup provides good flexibility in equipment placement and has lower OPEX.

- **Hybrid systems with cooling water pumps**
  In this configuration, the feed pumps deliver water to the scrubber in both open-loop mode and closed-loop mode. Since the scrubber is typically placed high in the funnel, the feed pumps are installed with high power. Cooling water for the PHE comes from an external source (like the central cooling water pumps) or is delivered by dedicated low-power PHE cooling water pumps for the scrubber system.

  The space demands for this setup are greater, in part because all closed-loop components are placed in the engine room or elsewhere low in the ship. Additionally, careful engineering is required to avoid losing the advantage of the low-power PHE pumps.

3.2 Design load considerations

In the case of a hybrid scrubber installation, the amount of time spent in closed-loop operation will depend on the ship's sailing schedule and route. Depending on its type and service, the ship may run at full or partial engine load during this time. For example, a RoRo ship operating in European ECAs will run at higher engine loads in closed-loop mode than a large container ship assisted by tugs during manoeuvring.

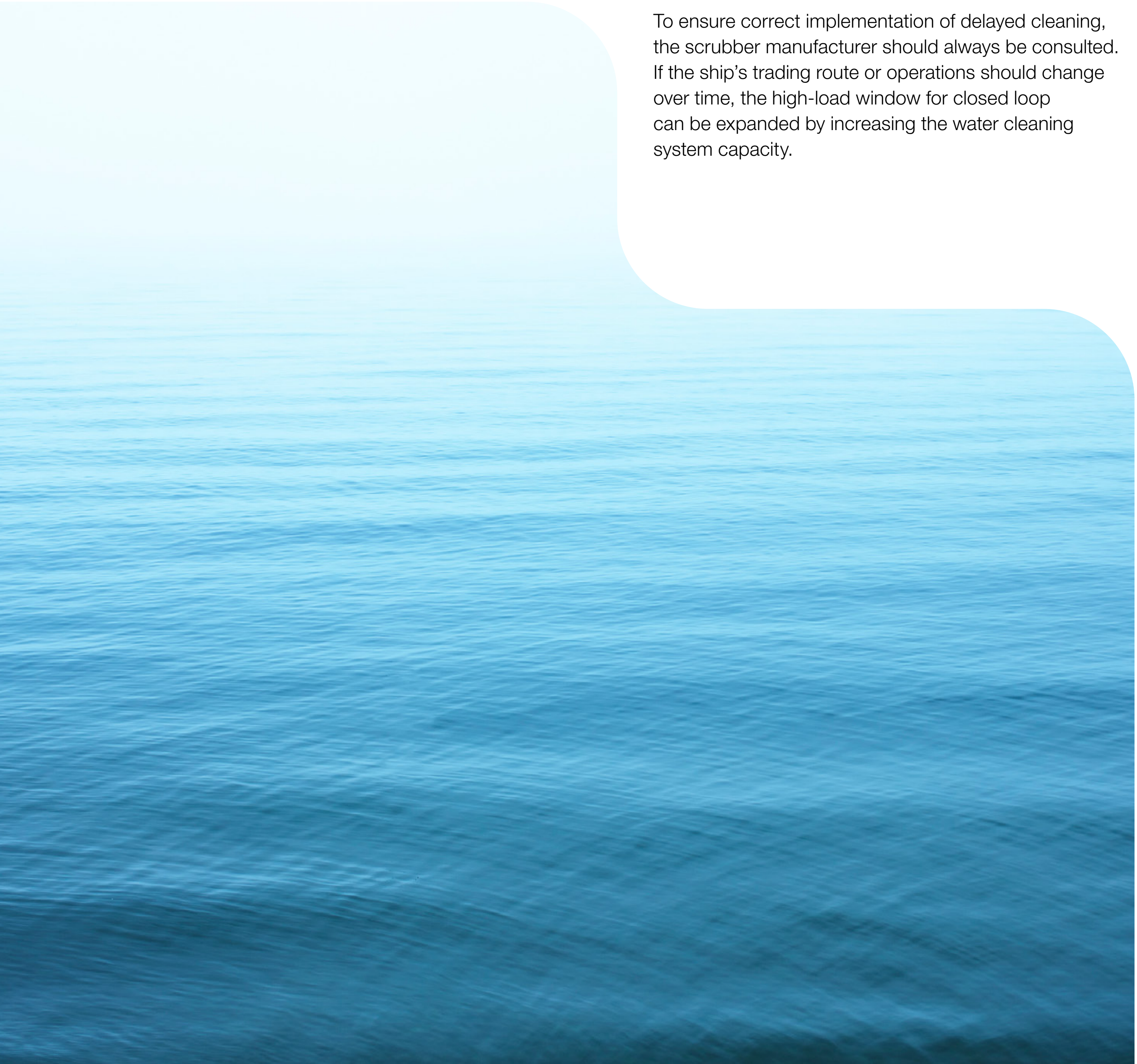
By evaluating the ship's sailing schedule and operating area, an optimal closed-loop system can be determined. Not only will this reduce the initial CAPEX of the system, it will also reduce OPEX over the system's lifetime.

3.3 Delayed cleaning

Delayed cleaning is another opportunity to tailor a closed-loop or hybrid scrubber system to the ship's sailing schedule. When applied, it reduces the initial CAPEX for the water cleaning system. However, it requires good insight into the ship's engine load and its duration throughout the sailing schedule.

Delayed cleaning involves increasing the tank volume available to the scrubber, typically by means of a larger circulation tank. This allows the closed-loop water to be stored on board for longer, so that it can be cleaned when the load is reduced or when the scrubber switches to open-loop operation. This lowers the peak water cleaning demand, which means the size and cost of the water cleaning system can be minimized.

To ensure correct implementation of delayed cleaning, the scrubber manufacturer should always be consulted. If the ship's trading route or operations should change over time, the high-load window for closed loop can be expanded by increasing the water cleaning system capacity.



3.4 Alkali dosing

During closed-loop operation, alkali is dosed to maintain the water's reactivity with SOx and the scrubber's ability to remove it. In addition, the alkali keeps the pH sufficiently high to comply with water discharge limits. Because SOx compounds are absorbed in the water as sulphuric acid, the alkali is needed to keep the pH neutral.

Alkali can be dosed in three forms: liquid, emulsion (a stable blend of unmixable liquids) or powder. NaOH (sodium hydroxide) is used for liquid dosing, whereas the other options are magnesium-based alkalis. Each form has benefits and drawbacks in the following categories:

- **Safety**
  Due to the solution's high pH, NaOH is harmful to humans and corrosive to metals. Precautions and correct equipment are needed when handling it.

  The moderate pH of emulsions and powders makes dosing them safe.

- **Settling**
  When dosing emulsions or premixed powders, there is a risk of particles settling in the dosing tank. Mixing equipment should be applied to the dosing tank to prevent this.

  Settling is not an issue with liquid alkali, as the alkali is fully dissolved.

- **Precipitation**
  NaOH and Na_2SO_4 (sodium sulphate, the resulting processing substance in the scrubber system) will precipitate at low temperatures, which means the dosing tank and lines for liquid dosing should be kept above 15°C. To prevent Na_2SO_4 from precipitating in the process water, the process water temperature should also be kept sufficiently high.

  Since there is no risk of precipitation with the magnesium-based alkalis used in emulsions and powders, $Mg(OH)_2$ (magnesium hydroxide) and MgO (magnesium oxide), these should simply be kept above 0°C.

- **Reaction/dissolving rate**
  Liquid NaOH mixes instantaneously with the process water. As a result, its effect is visible directly.

  Emulsion and powder dosing reaction rates depend on multiple parameters. Inadequate dosing strategies may lead to overdosing, as well as problems with the water treatment.

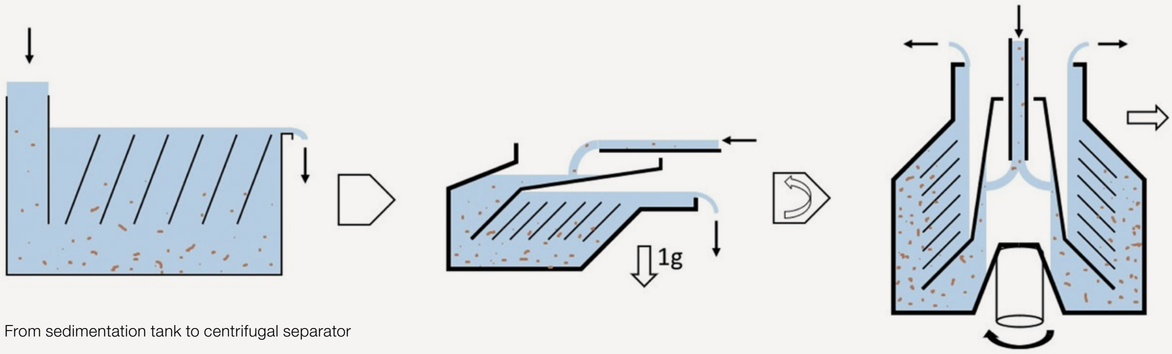
- **Availability**
  In general, NaOH is readily available for liquid dosing. Emulsions and powders are less available in some areas.

  The availability of alkali emulsions is complex, as mixing emulsions from different brands/sources may destabilize the emulsion. Alkali dosing tanks and equipment should always be thoroughly cleaned before filling them with another brand of alkali emulsion. Usually, suppliers recommend staying loyal to one emulsion supplier.

  Some scrubber suppliers offer dual-alkali dosing systems for their scrubbers, which combine the benefits of liquid and emulsion dosing. This provides flexibility in bunkering, since NaOH can be obtained worldwide while the right quality of $Mg(OH)_2$ may be unavailable in some ports.

The following table summarizes the strengths and weaknesses of the different alkali forms.

	Liquid dosing	Emulsion dosing	Powder dosing
Example medium	**50% NaOH**	**$Mg(OH)_2$ emulsion**	**MgO powder**
Safety	-	+	+
Settling	+	-	+/-
Precipitation	-	+	+
Reaction/dissolving rate	+	+/-	-
Availability	+	-	+/-



From sedimentation tank to centrifugal separator

3.5 Water cleaning technologies

Different technologies may be used by the water cleaning system to remove soot and salts during closed-loop scrubber operation.

- **Settling**
  Soot particles tend to settle in water. However, as the density difference is limited and the particle size is in the order of microns, the settling velocity is low. At sea, ship movements may also disturb the settling process, making the separation efficiency unreliable.
- **High-speed separation**
  High-speed separation is based on the same principle as settling. In a high-speed separator, however, gravitational force is replaced by centrifugal force, which is around 10,000 times stronger. Thus, separation efficiency is not affected by ship movements.
- **Membrane filtration**
  Unlike settling and high-speed separation, which utilize the difference between particle and water density, membrane filtration relies on particle size. Fluid and particles smaller than the membrane pore size permeate the membrane, whereas larger particles are filtered out.

  Until recently, membrane filtration was relatively unknown on ships, apart from reverse osmosis plants for producing fresh water. Having gained traction in the scrubber business, two types of membranes are now applied for cleaning scrubber water: cross-flow filtration and dead-end filtration.

3.6 Comparing high-speed separation and membrane separation technologies

High-speed separation and membrane separation can both meet discharge water criteria without issue, even on a moving ship. The choice between them has a number of operational implications:

- **Bleed-off water flow**
  When offering membrane filtration as the water cleaning method, scrubber suppliers often quote a smaller bleed-off water flow compared to high-speed separators. However, a very low flow through a membrane system may lead to high impurity concentrations. This introduces the risk of sulphate salt precipitation when the water is cooled down, for example around the heat exchangers or in a cold zero-discharge tank (when the hull is at seawater temperature).

  In addition, the high particle load could – when the membrane system is operated at high engine loads – lead to increased rates of membrane fouling. Membrane damage is often reported when a combination of emulsion and powder alkali dosing is used.

- **Residue production rate**
  The scrubber residue, or sludge, ejected from high-speed separators consists of 20% dry matter and 80% water. This sludge is pumpable.

  The waste from membrane systems consists of 2% dry matter and 98% water. For this reason, membrane systems often use a water-removing filter to thicken the sludge. This is a matter of preference and requires additional equipment, but it results in a dry sludge (containing around 50% dry matter).

  The composition and handling of sludge is discussed further in section 3.7.

- **Maintenance**
  All water cleaning systems require maintenance. High-speed separators must be serviced regularly, using procedures that crews are familiar with from similar separators on board. Most suppliers offer special separator service kits. Membrane-based systems require maintenance as a result of membrane fouling and wear, and worn out membranes must be replaced.

High-speed separation with a flocculator

For closed-loop and hybrid Alfa Laval PureSOx scrubber systems, Alfa Laval offers the unique combination of high-speed separation with a flocculator module. The flocculator module encourages particles to clump together, making them easier to remove from the discharge water. This patented application of two technologies has little impact on footprint and OPEX, yet it increases separation efficiency significantly.

3.7 Scrubber residue

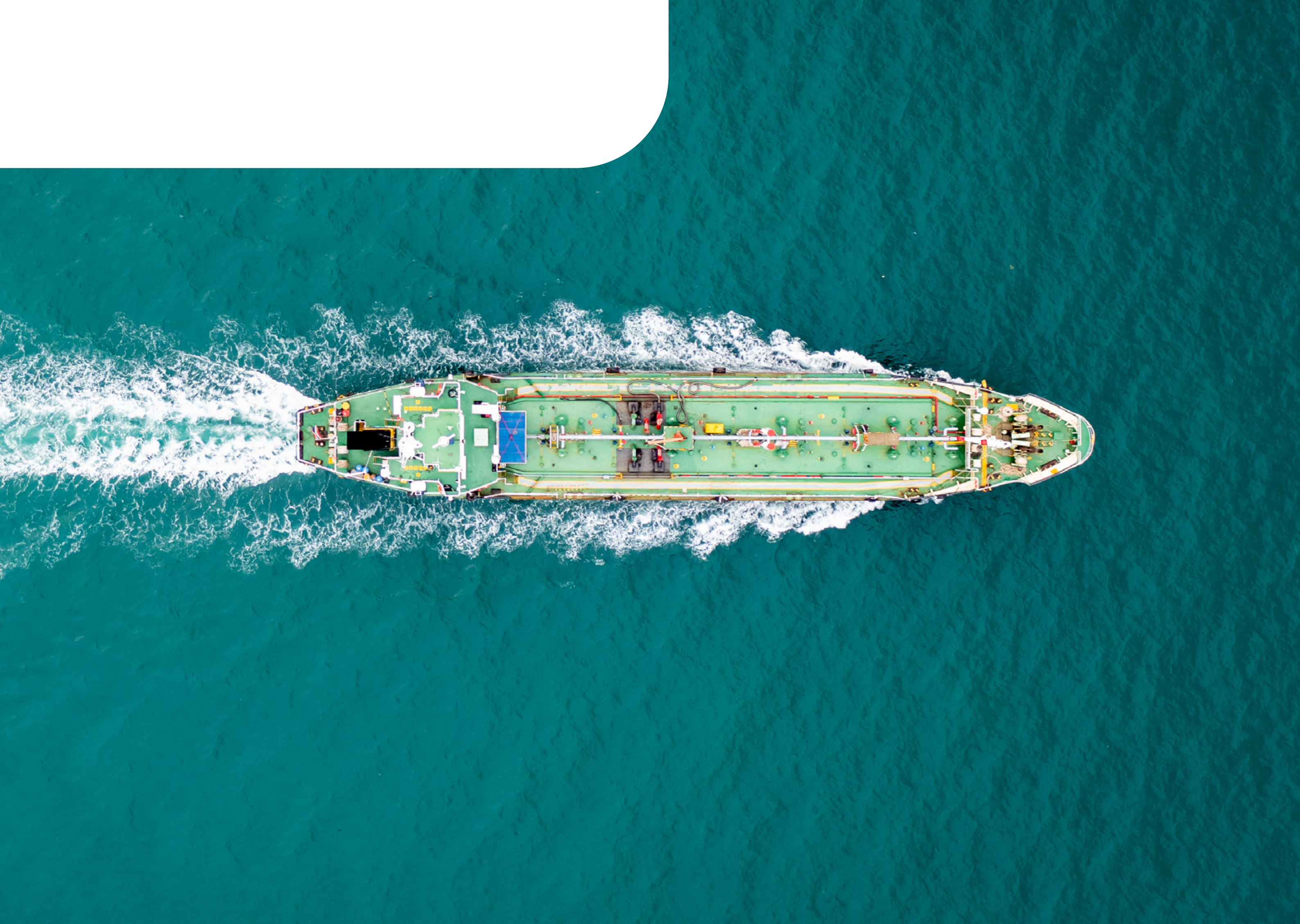
Scrubber residue, also referred to as sludge, is a waste product ejected by the water cleaning system. It consists mainly of soot and salts that the water cleaning system separates from the processing water during closed-loop operation. The extracted sludge must be delivered to an onshore waste reception facility as processing on board is not permitted.

Depending on the type of water cleaning system, the sludge will have higher or lower water content. Sludge with high water content (~80%) has a slurry-like consistency and can be stored in tanks on board. The higher the water content, the more storage volume the sludge will require.

Some water cleaning systems eject large quantities of sludge with a low concentration of soot and salts. To minimize storage needs, a decanter, filter press or belt filter is typically used. Such equipment drastically reduces the water content, resulting in solid or “dry” sludge (typically with a water content around 50%) that can be stored in bags with a limited volume.

The choice of whether to produce liquid or dry sludge is up to the shipowner, but it impacts the scrubber system OPEX. It is important to note that not all ports are able to receive dry waste, as appropriate waste treatment facilities are not always within a reasonable distance.

Ports may rely on third parties to handle the sludge for them, and these actors may perform additional steps such as mixing or dissolving the sludge to make it possible to process. The cost for these efforts is usually passed on to the customer, resulting in a higher cost rate compared to “wet” sludge.



4. Moving forward

When investing in a SOx scrubber system, there is ample reason to consider the possibility of closed-loop operation. Hybrid scrubber systems, especially, can provide an optimal balance between future-proof compliance, economy and operating flexibility.

However, there is more to the decision than choosing a supplier with closed-loop scrubber options. For initial cost efficiency, long-term OPEX savings and reliable compliance, it is important to match the scrubber system's configuration to the ship's onboard conditions and sailing profile. In particular, it is vital to make the right choices with regard to cleaning the discharge water.

As you evaluate closed-loop options, be sure that potential suppliers have a full overview of the complexities and can support you well in the decision process.

Contact us to discuss

Alfa Laval is a leading provider of marine SOx scrubber systems with vast experience configuring them for closed-loop operation – including upgrading from open-loop to hybrid systems. The very first Alfa Laval PureSOx system was a hybrid installation, giving us nearly 15 years of accumulated insight into closed-loop operation and meeting water discharge regulations.

Our SOx scrubber experts can provide more detailed information and are ready assist you in making the right choices for your ship. To open a dialogue, simply get in touch: puresox@alfalaval.com

This is Alfa Laval

Alfa Laval is active in the areas of Energy, Marine, and Food & Water, offering its expertise, products, and service to a wide range of industries in some 100 countries. The company is committed to optimizing processes, creating responsible growth, and driving progress – always going the extra mile to support customers in achieving their business goals and sustainability targets.

Alfa Laval's innovative technologies are dedicated to purifying, refining, and reusing materials, promoting more responsible use of natural resources. They contribute to improved energy efficiency and heat recovery, better water treatment, and reduced emissions. Thereby, Alfa Laval is not only accelerating success for its customers, but also for people and the planet. Making the world better, every day. It's all about *Advancing better*™.

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