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Outline of Scrubber Types & Technology

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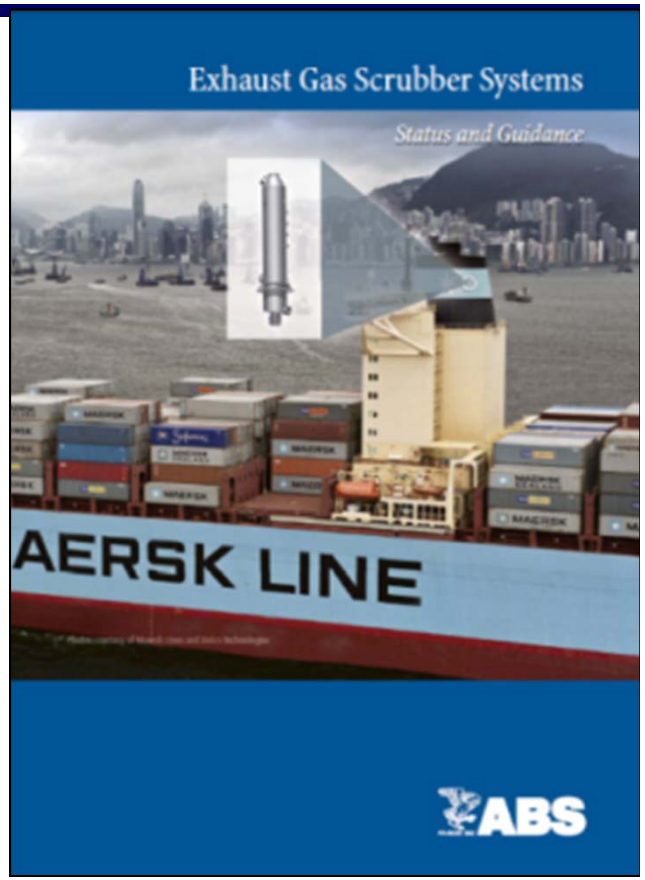
Outline

- General / Introduction
- Scrubber Types
- Considerations for EGC System Selection
- Further Advice & Conclusion

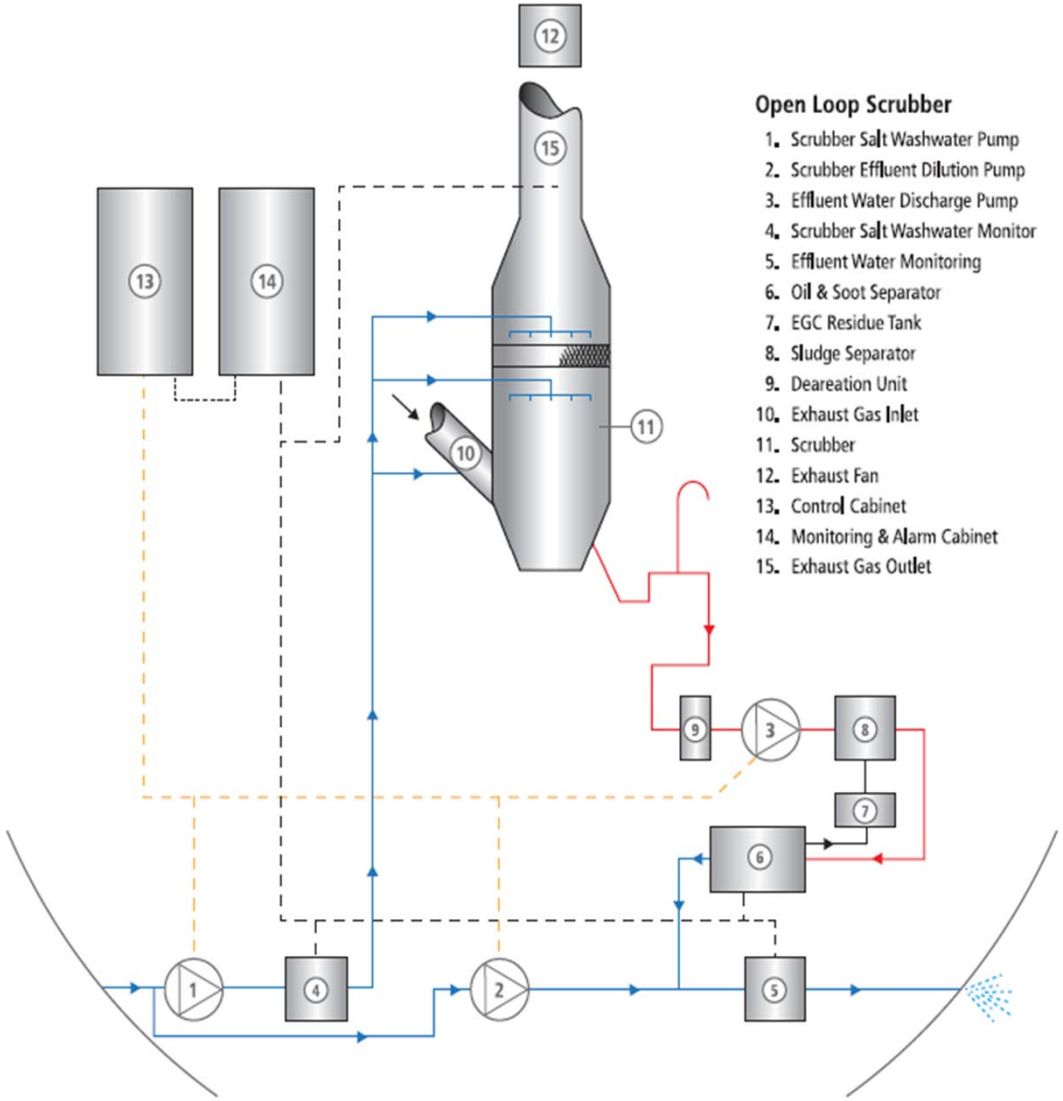


Drivers for SO_x Scrubber

- **Uncertainty in Regulatory Landscape**
  - MARPOL 73/78 Low Sulfur Phase-In Dates with a global sulfur cap expected 1 Jan 2020 subject to review in 2018
  - ECAs and SECAs North America and North-/Baltic Sea
  - EU Sulfur Directive 1999/32/EC, as amended by Directives 2005/33/EC and 2009/30/EC (0.1% sulfur at berth)
  - EU Directive 2012/33/EU (sulfur limit to 0.5 percent for operation in EU waters (i.e. outside SECAs) from 1 January 2020)
  - Potential increase in ECA coverage e.g. China, Mediterranean, Singapore
  - December 2015 COP21 may drive additional emission control initiatives
  - Widespread availability of LNG

EGCS Scrubbers

- Treats the exhaust gas with sea water, chemically treated fresh water or dry substances, to remove most of the SOx and reduce PM
- Effective in complying with for fuel with 1 or 0.5% sulfur content while for 0.1% sulfur fuel is uncertain for some scrubbers
- Typical scrubber provides only negligible reduction in NOx emissions
- Create a waste stream containing the substance used for the cleaning process plus the SOx and PM and forms a strong acid
  (react with the alkalinity of seawater and forming soluble sodium sulfat, a natural salt)



EGCS Guidelines 2015

- EGC system installations meeting **IMO 2015 EGCS Guidelines** will be accepted as **equivalent** by the Administrations. This should be confirmed by the flag Administration of each vessel onto which the equipment is to be installed on a case-by-case basis.
  - Also MEPC.1/Circ.799 from the Administration of Malta has to betaken into account
- "Interim GCARB has permitted the use of ECA compliant non-distillate low sulfur fuel or equivalent alternative emission control technologies under a 'Research Exemption' criteria. (exemption during the "sunset review period"). "Guidance on the Non-Availability of Compliant Fuel Oil for the North American Emission Control Area" dated 26 June 2012 and reference is made CARB Marine Notice 2014-1
- Guidelines are to specify the requirements for the testing, survey, certification, and verification of EGCS in order to ensure that they provide equivalence to the fuel sulfur content requirements of Regulations 14.1 and 14.4 and are applicable to all fuel oil combustion machinery installed on board ships.

EGCS Approval Scheme A & Scheme B

- Two basic Schemes (MEPC.259(68) for compliance to be used for EGCS approval, Scheme A or Scheme B, at the choice of the equipment manufacturer. (typically by a class society as RO on behalf of flag)

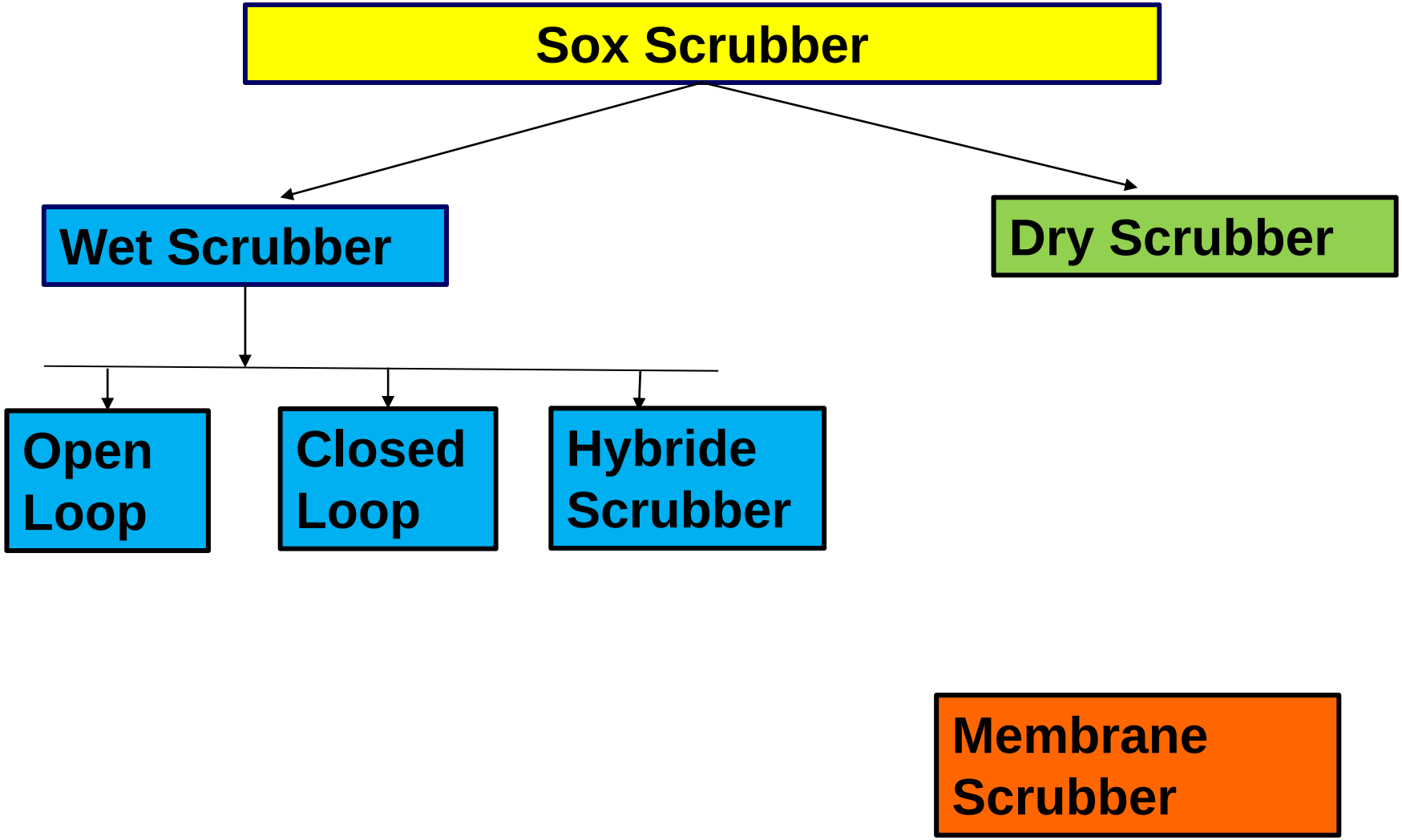
Scheme A	Scheme B
based on initial emission performance unit certification together with a continuous parameter check of operating parameters and daily exhaust emission monitoring.	based on continuous exhaust emission monitoring together with a daily parameter check of operating parameters. EGCS must meet set emission values equivalent to the fuel sulfur content

Required EGC System Documentation

- SOx Emissions Compliance Plan (SECP) must be approved on behalf of the Administration and is required to detail the method of compliance for all fuel oil combustion machinery installed on board.
- Onboard Monitoring Manual (OMM) - approved by flag)
- SOx Emissions Compliance Certificate (SECC)
- EGCEGCS Record Book or Electronic Logging system
- EGCS Technical Manual, Scheme A (ETM-A)
- EGCS Technical Manual, Scheme A (ETM-A)
- EGCS Record Book or Electronic Logging system

Types of EGC Systems

Hierarchy of Sox EGCS

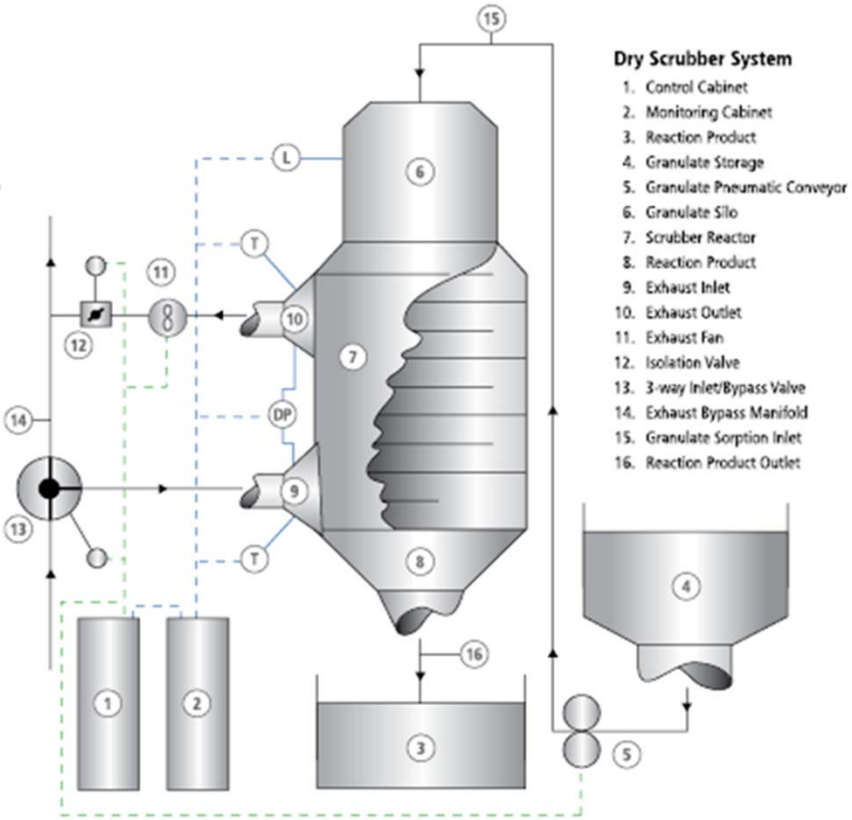


EGC System Concepts

Wet Scrubber	Dry Scrubber
Wet scrubbers are able to capture and neutralize SOx (SO2 plus SO3) gases as these are soluble in water. In addition, the PM in the exhaust will become entrapped in the washwater, adding to the sludge generated by a scrubber. The waste stream and generated sludge has to be processed before discharge overboard, where allowed or stored and discharged to shore as a waste substance.	Dry scrubbers effectively remove SOx from exhaust gases by directing the gas over an alkaline substance, such as calcium hydroxide (Ca (OH)2) (hydrated lime as it is more commonly known). The reaction between SOx produces solid calcium sulfate (CaSO4), or gypsum as it is more commonly known, as the product of the following reaction:

Dry Scrubber

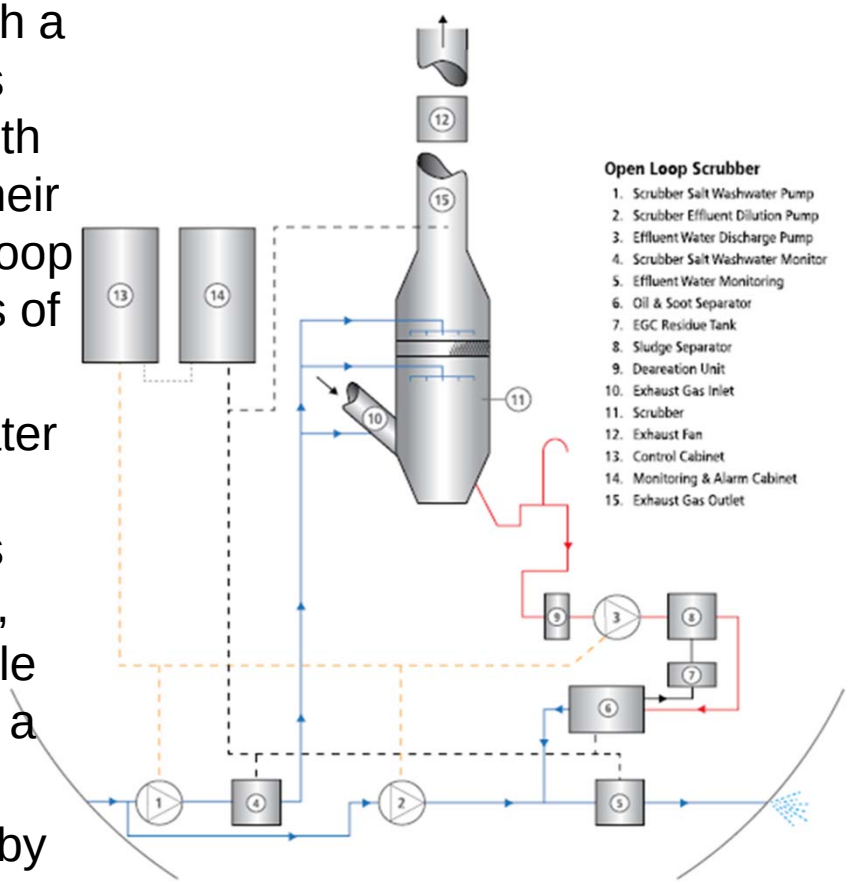
- A dry scrubber exposes hydrated lime-treated granulates to the exhaust gas to create a chemical reaction that removes the SOx emission compounds.
- The exhaust does not pass through water and an exhaust gas economizer (EGE) - 350°C are required - can placed before or SCR units can be connected
- Dry scrubbers use granulates with caustic lime (Ca(OH)2) which reacts with sulfur dioxide (SO2) to form under influence of O2 and H2O **Gypsum** or CaSO4 • 2H2O



- Hence there is no CO2 release.

Wet Scrubber

- Wet scrubbers pass the exhaust gas through a liquid media to remove the SOx compounds from the gas through a chemical reaction with the wash liquid. Systems are identified by their operation as either an open loop or closed loop system. Hybrid systems offer both methods of scrubbing.
- The source water generally must be sea water with a high sodium chloride content. In a closed loop scrubber, the treatment water is generally freshwater provided by the vessel, but a couple of closed loop systems available in the market use sea water. sea water with a high sodium chloride content.
- Due to washwater discharge limitations set by the IMO, regional and U.S. regulations, the pH of the washwater discharge must be measured prior to overboard discharge. Monitoring of turbidity and PAH are also necessary.



Wet Scrubber – Open Loop

- An open loop scrubber uses sea water as the medium for cleaning.
- an open loop scrubber is only effective if the source water is alkaline. (rivers, brackish water, seawater!?)
- It is necessary for a vessel to know the alkalinity of the intended source water to determine effective operation of the EGCS.
- The exhaust pass through a demister or water droplet separator. This process reduces the potential for steam generation, but creates an avoidable steam plume (solution = re-heating after the EGC system unit).
- Removed residuals must be retained onboard and held in a dedicated residue tank; it must be disposed of at suitable reception facilities ashore.
- Residue will contain PM, ash, heavy metals, insoluble calcium sulfate and silt. (can dominant portion of the sludge volume).
- Once the residuals are cleaned from the washwater it can be discharged overboard.
- Washwater pH may be adjusted by washwater pH through the addition of reaction water (e.g. vessel sea water cooling) to more fully neutralize the washwater prior to overboard discharge. (IMO PH= 6,5 / EPA = 6,0 PH value)

Wet Scrubber – Closed Loop

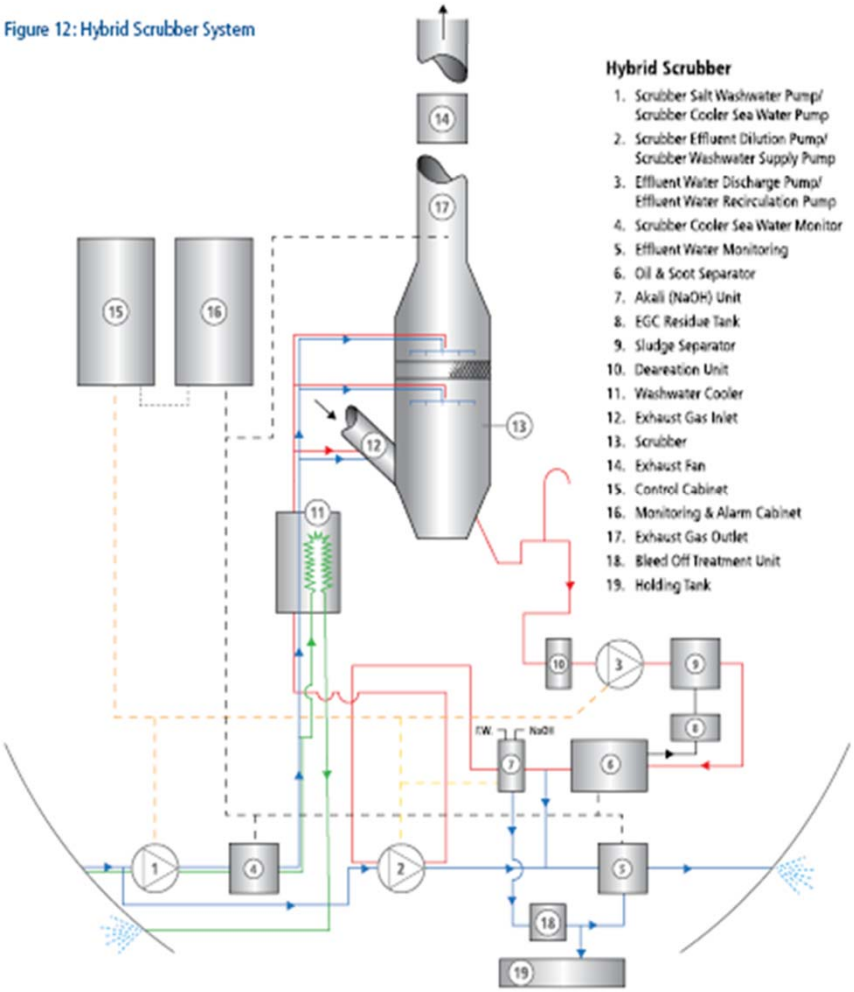
- In a closed loop scrubber, treated water is circulated through the scrubber, (chemistry of the waters the vessel is sailing has no influence) .
- Ensuring vessel compliance with all port restrictions on washwater effluent overboard discharge.
- The chemical additive sodium hydroxide is typically used to control the water alkalinity.
- Closed loop scrubber internals are similar to those of an open loop scrubber,
- The major difference between the two systems is that rather than going overboard, washwater is processed after it leaves the scrubber tower to make it suitable for recirculation as the scrubber washwater medium.
- The washwater (half or less of the washwater flow compared to an open loop scrubber) can be fresh or salt water. In this treatment process, the residues are removed from the washwater, and the water is dosed with caustic soda to restore its alkalinity prior to returning to the scrubber tower.
- Washwater goes a circulating tank, where the residuals will be collected, the make up water is added to the process tank to replace the washwater lost – cooled down and added by caustic soda - in the particulate treatment process.

Hybrid Scrubber

- Able to operate as an open loop system, where permitted, and as a closed loop system when in restricted areas.

- Advantages:
  - Open loop systems permit the avoidance of purchasing caustic soda, and the need to process washwater.
  - Closed loop: the scrubber efficacy is independent from the vessel's operating location and there is little or no water discharge,

Figure 12: Hybrid Scrubber System

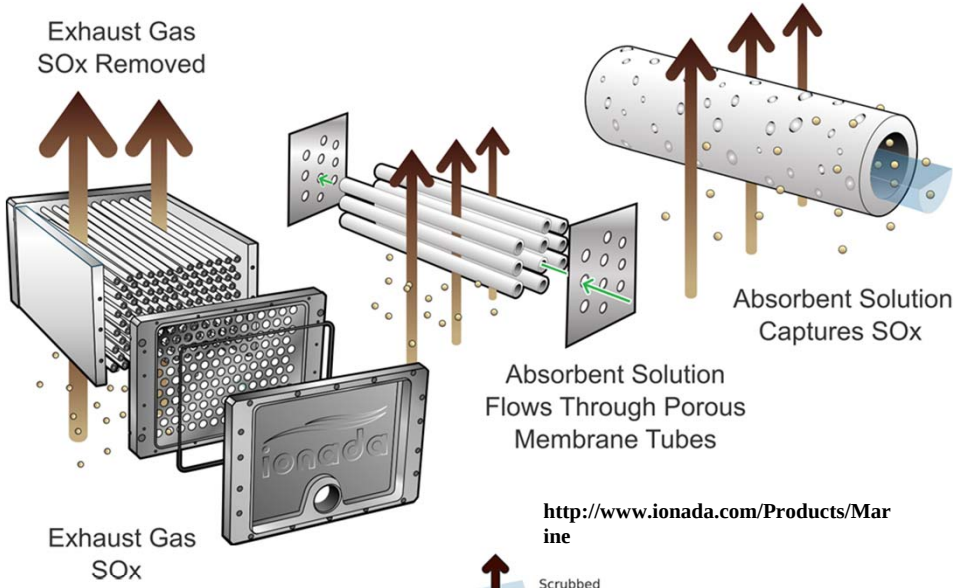


Membrane Scrubber

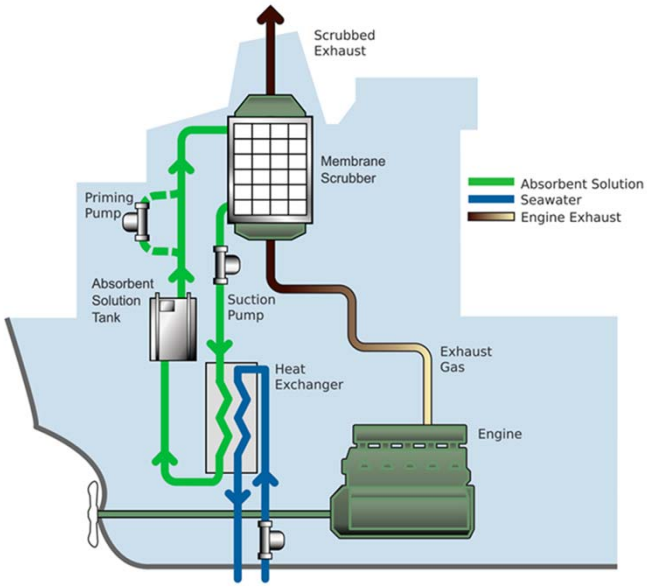
- Ionada SOx Membrane Scrubber System ™ (MSS) is a wet scrubber. http://www.ionada.com/Products/Marine
- instead of mixing the exhaust gas with the scrubbing solution it relies upon a membrane contactor to capture and remove SOx.
- The membrane scrubber consists of an array of ceramic tube membranes, suspended in the exhaust stream. An absorbent caustic solution circulates through the membrane tubes. Exhaust gases pass over the porous membranes, and SOx is captured by the absorbent solution.
- The Membrane scrubber modules can be turned off or on to adjust to engine load and fuel sulfur concentrations
- No water is consumed and no wastewater during the regular operation of the regular operation
- The system requires periodic cleaning to remove soot fouling on the membrane outer surfaces.

Membrane Scrubber

- The key advantage of membrane scrubber advantages over wet scrubbers for shipowners is the elimination of wash water generated by wet scrubbers. Overboard discharge PAH, turbidity, and pH issues that plague wet scrubbers are no longer a concern. Even no steam plume.
- The key disadvantage is the additional operating cost of the caustic soda.
- The membrane scrubber is recommended for ships that operate in sensitive waters



http://www.ionada.com/Products/Marine



Considerations for EGC System Selection

Considerations for EGC System Selection

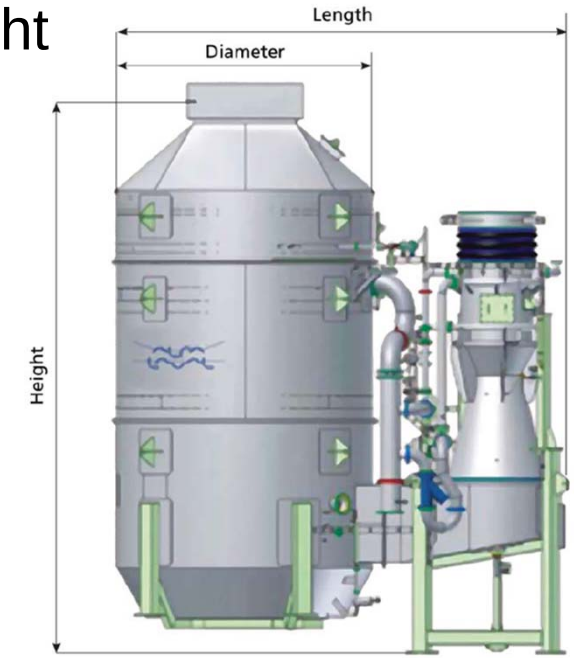
- New building or Retrofit
- Trade pattern(how many days in SECAs, or local effluent regulations)
- Ship Type (Tanker, Container Ship)
- Placing of Scrubber (above of Economizer?)
- EGCS able to operate „dry“ (Bypass required?)
- Sufficient electrical power?
- Washwater discharge prohibition

Considerations for EGC System Selection

- Wet scrubbers and their associated auxiliary **equipment are large units** + the engine exhaust system casing structure will weigh about 50 percent of the scrubber weight

Engine MW	Diameter m	Length m	Height m	Dry Weight tonnes	Operational Weight tonnes
4	1.8	3.5	7.2	5.0	6.0
8	2.5	4.8	8.6	6.0	9.0
12	3.0	5.7	9.5	8.0	12.0
16	3.5	6.7	10.4	12.0	17.0
20	3.9	7.4	11.2	15.0	21.0
24	4.3	8.1	11.9	16.0	24.0
32	5.0	9.4	13.1	23.0	34.0
55	6.5	12.2	15.7	41.0	59.0

Wet Scrubber Principal Dimensions by engine power (courtesy of Alfa Laval Nijmegen)

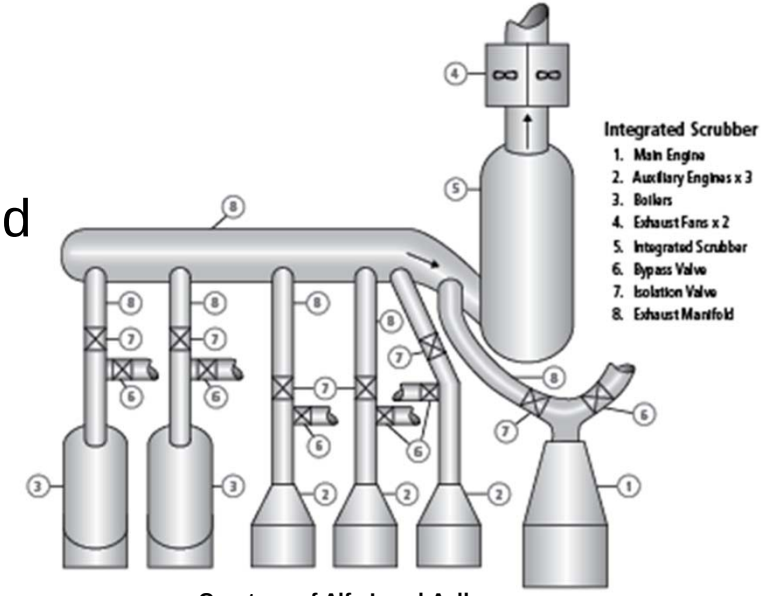


- Scrubber Dimension Layout (Courtesy of Alfa Laval Aalborg)

- **Stability** (>2%lightship displacement) a review of the stability may need to be considered due to the increased wind profile and additional weight of the scrubber

Considerations for EGC System Selection

- **Scrubber Material Selection** due to high concentration of acid and chlorides and in case of “dry” operation resistant against higher operating temperatures
- If an **exhaust bypass** is required by the design, it will have an impact on the dimension of the system (remaining of backpressure limits)
- When using an **integrated scrubber**:
  - bypasses for each exhaust
  - bypass valves are positioned and sealed
  - installation of exhaust fan to lower the
  - pressure in the scrubber



Courtesy of Alfa Laval Aalborg

Considerations for EGC System Selection

Scrubber Piping Systems

- Sea Water Supply
- Fresh/Sea Water Supply for Closed Loop,
- Scrubber Drainage Pipe
  - Erosion from high flow velocities is always a concern for any piping system, particularly for systems using coatings
  - Structural consideration for multi outlets
- Exhaust Pipe
- Sludge Pipe
- Washwater Processing Tanks

Considerations for EGC System Selection

- **Flooding** possible, if washwater drainage stops (causing by pump or gravity drain)
- Scrubber **Electrical Systems** (several hundred kW for open loops)
  - For wet scrubbers, the main electric load is to pump the washwater.
  - For dry scrubbers, the main load is for the pneumatic systems that transport the pellets to and from the scrubber.
  - For retrofit installations, the electrical distribution system needs modification of the main switchboard to provide feeder circuit breakers.
- **Redundancy** is not required and general exceptions and exemptions for the purpose of securing life at sea and any emission resulting from damage are granted. Collision, accidental and heavy weather damage events are exempt, but due diligence in design and operation must be exercised to minimize equipment breakdowns

Considerations for EGC System Selection

- **Space and power** requirements of Auxiliary Equipment (pumps, process tanks, particulate separators, and coolers) are to be considered
- **Water supply** to the scrubber can be varied with engine load and requires multiple water supply or circulating pumps or variable speed pumps

Engine Size	5 MW		20 MW		40 MW	
Equipment	Open loop	Closed loop	Open loop	Closed loop	Open loop	Closed loop
Scrubbing water flow (m^3/hr)	225	120	900	480	1,800	960
Pump electric load (kW)	70	15	280	60	560	120
Process tank (m^3)	N/A	12	N/A	30	N/A	60
Sludge generation (liter/hr)	10	10	40	40	80	80
Caustic soda usage – 50% Solution (kg/hr)	N/A	150	N/A	600	N/A	1,200

Notes:

1. Scrubbing water flow rate and power estimates are based on Wartsila data.
2. N/A indicates not applicable.
3. Open loop-type scrubber has higher water flow because sea water is less effective as a scrubbing medium than treated fresh water.
4. Sludge generation rate can be reduced if effective means are used to remove water, and depends on water overboard discharge quality requirements, which affects how much sludge has to be removed.
5. Caustic soda usage rates and storage requirements can vary significantly depending on the engine load and scrubber operation. Indicated values of the expected requirements.

Considerations for EGC System Selection

- EGCS require **automation and monitoring** in order to be in compliance within required limits for exhaust gas and washwater
- Scrubber Automation and Monitoring should be tamper-proof

Table 10: Scrubber Automation and Monitoring Requirements

Function	Control Mechanism	Remarks
Water flow rate varied by engine load	Number of pumps or pump speeds	Necessary to reduce water flow rate at low engine power
Alkalinity of water	Control of dosing rate	Applies to closed loop scrubber
Washwater temperature	Control of sea water cooler	Applies to closed loop scrubber
Monitor exhaust emissions	Monitor SO_2/CO_2 ratio (ppm/%) with specialized analyzers	For scrubbers certified under Scheme A, exhaust emissions monitoring is to be undertaken on a periodic basis. For scrubbers certified under Scheme B, the SO_2/CO_2 ratio monitoring is to be continuous.
Monitor scrubber operation	Record key scrubber parameters	Records at required frequency (per Schemes A or B) scrubber usage, washwater pressure and temperature, exhaust pressure and temperature, engine load, rate of chemical usage
Monitor washwater discharge	Record key parameters and adjust them by controlling washwater treatment prior to discharge	Record continuously washwater discharge pH, PAH, and turbidity levels. Temperature is also normally recorded. Nitrates levels (from NOx) should be periodically tested and recorded. Levels of any additives to the washwater discharge should be periodically recorded.

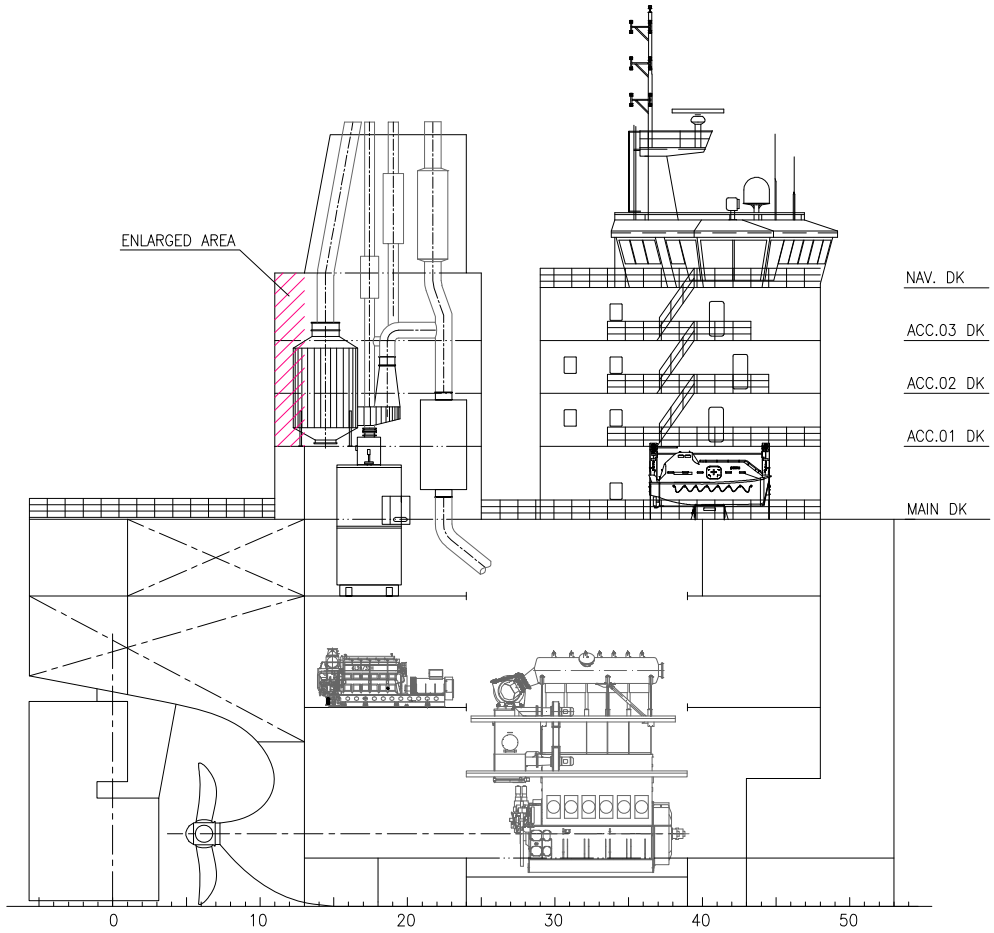
Considerations for EGC System Selection

- **Washwater discharge provision** are to be taken into account, e.g.
  - Germany: inland waters rivers, certain ports, Kiel Canal
  - Belgium: within three nautical miles off its coast.
  - The Baltic Sea area has a limit on the capacity of closed loop systems.
  - Connecticut prohibits the discharge
  - Hawaii requires reporting of specific information regarding the onboard treatment system.
  - In future some other authorities may impose similar restrictions on washwater discharges within their area of jurisdiction.
  - Prohibiton of incineration of Sludge
- ABS strongly recommend to consider a Hybrid scrubber system for a vessel unless the owner/operator can be certain that the intended area of operation will not be prohibited from washwater discharge in the future.

Further Advice & Conclusion

SOx Scrubber Ready: 114,000 Dwt Oil Carrier

Ship Particulars		
Ship Type	Aframax Tanker	
Length overall	249.90	m
Length BP	239.00	m
Breadth	44.00	m
Depth	21.20	m
Draught - scantling	15.00	m
Draught - design	13.60	m
Draught - Ballast	6.40	m
Deadweight	114,000	ton
Speed	15	kts
Main Engine		
Model	Wartsila W6X62	
MCR	11,656	kW
CSR	9,324	kW
Number	1	
Auxiliary Engine		
Model	Wartsila -	
Output	1,000	kW
Number	3	
Oil-fired Boiler		
Model		
Output	30,000	kg/h
Number	2	
Composite Boiler		
Model		
Output		kg/h
Number	0	



SOx Scrubber Ready Cost Break Down

114,000 Dwt Oil Carrier Scrubber Ready Concept Design

1. Initial CAPEX @ New Construction – *US$*

1.1 Hull Structural Arrangement and Reinforcement	14,000
Cost for additional structure readiness	8,000
Cost for equipment foundation readiness	6,000
1.2 Scrubber System Configuration And Vessel Integration	23,000
Control and monitoring system reservation (cable, ECR, switch board reservation)	15,000
Power supply system reservation	8,000
1.3 Exhaust Gas System	-
Exhaust gas piping readiness	
1.4 Washwater System	10,000
Tanks reservation(including air pipe, sounding pipe)	10,000
Sea chest readiness	
1.5 Chemical Treatment System	10,000
Bunker station system reservation	10,000
1.6 Residue System	-
	-
Sub Total	**57,000**

2. CAPEX Items @ Retrofic – *US$*

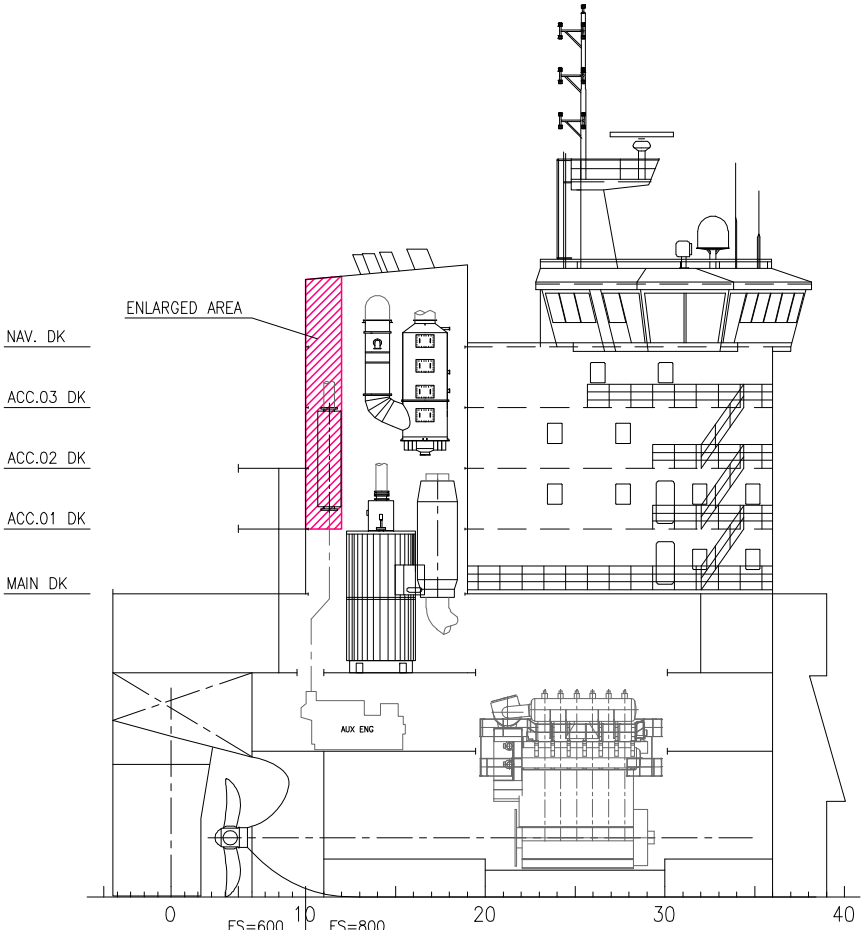
2.1 Hull Structural Arrangement and Reinforcement	40,000
Cost for additional structure construction	40,000
2.2 Scrubber System Configuration And Vessel Integration	3,600,000
Scrubber Unit and associated system	3,600,000
2.3 Exhaust Gas System	130,000
Exhaust gas piping new building	80,000
Existing exhaust gas piping retrofitting	50,000
2.4 Washwater System	15,000
Tanks and associated components (including air pipe, sounding pipe)	10,000
Sea chest retrofitting	5,000
2.5 Chemical Treatment System	20,000
Bunker station system	20,000
2.6 Residue System	-
Sub Total	**3,805,000**

Grand Total 3,862,000

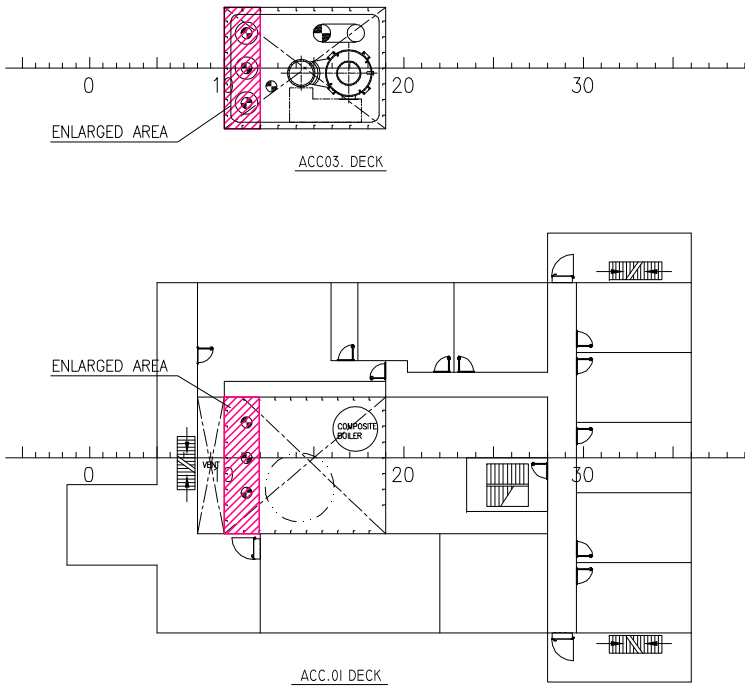
For illustration purposes only

Indicative figures subject to actual scrubber system and arrangement

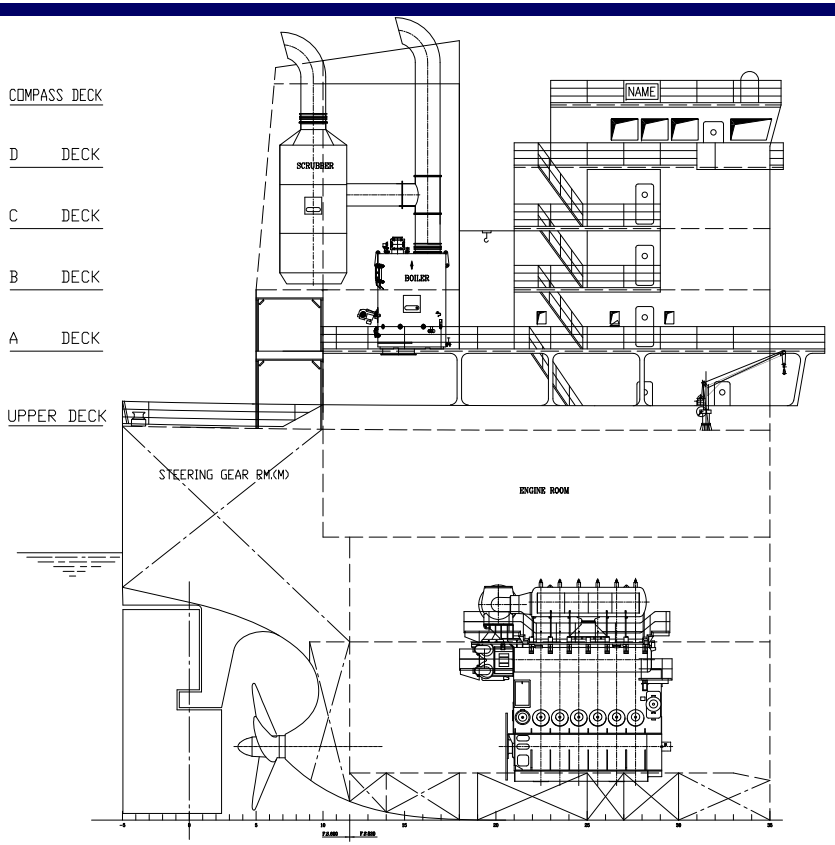
21K Dwt Chemical Carrier

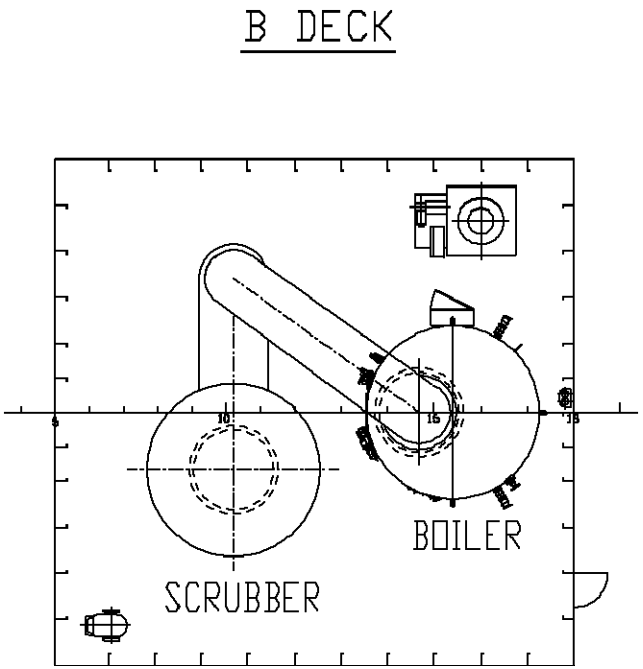


SOx Scrubber Ready Concept Design
--- 21k Dwt Chemical Tanker



57K Dwt Bulk Carrier

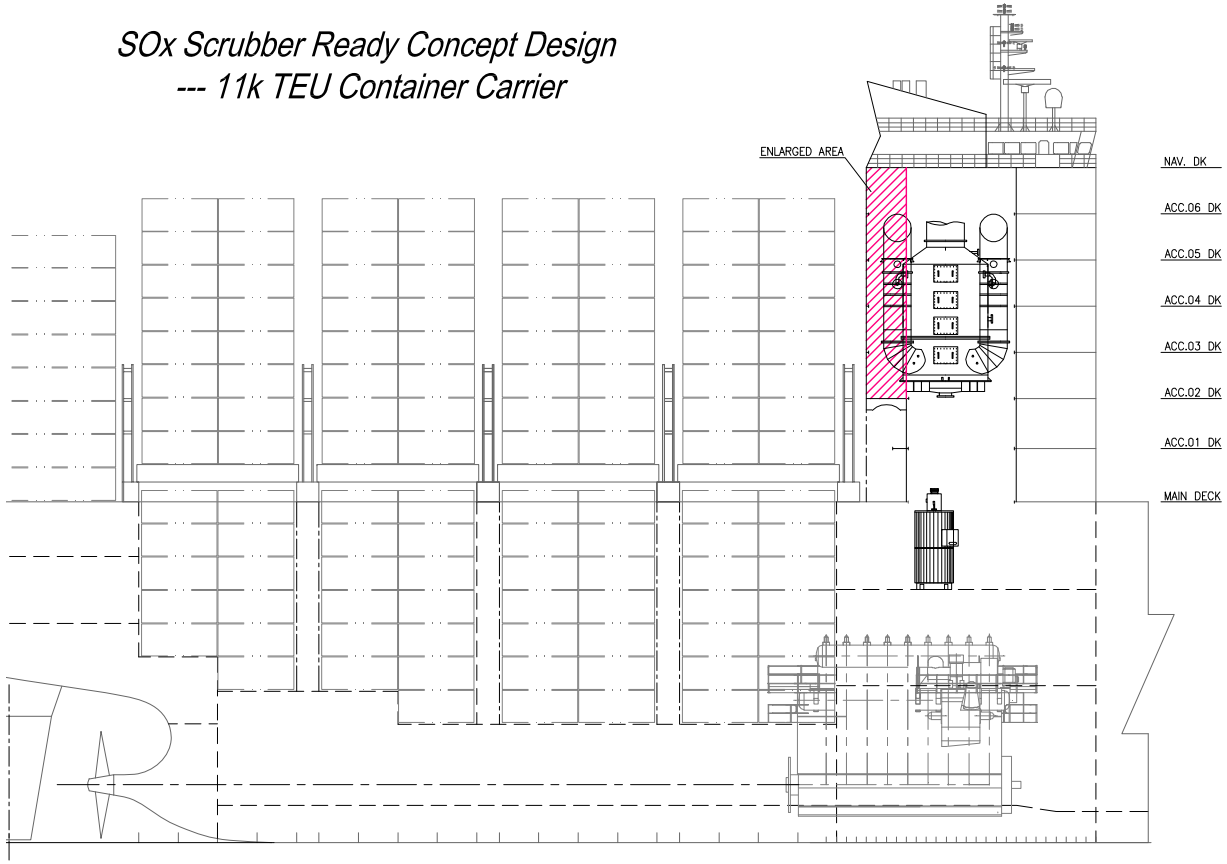


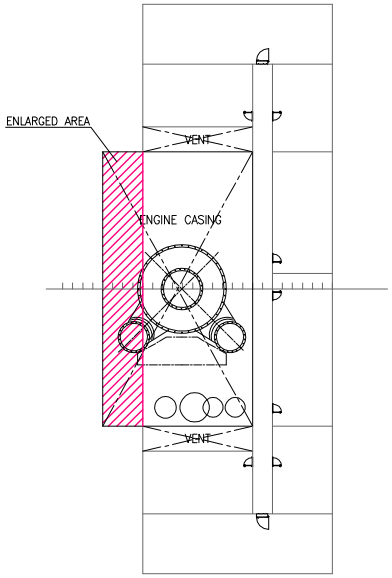


- Extending the funnel backwards (5 frames) facilitates of the Scrubber
- Scrubber supports structure may be included
- Engine casing may be enlarged at new construction (recommended) or retrofitting stage

11K TEU Container Carrier Concept Design

SOx Scrubber Ready Concept Design
--- 11k TEU Container Carrier





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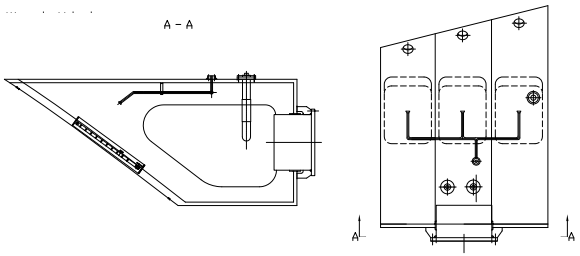


Considerations for EGC System Selection

Decision baseline on the installation of EGCS

1. Does the vessel have a fuel system suitable for switching to low sulfur fuel and, if so, does it have adequate capacity for operation for the full period of time the vessel will be in an ECA? Currently ECA operation requires 0.1 percent sulfur fuel.
2. If the vessel does not currently have an adequate capacity for the accommodation of compliant low sulfur fuel or a proper fuel system for operation on low sulfur fuel, the shipowner/operator should develop a list of required modifications and determine the cost for these. This will be the baseline for comparisons to the costs associated with installing a scrubber.
3. The shipowner/operator should estimate the annual additional operating cost for operation in ECAs using low sulfur fuel compared to using standard, typically HFO, fuel oils. This cost will be the baseline for comparison to the operating costs if a scrubber is installed.

Exhaust Gas Cleaning System Association Members

The EGCSA periodically offers instruction courses and workshops and can be a good source of information on the latest types of scrubbers being marketed and developed, technical details, performance and how EGCS impact the environment.

- AEC Maritime
- Alfa Laval Nijmegen
- Clean Marine
- CR Ocean Engineering
- DuPont BELCO Clean Air Technologies
- Eco Spray Technologies
- Fuji Electric
- Ionada
- Langh Tech
- MAN Diesel (does not offer scrubbers independently. They have developed a scrubber as an integrated part of their Tier III EGR system for NOx control.)
- PureteQ Marine Turbo Scrubber
- Saacke Marine System
- Wartsila Hamworthy
- YARA Marine Technologies

EGCS Scrubbers: Statutory Requirements I

- MARPOL Annex VI Regulation 16, Paragraph 2.6 prohibits incineration of sludge generated from a scrubber; it must be disposed at reception facilities.
- California does not currently accept SOx scrubbers as an alternative means, unless it is being used for the purpose of testing / but ship operators can request an exemption during the “sunset review period”. Reference is made to CARB Marine Notice 2014-1.
- EU Directive 2012/33/EC requires:
  - The emission monitoring system to be of the continuous type
  - Scrubbers operated in closed mode (EU Directive 2012/33/EC, $9 applicable for fuel with sulphur content above 3,5%.

EGCS Scrubbers: Statutory Requirements II

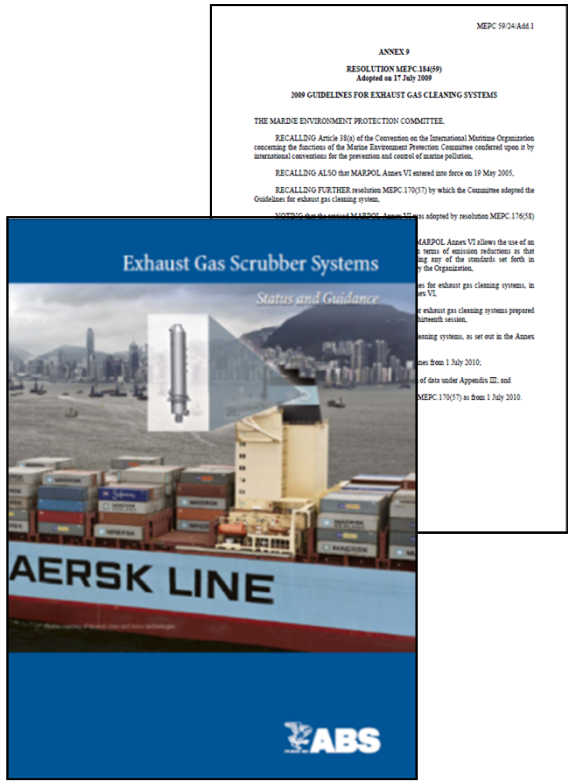
- IMO Resolution MEPC.259(68) defines washwater criteria limits for pH, polycyclic aromatic hydrocarbons (PAH), turbidity/suspended PM and nitrates:
  - The washwater is required to be continuously monitored for pH, PAH and turbidity.
  - At each renewal survey nitrate discharge data is to be available in respect of sample overboard discharge drawn from each EGC system within the previous three months prior to the survey
- 2013 EPA/VGP Generally consistent with IMO except pH limit (6.5). Require:
  - Require continuous monitoring pH, PAH, turbidity and temperature.
  - Sampling twice 1st year and once from the 2nd year:
    - Three samples locations - inlet water, washwater after the scrubber but before treatment, and discharge water
- Connecticut prohibits the discharge of exhaust gas scrubber water

EGCS Scrubbers: ABS Requirements

- ABS Guide for Exhaust Emission Abatement (2013) in conjunction with the appropriate Rules found in the ABS Rules for Building and Classing Steel Vessels (Steel Vessel Rules)
  - **EGC-– SOx Scrubbers**: Where an EGCS primarily designed for the reduction of SOx emissions using exhaust gas scrubbing is designed, constructed, and tested in accordance with Section 2 of the Guide.
  - **EGC – SCR Systems**: Where an EGCS primarily designed for the reduction of NOx emissions by the use of SCR catalysts is designed, constructed, and tested in accordance with Section 3 of the Guide
  - **EGC – EGR Systems**: Where an exhaust gas cleaning system primarily designed for the reduction of NOx emissions by the use of EGR is designed, constructed, and tested in accordance with Section 4 of the Guide.
  - **EEMS**: Where a permanently installed exhaust emission monitoring system is designed, constructed and tested in accordance with Section 5 of the Guide.
- An initial survey of the systems installed (paragraphs 2/17.5, 3/17.5, 4/17.5, 5/13.3) and a shipboard function test (paragraphs 2/17.7, 3/17.7, 4/17.7, 5/13.5) are required for the issuance of notations.
- Surveys after construction are required for retention of the notations (Section 6/3).
- ABS has determined specific redundancy arrangements (e.g. essential supplementary systems, such as pumps, fans, blowers)
- ABS requires appropriate safety measures to verify safe storage, handling and use of toxic or corrosive chemicals (i.e. caustic soda)

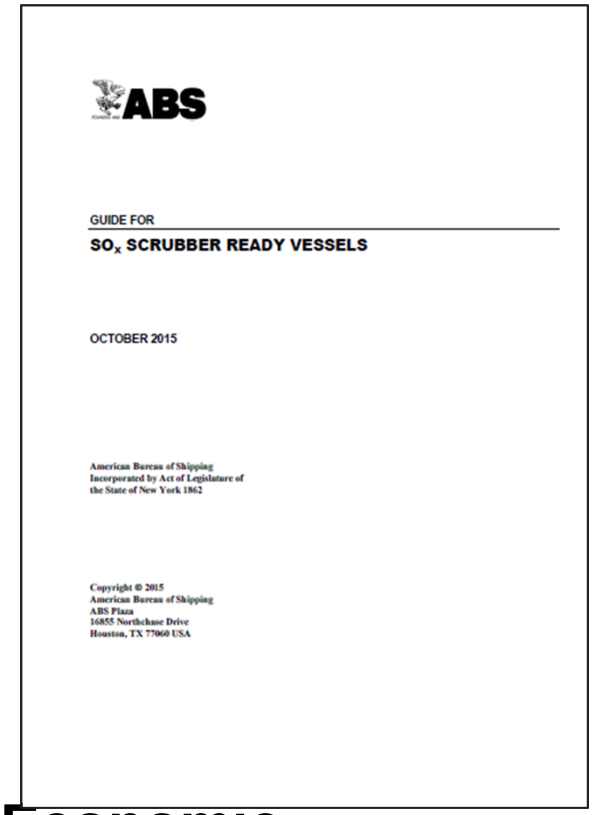
MARPOL Annex VI: After Treatment Guidelines

- MARPOL Annex VI Regulation 4 'Equivalents' allows for alternative solutions including SOx and NOx cleaning devices
- Resolution MEPC.259(68) – scrubbers
- Resolution MEPC.260(68) – SCR
- MEPC.1/Circ.789 – Bahamas 'Emission averaging' – Cruise Liner – USCG/Canada
- MEPC.1/Circ.799 Malta 'Emission averaging'
- MEPC.65: "…The committee agreed that sulphur emission-averaging schemes should not be accepted under Reg. 4 …"
- Scrubbers are an option
- **http://ww2.eagle.org/content/dam/eagle/publications/2013/Scrubber_Advisory.pdf**



ABS Guide for SOx Scrubber Ready Vessels

- **World's First Notation**
  - Demonstrate Environmental focus
  - Manage Future Fuel Oil Price Risk
  - Cost Effective and Time Efficient Retrofit
  - Future proofing Asset
- **ABS Unique Multi Level Approach**
  1. Concept Design
  2. General Approval
  3. Detail Approval & Installation (partial)
- **ABS Ready** to provide Independent **Techno Economic Evaluation** tailored to your operational profile for **Decision Support**


ABS

GUIDE FOR

SO_x SCRUBBER READY VESSELS

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