INTRODUCTION TO SCRUBBER TECHNOLOGIES
Newark, NJ Jan 2015

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Wärtsilä North America
1. Wärtsilä Environmental Solutions
2. Ship air emission legislation
3. SOx scrubbing chemistry
4. Wärtsilä SOx Scrubber portfolio
5. Retrofit aspects
6. Economics of scrubber installation
7. Summary
Environmental Solutions

- Waste Water Treatment
- Oily Water Separation
- Inert Gas Systems
- Ballast Water Management
- Exhaust Gas Cleaning
Wärtsilä SOx Scrubbers Milestones

1993
- M/S Fjordshell equipped with Kværner EGC

2005
- Hamworthy test scrubber on Pride of Kent
- Wärtsilä marine scrubber project started

2010
- Hamworthy contract for 20 scrubbers (Messina)
- Start of Wärtsilä pilot scrubber Suula

2012
- Wärtsilä acquires Hamworthy
- Wärtsilä first commercial scrubber delivery
- Wärtsilä/ Hamworthy scrubbers delivered or on order 65 ships

2005

2009

2011

2014

30/12/2014 Wärtsilä Environmental Solutions 4
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### Air emissions

<table>
<thead>
<tr>
<th>SO$_x$</th>
<th>NO$_x$</th>
<th>PM</th>
<th>GHG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid rains</td>
<td>Acid rains</td>
<td>Impact on air quality</td>
<td>Global warming</td>
</tr>
<tr>
<td>ECA 0,1% (2015)</td>
<td>Tier II (2011)</td>
<td>Along with SO$_x$ reduction</td>
<td>Under evaluation by IMO</td>
</tr>
<tr>
<td>EU 0,5% (2020)</td>
<td>Tier III in ECA (2016)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global 0,5% (2020 or 2025)</td>
<td></td>
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</tr>
</tbody>
</table>
Geographically defined SO$_x$ Emission Control Areas (SECA) where ships must limit their emissions.*

* As of February 2006
For both SO$_x$ and NO$_x$

In force since August 2012

200 miles from coast.

**Fuel Sulphur** Initially 1%, then 0.1 % from 2015, all ships.

**NO$_x$** Tier III (Tier I minus 80 %) 2016, new buildings.
Future ECAs?

Other ECA currently being discussed:
Coasts of Mexico, Coasts of Alaska and Great Lakes, Singapore, Hong Kong, Korea, Australia, Black Sea, Mediterranean Sea (2014), Tokyo Bay (in 2015)
Review of the 0.5% S global limit to be performed in 2018. In case readiness is not deemed to be sufficient by 2020, the introduction of the limit will be postponed to 2025.
The VGP 2013 states on page 21 that dilution is not allowed. However, on page 55 for pH (2.2.26.1.1) restriction of dilution is not specifically mentioned in the same manner as it is e.g. with regards to PAH (2.2.26.1.2).

EPA has admitted the mistake in the rule text. However, they say the text cannot be corrected, so the issue needs to be dealt with in the implementation phase (by the USCG).
Fines could be increased in US waters

The US Environmental Protection Agency (EPA) could be planning a substantial increase in the level of fine ship operators face if they fail to comply with emission control area (ECA) regulations.

The specialist news provider InsideEPA quotes sources as saying the penalties could rise from the current $25,000 per day per infraction to at least $38,000 per day.

The US Coast Guard (USCG) and the EPA said this month they were taking steps to ensure compliance with the 0.10% sulphur cap. It comes into force in January for fuels used inside the North American ECA.

In other comments, InsideEPA quoted what it called an environmental source as saying observers were not "overly concerned" about EPA enforcement.

The sources noted there had been 35,000 fuel checks by the US Coast Guard since the current ECA regulations came into effect in August 20
<table>
<thead>
<tr>
<th><strong>How to minimise $SO_x$ – Alternatives</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUEL SWITCH</strong></td>
</tr>
<tr>
<td>Switch to low sulphur fuel in SECA.</td>
</tr>
<tr>
<td><strong>CHANGE TO MGO</strong></td>
</tr>
<tr>
<td>Run full time on Marine Gas Oil (MGO).</td>
</tr>
<tr>
<td><strong>CONVERT TO LNG</strong></td>
</tr>
<tr>
<td>Convert engines to run on gas (LNG).</td>
</tr>
<tr>
<td><strong>USE SCRUBBERS</strong></td>
</tr>
<tr>
<td>Install an exhaust gas cleaning system (scrubber).</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
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Sulphur Oxides $\text{SO}_x$ ($\text{SO}_2$)

- Formed from the sulphur contained in raw materials such as coal and oil during combustion and refining processes
- Exhaust gas: sulphure and oxygen $\rightarrow$ $\text{SO}_2$ (~95%) + $\text{SO}_3$ (~5%)
- $\text{SO}_2$ dissolves in water vapour in the air to form acids
- Harmful to people and their environment
- Example: burning 1 ton of 2.7% sulphur fuel results in 54 kg of $\text{SO}_2$ emission
Chemistry – Scrubbing process

SULPHUR + ABSORBENT =

ACID  NEUTRAL  ALKALI
Sulphur removal from marine exhaust gas

Typical absorbents for wet sulphur removal process:

- Lime(stone) CaCO₃ (calcium carbonate)
- Caustic soda NaOH (sodium hydroxide)
- Magnesium hydroxide
- Ammonium hydroxide
- Seawater

Feasible choices:
What happens with sulphur in OL scrubber?

SO₂ + Water → Sulphuric acid (H₂SO₄)
H₂SO₄ ← 2H⁺ + SO₄²⁻

Seawater reaction:
Alkalinity (Bicarbonates (HCO₃⁻) / carbonates (CO₃²⁻))
– neutralize the pH rapidly

2CO₃²⁻ + Sulphuric acid → 2HCO₃⁻ + SO₄²⁻ (Sulphate)
2HCO₃⁻ + Sulphuric acid → 2H₂CO₃ + SO₄²⁻ (Sulphate)

Sulphate:
Natural substance in seawater

Approximate amount:
2 700 mg/l
Natural sea water composition

Sea salts

Chloride
55% (19.25 g)

Sulfate
7.7% (2.7 g)

Sodium
30.6% (10.7 g)

Calcium
1.2% (0.42 g)

Potassium
1.1% (0.39 g)

Magnesium
3.7% (1.3 g)

Minor constituents
0.7% (0.25 g)

Sea water

Water
96.5% (965 g)

Salt
3.5% (35 g)

Quantities in relation to 1 kg or 1 litre of sea water.
Sulphates naturally occurring in the seas

- Sulphate is a naturally occurring constituent of seawater. It is soluble and has a long “residence time”, as it is unaffected by the natural pH, temperatures and pressures found in the oceans.
- It is therefore said to be “conservative” in that regardless of the total salinity it occurs mixed throughout the oceans in the same ratio to the other conservative constituents such as sodium.
- The large amount of sulphate in seawater is derived from volcanic activities and degassing at the seafloor. Further, sulphates reach the oceans via river flows, but the concentration in open seawater remains constant at around 2.7 g/l.
- Studies and in-field testing confirm that the sulphate increase from exhaust gas scrubbing will be insignificant when compared with the quantity already in the oceans.
- An analogy that has been used is if all the sulphur in the world’s oceans were to be removed, it would form a layer around the earth about 1.7 m thick. All the sulphur in all the known oil reserves would add only another 10 micron (10^{-6} m) to this layer.
Sulphur in the exhaust gas

**High S fuel oil without a scrubber**

- \( \text{SO}_2 \) is a toxic gas, which is directly harmful to human health
- Formation of sulphates, in the form of aerosols or very fine airborne particles, which can comprise a significant proportion of the particulate matter
- Further away from the emission source the \( \text{SO}_X \) can have been converted to acids by aqueous phase reactions in the atmosphere. These acidic aerosols are eventually precipitated as acid rain, snow, sleet or fog but only when they encounter the right meteorological conditions

**High S fuel oil with a scrubber**

- Scrubber removes \( \text{SO}_2 \) in the excess of 97%
- Scrubber removes majority of these harmful airborne sulphate particles
- Scrubber eliminates majority of these \( \text{SO}_X \) emissions
## Example alkalinity level

<table>
<thead>
<tr>
<th>AREAS</th>
<th>Alkalinity (μmol/l)</th>
<th>PORTS</th>
<th>Alkalinity (μmol/l)</th>
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<tbody>
<tr>
<td></td>
<td>Location</td>
<td>Min</td>
<td>Maks</td>
</tr>
<tr>
<td>Arabian Sea</td>
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<tr>
<td>Baltic Sea</td>
<td>500</td>
<td>2000</td>
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<tr>
<td>Bay of Bengal</td>
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<tr>
<td>Black Sea</td>
<td>2500</td>
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</tr>
<tr>
<td>Caribbean Sea</td>
<td>2250</td>
<td></td>
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<tr>
<td>Coral Sea</td>
<td>2150</td>
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<tr>
<td>Gulf of Alaska</td>
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<tr>
<td>Gulf of California</td>
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<td>Gulf of Mexico</td>
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<td>Gulf of Thailand</td>
<td>2000</td>
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<tr>
<td>Indian Ocean</td>
<td>2200</td>
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</table>
### Example alkalinity level

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<thead>
<tr>
<th>AREAS</th>
<th>Alkalinity (μmol/l)</th>
<th>PORTS</th>
<th>Alkalinity (μmol/l)</th>
<th>Min</th>
<th>Max</th>
<th>Estuary</th>
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<tbody>
<tr>
<td>Location</td>
<td>Min</td>
<td>Maks</td>
<td>Port</td>
<td>Min</td>
<td>Max</td>
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<tr>
<td>Mediterranean Sea</td>
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<td></td>
<td>Krotta</td>
<td>900</td>
<td>1000</td>
<td>Kymijoki</td>
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<tr>
<td>North Atlantic Ocean</td>
<td>2300</td>
<td></td>
<td>Miami</td>
<td>2300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Pacific Ocean</td>
<td>2100</td>
<td></td>
<td>Moss</td>
<td>850</td>
<td>2000</td>
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<td>North Sea</td>
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<td></td>
<td>New Orleans</td>
<td>2400</td>
<td>3000</td>
<td>Mississippi</td>
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<td>Oslo</td>
<td>1350</td>
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<tr>
<td>Panama</td>
<td>1800</td>
<td></td>
<td>Rotterdam</td>
<td>2200</td>
<td>2700</td>
<td>Rhine</td>
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<tr>
<td>Panama Canal</td>
<td>1000</td>
<td></td>
<td>St.Petersburg</td>
<td>490</td>
<td></td>
<td>Neva</td>
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<tr>
<td>Persian Gulf</td>
<td>2500</td>
<td></td>
<td>Travemünd</td>
<td>1800</td>
<td></td>
<td></td>
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<tr>
<td>Philippine Sea</td>
<td>2100</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Red Sea</td>
<td>2400</td>
<td></td>
<td>River St. Lawrence</td>
<td>~ 850-900 umol/l</td>
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<tr>
<td>South Atlantic Ocean</td>
<td>2300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Typical open sea alkalinity outside Baltic Sea is ca. 2200 – 2400 µmol/L
Discharge water quality

- International Maritime Organization (IMO) requires that the following wash water parameters are continuously monitored and the results securely logged against time and ship’s position:
  - pH (with temperature compensation)
  - PAH (polyaromatic hydrocarbons)
  - Turbidity
- Each parameter has a limit that the discharge water must fulfill
- U.S. EPA has the same approach with some small differences in the pH limit measurement
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<th>OPEN LOOP</th>
<th>CLOSED LOOP</th>
<th>HYBRID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependable on seawater alkalinity</td>
<td>Yes</td>
<td>No</td>
<td>Partly</td>
</tr>
<tr>
<td>Alkaline reactant</td>
<td>Seawater</td>
<td>NaOH</td>
<td>NaOH / Seawater</td>
</tr>
<tr>
<td>Zero discharge possible</td>
<td>No</td>
<td>Yes</td>
<td>Yes, in closed loop</td>
</tr>
<tr>
<td>Applications</td>
<td>Ocean-going ships</td>
<td>Low-alkalinity waters and for zero discharge</td>
<td>Ships operating in both types of waters or requiring full flexibility of operations</td>
</tr>
</tbody>
</table>

**Applications**

- **OPEN LOOP**: Ocean-going ships
- **CLOSED LOOP**: Low-alkalinity waters and for zero discharge
- **HYBRID**: Ships operating in both types of waters or requiring full flexibility of operations
How a wet scrubber works?

Exhaust gas in

Water spray

Packed bed*

Water + NaOH
or
Plain sea water

Water + Sulphates

Exhaust gas out

* No packed bed in inline scrubbers
Types of scrubber units

Scrubber with venturi
- SOx reduction from 3.5% to 0.1%
- PM reduction up to 80%
- By-pass needed
- Existing silencer recommended to be kept

Inline scrubber
- Smaller footprint
- No by-pass – can run hot
- Pressure drop at design: 150 mm WG
- SOx reduction from 2.5% to 0.1%
- Can replace silencer
Open Loop Scrubber, Inline

- Scrubbing water
- Reaction water
- Wash water
- Effluent
- Sludge
- *Optional

Exhaust Gas Out

Deplume System*

Inline Scrubber

Scrubbing Water Pump

Reaction Water Pump*

Residence Tank

CEMS

SOx, CO2

Wash Water Pump

Hydrocyclone

Wash water Monitoring Module

pH, PAH, Turb, T

Sludge Tank

Effluent

Open Loop Sea Water Inline Scrubber

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## Exhaust Gas Cleaning reference list

<table>
<thead>
<tr>
<th>Vessel/Owner</th>
<th>Application</th>
<th>Vessel type</th>
<th>Engines</th>
<th>No. Of Vessels</th>
<th>Open loop</th>
<th>Closed loop</th>
<th>Hybrid</th>
<th>Scrubber delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS Pride of Kent / test unit</td>
<td>Retrofit</td>
<td>RoPax</td>
<td>4-str</td>
<td>1</td>
<td></td>
<td></td>
<td>x</td>
<td>2005</td>
</tr>
<tr>
<td>MS Zaandam / test unit</td>
<td>Retrofit</td>
<td>Cruise</td>
<td>4-str</td>
<td>1</td>
<td></td>
<td></td>
<td>x</td>
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</tr>
<tr>
<td>MT Suula/ Neste shipping / test unit</td>
<td>Retrofit</td>
<td>Tanker</td>
<td>4-str</td>
<td>1</td>
<td>x</td>
<td></td>
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<td>Containerships VII / Containerships</td>
<td>Retrofit</td>
<td>Container</td>
<td>4-str</td>
<td>1</td>
<td>x</td>
<td></td>
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<td>Ignazio Messina &amp; C.S.p.A</td>
<td>Newbuilding</td>
<td>Cont/RoRo</td>
<td>4-str</td>
<td>4</td>
<td></td>
<td>x</td>
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<td>2012</td>
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<td>Bulk</td>
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<td>x</td>
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<td>x</td>
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<td>Mein Schiff 4 &amp; 4 / TUI</td>
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<td>Cruise</td>
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<td>x</td>
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<tr>
<td>HHI H2516 and 2517 / Solvang</td>
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<td>RoPax</td>
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<td>MV Robin Hood / TT-Line</td>
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<td>x</td>
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<td>8 vessels / X*</td>
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<td>Cruise</td>
<td>4-str</td>
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<td>x</td>
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</tbody>
</table>

* Undisclosed customer

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65 installations in total

25 x Open loop / 10 x closed loop / 30 x hybrid
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SOx Scrubber Retrofit Design Parameters

Vessel operation and routes:
- Operation profile and fuel oil consumption
- Time spent in ECA areas

Equipment onboard:
- Main and auxiliary engines, boilers
- Exhaust gas flow
- Exhaust gas temperature
- Back pressure

Current configuration:
- Ship design layout
- Available space in stack
- Sea chest capacity
- Tank arrangement
- Noise attenuation

Load profile vs. vessel itinerary:
- At sea: high load / low load
- In manoeuvring
- In port

Water treatment:
- Effluent discharge strategy
- VGP

Ship stability:
- Total weight increase
- Stability check
“Turn – key” contract including:

- 4 x hybrid scrubbers with venturi
- Complete retrofit engineering (basic and detail)
- Plan approval coordination with Class and Flag
- Pre – fabrication
- Installation

Owner: TT Line
Type of vessel: Ro-Ro / Passanger Ship
Scrubber system: Hybrid, Scrubber with Venturi
Delivered: Q3 2014
Retrofit contract – TT-Line Robin Hood
Retrofit contract – TT-Line Robin Hood
Retrofit contract – TT-Line Robin Hood
Equipment and engineering contract including:

- 4 x open loop inline scrubbers
- Complete retrofit design (basic and detail)
- Plan approval coordination with Class and Flag

Owner: Color Line
Type of vessel: Ro-Ro / Passanger Ship
Scrubber system: Open loop, Inline Scrubber
Delivered: Q1 2014
Retrofit contract – Color Line Superspeed II
Retrofit contract – Color Line Superspeed II
Retrofit contract – Color Line Superspeed II
Retrofit contract – Color Line Superspeed II
Retrofit contract – Color Line Superspeed II
Retrofit contract – Color Line Superspeed II
Retrofit contract – Color Line Superspeed II
Retrofit contract – Wilhelmsen Tarago

- 25MW multi inlet scrubber for ME and AEs
- 6MW scrubber for AEs, port mode
- Hybrid system

Wärtsilä Scrubber installation Q1 2013 at Sembawang Singapore
Newbuild contract – Solvang VLGC

- 15MW scrubber for ME
- 4MW multi inlet scrubber for AEs
- Open Loop system
- Wärtsilä Scrubber installation 2013 at HHI Korea
1. Wärtsilä Environmental Solutions
2. Ship air emission legislation
3. SOx scrubbing chemistry
4. Wärtsilä SOx Scrubber portfolio
5. Retrofit aspects
6. Economics of scrubber installation
7. Summary
Pain related to 2015 ECA regulations

- The rising cost of bunker fuel
- The rising cost of transportation
- Fuel availability
- Lubricant: switching plus supply & demand
- Mechanical problems arising from fuel switching
- Loss of vessel power
- Competitive disadvantage
- The practicality of retrofitting vessels

http://gcaptain.com/10-reasons-ship-operators-nervous-2015-eca-regulations/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+Gcaptain+%28gCaptain.com%29
Feasibility of scrubbers

Key Drivers:

- ECA fuel consumption (> 4000 tons/year)
- Cost difference between MGO and HFO

IFO380 $632/MT, MGO$1026/MT, Avg. of 13 ports (19/11/2013 Bunkerworld.com)

\[ 4,000 \text{ MT} \times (1026-632) = \$1.58 \text{ million/year savings} \]

- Fuel cost escalation is CRITICAL

Year 10 at 8% yields $2.86 million/year

- Capital and Operating Expenses are important, but may NOT be primary drivers!

Source: Kevin J. Reynolds, PE, The Glosten Associates
Reasons behind installing scrubbers

Conclusions:
- Primary Drivers: ECA Fuel Consumption, Fuel Cost Differential
- Select Technology for Technical, not Cost, Reasons
- Life Cycle Cost is ONLY Reason for Ship Operator to Install Scrubbers – Evaluate using Net Savings (NS) Metric
- Net Savings Become Positive at ~ 4,000 MT/Year within ECA
- At Higher ECA Fuel Consumption Rates, Scrubbers (or Natural Gas) may become a Competitive Necessity

Source: Kevin J. Reynolds, PE, The Glosten Associates
Fuel prices

Source: bunkerworld.com
Fuel oil prices – The future?

Scrubber economics are likely to become even more attractive!

*Source: Analysis of the Consequences of Low Sulphur Fuel Requirements; Notteboom, Delhaye, Vanherle
** Source: Bunkerworld (Rotterdam prices), updated on April 2nd 2013
Background information:
- Main engine 12 MW, fuel consumption 7000 tons / year
- Aux. Engines: 3 x 900kW, fuel consumption 1500 tons / year
- 50% of time spent in ECA
- HFO price: $600/ton, MGO price: $950/ton
- Fuel sulphur content: 3.5%

Scrubber system:
- Hybrid scrubber
- One main stream scrubber for main engine
- One integrated scrubber for aux. engines
- Equipment price: 2.5 Meur, installation cost: 3 Meur
Example: Merchant vessel 50% in ECA

Annual consumptions of fuel and NaOH

<table>
<thead>
<tr>
<th>Consumption (t/year or m3/year)</th>
<th>Integrated scrubber</th>
<th>Running on MGO in SECA-areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH 50% (m3/year)</td>
<td>77</td>
<td>4,031</td>
</tr>
<tr>
<td>MGO (t/year)</td>
<td>8,612</td>
<td>4,250</td>
</tr>
<tr>
<td>HFO (t/year)</td>
<td></td>
<td>4,250</td>
</tr>
</tbody>
</table>

Wärtsilä Environmental Solutions
Example: Merchant vessel 50% in ECA

<table>
<thead>
<tr>
<th>Annual operating costs (USD)</th>
<th>Integrated scrubber</th>
<th>Running on MGO in SECA-areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental incentives ($/a)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Loss in cargo space ($/a)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Engine maintenance cost ($/a)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Man power cost ($/a)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>EGCS maintenance cost ($/a)</td>
<td>31,378</td>
<td></td>
</tr>
<tr>
<td>Lube oil cost ($/a)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sludge disposal cost ($/a)</td>
<td>5,502</td>
<td></td>
</tr>
<tr>
<td>NaOH cost ($)</td>
<td>47,852</td>
<td></td>
</tr>
<tr>
<td>MGO cost ($)</td>
<td>3,829,479</td>
<td></td>
</tr>
<tr>
<td>HFO cost ($)</td>
<td>5,167,290</td>
<td>2,550,000</td>
</tr>
</tbody>
</table>

Fuel cost savings 1,1 MUSD /year
Example: Merchant vessel 50% in ECA

- Operating cost saving, integrated scrubber [$/year]
- Current MGO-HFO price difference [$/ton]
- Payback time, integrated scrubber [years]
- Discounted payback time, integrated scrubber [years]

- $350 → fuel cost savings 1,1 MUSD → payback time 6,1 / 11,7 years with 12% discount rate
- $450 → fuel cost savings 1,5 MUSD → payback time 4,5 / 6,9 years with 12% discount rate
- $550 → fuel cost savings 1,9 MUSD → payback time 3,6 / 4,9 years with 12% discount rate
Example: Merchant vessel 50% in ECA

- 50% in ECA → fuel cost savings 1,1 MUSD
- 80% in ECA → fuel cost savings 1,8 MUSD
- 100% in ECA → fuel cost savings 2,3 MUSD
Example: Cruise ship

Background information:
- Gen.sets 4 x 11 MW, fuel consumption 17000 tons / year
- 100% of time spent in ECA
- HFO price: $600/ton, MGO price: $950/ton
- Fuel sulphur content: 2,5%

Scrubber system:
- Hybrid inline scrubber for each gen.set
- Equipment price: 3 670 000 eur
- Installation cost estimate: 4 300 000 eur
Example: Cruise ship

Annual consumptions of fuel and NaOH

Consumption (t/year or m³/year)

- NaOH 50% (m³/year)
- MGO (t/year)
- HFO (t/year)

Main stream scrubber
- Running on MGO in SECA-areas

Consumption values:
- NaOH: 17,367 m³/year
- MGO: 16,124 t/year
- HFO: 209 t/year
Example: Cruise ship

Fuel cost savings: 4,4 MUSD / year

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>Environmental incentives ($/a)</th>
<th>Loss in cargo space ($/a)</th>
<th>Engine maintenance cost ($/a)</th>
<th>Man power cost ($/a)</th>
<th>EGCS maintenance cost ($/a)</th>
<th>Lube oil cost ($/a)</th>
<th>Sludge disposal cost ($/a)</th>
<th>NaOH cost ($)</th>
<th>MGO cost ($)</th>
<th>HFO cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main stream scrubber</td>
<td>0</td>
<td>0</td>
<td>223,477</td>
<td>27,250</td>
<td>50,004</td>
<td>41,902</td>
<td>17,242</td>
<td>99,883</td>
<td>0</td>
<td>10,420,320</td>
</tr>
<tr>
<td>Running on MGO in SECA-areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15,317,916</td>
<td>0</td>
</tr>
</tbody>
</table>

Total Annual operating costs (USD): 18,000,000
Example: Cruise ship

- Operating cost saving, main stream scrubber [$/year]
- Current MGO-HFO price difference [$/ton]
- Payback time, main stream scrubber [years]
- Discounted payback time, main stream scrubber [years]

Operating cost saving [$/year] vs. Fuel price difference (MGO-HFO) [USD/t]

Payback time [years]
Example: Cruise ship

Time spent in SECA and payback time

- Main stream scrubber
- SECA % used in the study, main stream scrubber
1. Wärtsilä Environmental Solutions
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Summary

- Global demand for distillates is likely to increase → Price of MGO is expected to increase while price of HFO will stay the same or even decrease
- Scrubbers have been demonstrated to work in marine environment
- Scrubbers allow for same bunkering and same engine operation as before
- European ECA & North American ECA are now ratified – more can be expected in the future
- Wärtsilä has the largest portfolio and reference base of marine scrubber solutions
- Wärtsilä scrubber solutions are fit for new builds and retrofits, for any engine and boiler brand
Scrubber animations

Available in:
- Wärtsilä.com
- YouTube
THANK YOU!