NO_x Reduction - Overview

- Primary measures
  - Retarding fuel injection timing
  - Low NO_x combustion
  - Optimization of the fuel spray pattern on 2-stroke engines
  - Miller timing on 4-stroke engines
  - Late exhaust valve closing on 2-stroke engines
  - Direct Water Injection
- Secondary measures
  - SCR catalyst (Selective Catalytic Reduction)

NO_x Reduction - Secondary Measures

Catalysts for Diesel Engines

- In contrast to spark ignition engines operating stoichiometrically (gasoline car engines) , the diesel engines always operate lean i.e. the air / fuel ratio is about 2.0 resulting in a high oxygen content in the exhaust gas
- Employing three-way catalysts in diesel engines for simultaneous removal of NO_x, HC and CO is not possible due to the high oxygen content in diesel exhaust. Three-way catalysts are used only in gasoline car engines and stoichiometrically operated gas engines
- The only viable after-treatment method for reducing NO_x emissions in diesel engines is the SCR catalyst (Selective Catalytic Reduction)

NO_x Reduction - Secondary Measures

Working Principle of SCR

- Reactions in the exhaust pipe before the catalyst
  - An aqueous solution of urea, typically 40% urea in water, is injected into the exhaust stream before the catalyst. The urea is decomposed to ammonia before entering the catalyst. A certain residence time is needed for this reaction i.e. a few meter distance between the injection point and the catalyst.
  - Reaction: $CO(NH_2)_2 + H_2O \Rightarrow CO_2 + 2NH_3$
  - In principle ammonia can be directly used instead of urea - this alternative, however, is not recommended onboard a ship due to safety reasons

- Reactions in the catalyst
  - The catalyst is lowering the activation energy needed for the NO_x reducing reactions
  - Reactions: $4NO + 4NH_3 + O_2 \Rightarrow 4N_2 + 6H_2O$

    $4NO_2 + 4NH_3 + O_2 \Rightarrow 3N_2 + 6H_2O$

NO_x Reduction - Secondary Measures

SCR working conditions

- The working temperature of the SCR system is 340 to 450°C - in order to achieve good efficiency and durability

- Above 480°C ammonia starts to burn and loses its property as a NO_x reducing agent. Further the catalytic material may be damaged at temperatures above 480 °C

- When operating on heavy fuel oil at a temperature below 340°C, condensation of hydrocarbons and sulphuric acid and the formation of ammonium-bi-sulphates may start, causing potentially severe problems in form of increased pressure drop due to clogging

NO_x Reduction - Secondary Measures

SCR design - important aspects

- Positioning of the urea injectors
  - The injectors should be placed in a straight sector of the piping system in order to guarantee complete decomposition and evaporation of the urea and avoid any contact of urea and the pipe surface
  - To guarantee a good mixing of the injected urea with the exhaust gas as well as good decomposition and evaporation of the urea, the exhaust pipe between injector(s) and the catalyst unit should be long enough - if needed static mixers can be installed
- Purging of the urea injectors:
  - The injectors are recommended to be purged regularly with pressurized air to avoid deposits on the injector surface and the piping system. Additionally, the injectors should be corrosion resistant to avoid cold corrosion effects

NO_x Reduction - Secondary Measures

SCR design - important aspects

- Positioning of the catalyst
  - Before the turbocharger turbine on 2-stroke engines
  - After the turbocharger turbine on 4-stroke engines - always before the exhaust gas boiler
- Deposit cleaning system
  - Deposits like soot, ash, dust and ammonium-sulphates may influence the activity of the catalyst and cause an increased pressure drop over the catalyst. To avoid clogging, a pressurised air system or alternative infra-sonic soot cleaning system for regular cleaning of the catalyst surfaces can be installed. The need for this kind of system depends on the fuel quality (sulphur and ash content) used etc. - the need should always be evaluated on a case by case basis

NO_x Reduction - Secondary Measures

SCR design - important aspects

- Control system
  - The urea solution flow rate is controlled - two different control strategies can be used
  - Feedback control: Urea dosage as a function of an on-line measurement of the NO_x concentration after the SCR catalyst
  - Feed-forward control: Urea dosage as a function of some engine parameter(s) e.g. speed and load
  - The urea injection should be stopped when/if the temperature in the catalyst drops below 340°C (HFO operation) - this temperature limit can be slightly lower when operating on light fuel oil. In order to maintain sufficient high exhaust gas temperatures for the catalyst a by-pass can be installed on the turbine side of the turbocharger on 4-stroke engines
  - On low speed engines with pre-turbo SCR arrangement a waste gate has to be installed for stable running behaviour of the engine

NO_x Reduction - Secondary measures

4-stroke engines - SCR State-of-the-Art

- NO_X reduction: 85-95%
- Combined silencer and catalyst; Noise reduction: 25 to 30 dB(A)
- Space requirement: 2 to 5 m^3 / MW
- Location: after the turbine of the turbocharger
- Pressure drop: 10 - 20 mbar
- Temperature increase over the catalyst: ≈ 0-10 °C
- Operating temperature range:

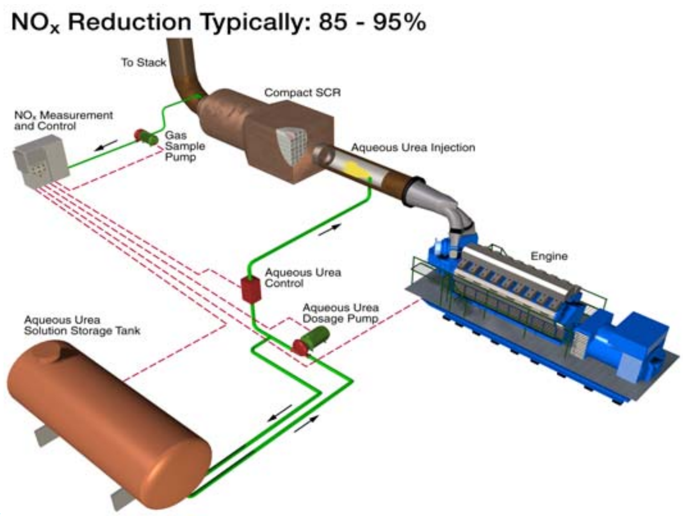
  340 - 480 °C

- Typical SCR system costs:
  - Investment costs (including installation and commissioning): ≈ 35-65 k€EUR / MW
  - Running costs: ≈ 3.0 EUR €/ MWh

    (urea cons. ≈15-20 liter / MWh)
  - Maintenance costs: ≈ 1.0 EUR €/ MWh
  - Catalyst replacement costs (after ~20000h): ≈ 1.7 EUR €/ MWh

NO_x Reduction - Secondary measures

After-turbo charger SCR arrangement - 4-stroke engine



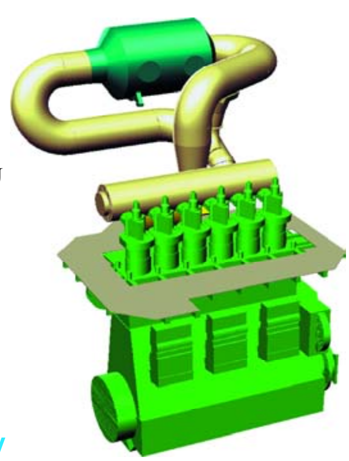
Technology

H:\GHn\Env_booklet\section_7\s_7B_9.PPT

Technology Development for Future Requirements

SCR: selective catalytic reduction, integrated with the turbocharging system:

Sulzer 6RTA52U with SCR system



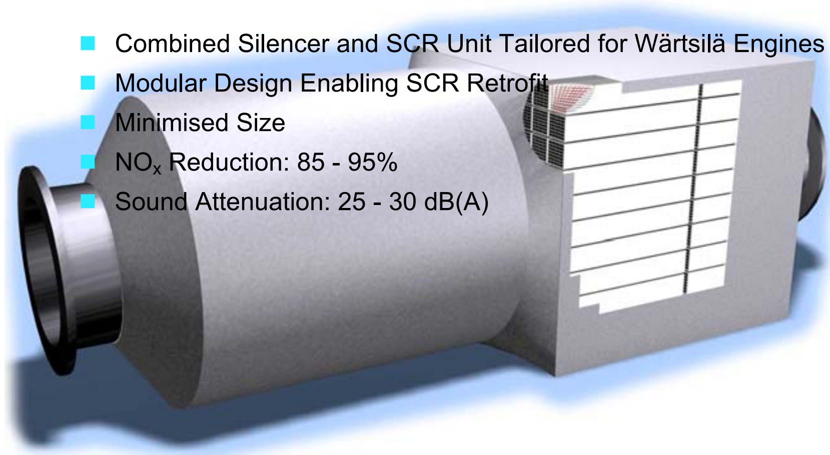
- Exhaust gas temperature
  ≈ 350°C ⇨ before T/C
- Urea consumption
  ≈ 25 l / MWh
- NOx reduction
  ≥ 90% ⇨ ≤ 2 g/kWh
- Investment costs
  40'000-60'000 US$ / MW
- Running costs (urea)
  ≈ 3.75 US$ / MWh
- Maintenance costs
  ≈ 0.9 US$ / MWh

Technology

H:\GHn\Env_booklet\section_7\s_7B_10.PPT

NO_x Reduction - Secondary measures

Compact SCR arrangement - 4-stroke emgines



- Combined Silencer and SCR Unit Tailored for Wärtsilä Engines
- Modular Design Enabling SCR Retrofit
- Minimised Size
- NO_x Reduction: 85 - 95%
- Sound Attenuation: 25 - 30 dB(A)

Marine SCR reference list 2004
Totally 64 engines with SCR installed/on order

Vessel	Engines	Delivery	Fuel	Reduction agent	Notes
Aurora af Helsingborg	1 x WV6R32	1992	MDO	40% urea water	
Silja Serenade	1 x WV8R32	1995	HFO 0.5% S	40% urea water	
Silja Symphony	1 x WV8R32	1995	HFO 0.5% S	40% urea water	
Gabriella	1 x WV6R32	1997	HFO 0.5% S	40% urea water	Retrofit
Thjelvar	2 x WV4R32 + 4 x WV12V32	1997	HFO 0.5% S	40% urea water	Compact SCR
Birka Princess	4 x WV12V32 + 2 x WV6R32 + 1 x WV4R32	1999 1999	HFO 0.5%S HFO 0.5%S	40% urea water 40% urea water	Compact SCR, retrofit Compact SCR, retrofit
M/V Spaarneborg	1 x 7RTA52U + 2 x W6L20	1999	HFO + MDO	40% urea water	
M/V Schieborg	1 x 7RTA52U + 2 x W6L20	1999	HFO + MDO	40% urea water	
M/V Slingeborg	1 x 7RTA52U + 2 x W6L20	2000	HFO + MDO	40% urea water	
Visby	4 x 12V46 + 3 x 9L20	2000	HFO	40% urea water	Compact SCR
Gotland	4 x 12V46 + 3 x 9L20	2000	HFO	40% urea water	Compact SCR
Birka Exporter	1 x WV16V32	2000	HFO	40% urea water	Compact SCR, retrofit
Birka Transporter	1 x WV16V32	2002	HFO	40% urea water	Compact SCR, retrofit
Birka Shipper	1 x WV16V32	2001	HFO	40% urea water	Compact SCR, retrofit
Birka Paradise	4 x 6L46 + 4 x 6L32	2002	HFO	40% urea water	Compact SCR
Tallink Victoria	4 x 16V32LNE + 3 x 6R32LNE	2002	HFO	40% urea water	Compact SCR
Balticborg	1 x 9L46C	2003	HFO <1%S	40% urea water	
Newbuilding	1 x 9L46C	2004	HFO <1%S	40% urea water	
Newbuilding	4 x 6R32LNE	2004	MDO	40% urea water	