Wärtsilä Low NOx Solutions

Scope and experience

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Presentation agenda:

1. New requirements regarding emissions. Proposal from IMO for the future emission levels.
2. NOx formation in diesel engines. What is making the NOx in a marine diesel engine?
3. Wärtsilä’s NOx reducing technologies:
   – ”Primary” methods:
     • Wärtsilä “Dry” packages (including scope)
     • Wärtsilä “Wet” packages (including scope)
   – “Secondary” methods
     • Wärtsilä SCR solutions.
4. Experience from Wärtsilä Norway conversions
5. Other environmental solutions from Wärtsilä

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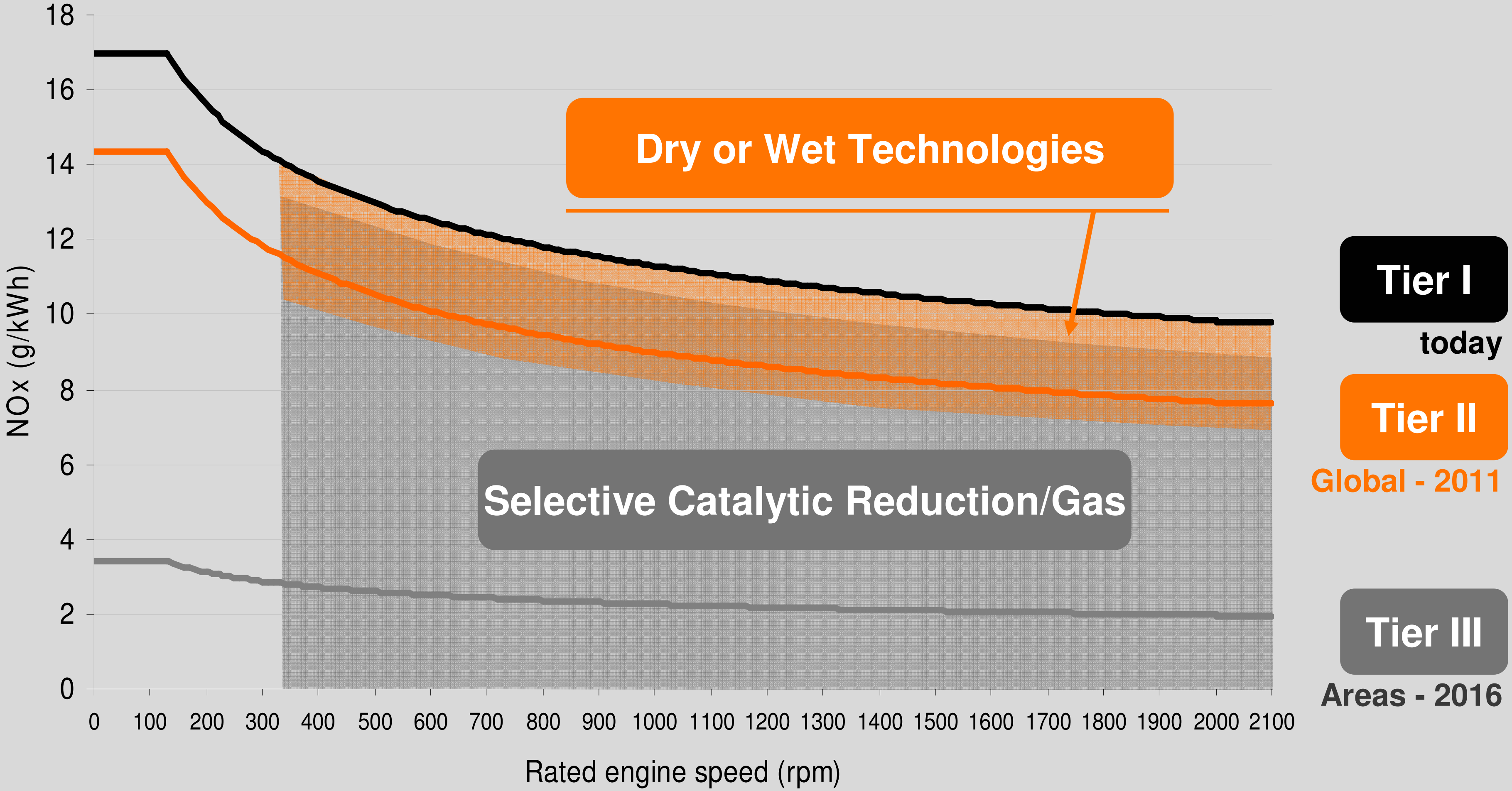
1. New requirements regarding emissions.

IMO MEPC meeting, week 14 - 2008

Current IMO requirements

Revised Marpol Annex VI
Outcome of IMO MEPC 57, week 14, 2008



- Tier I - 130 kW - New ships 2000
- Tier II - 130 kW - New ships 2011
- Tier III - 600 kW - New ships 2016 in designated areas

- Tier I - 1990-2000 ships
  Engines >90 litre/cyl
  and >5000kW

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2. NOx formation in diesel engines.

Short introduction

Facts about NO_x

How is NO_x produced in a diesel engine?

- At temperatures from approx 1600 ℃ and above, a chemical process starts between N_2 and O_2 in the combustion air, and the production of NO_x is started.
- Amount of produced NO_x is dependent on process temperature and length.
- In a diesel process the amount of NO_x production is like the ratio
  delta temperature (temperature incease) x time (combustion length).
- By decreasing local combustion temperature (peak temperatures/hot spots) and the combustion length (injection time) production of NO_x is reduced.

3. Wärtsilä’s NOx reducing technologies

Different approaches:

- **Primary: Dry or Wet**
- **Secondary: SCR**

Primary methods:

”Dry package”

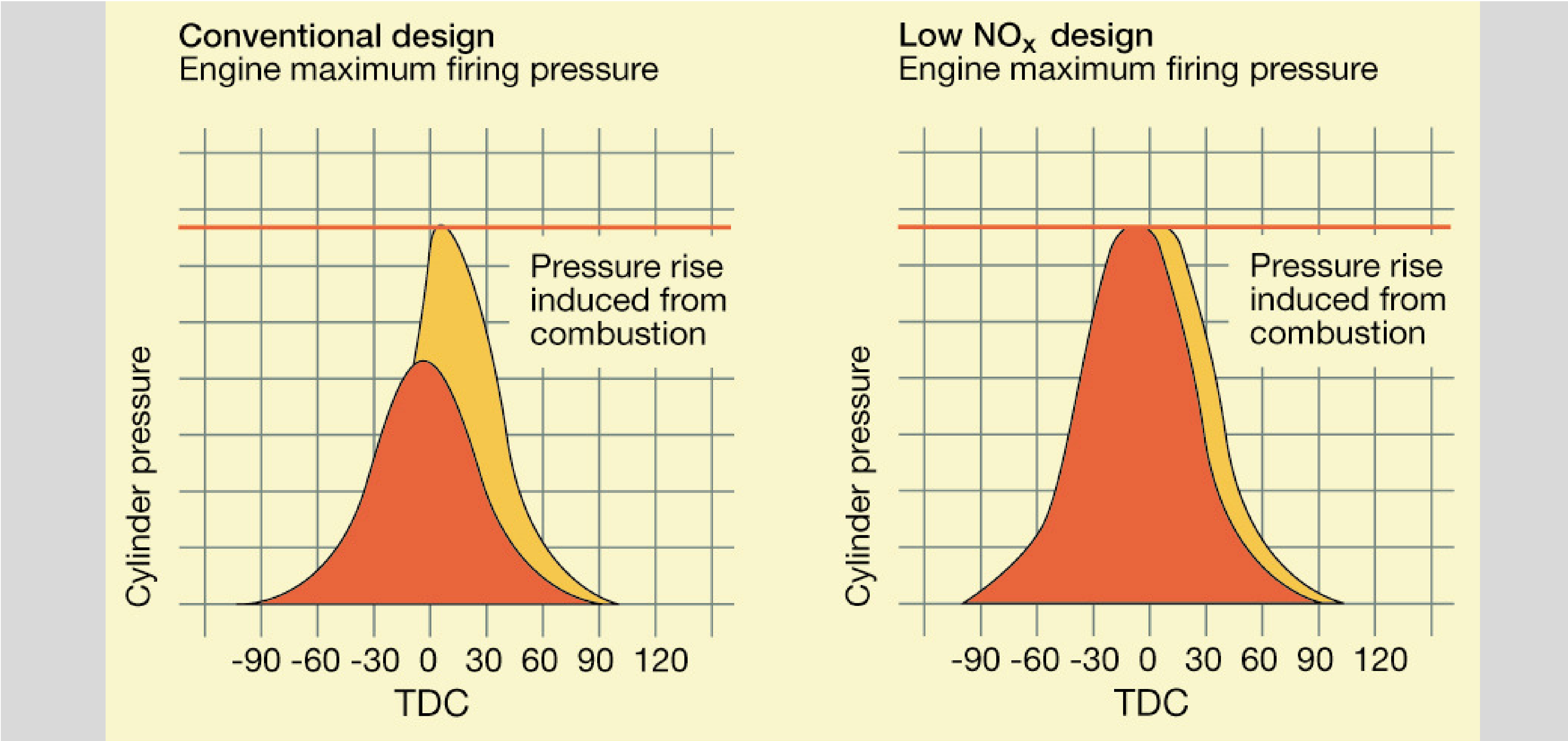
Dry Low NOx Technologies

NOx reduction due to:

- Higher temperature of combustion air when the injection starts. This implies a considerable reduction of the ignition delay (shorter combustion period).
- Approximately constant pressure during the combustion process.
- Later start of injection and up till 30% shorter injection period. This implies optimal conditions in the combustion process with regard to thermal efficiency and a NO_x production at lowest possible level.
- Improved combustion atomization with optimised combustion chamber and nozzle geometry, gives a better fuel and air mixture.
- Above changes guarantee a permanent reduction of NO_x from 25 to 40 %, and a reduction of SFOC from 2 – 7 % (dependent on engine type and production year).

LowNO$_x$ combustion

Cylinder pressure Standard engine vs. LowNO$_x$ engine



LowNO$_x$ Wichmann 28

- New cylinder covers (new geometry in combustion chamber)
- New fuel injection nozzles and nozzle holders. Opening pressure increased from 250 to 720 bar
- New cams for fuel oil pumps (faster cam profile), which implies 30% shorter injection length
- New injection pipes

Recorded reductions:

NO$_x$	30 - 40 %
Fuel	2 - 5 %

LowNO$_x$ Wichmann AXA/AXAG

- New cylinder covers (new geometry in combustion chamber)
- New fuel injection nozzles and nozzle holders. Opening pressure increased from 250 to 720 bar.
- New cams for fuel oil pumps (faster cam profile), which implies 30% shorter injection length
- New injection pipes
- New turbo charger

Recorded reductions:

NO$_x$	**30 - 40 %**
Fuel	**4 - 7 %**

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LowNO$_x$ Wichmann AX/AXG

- New cylinder liners and cylinder heads.
- New piston crowns
- New fuel oil system (inclusive injection nozzle, nozzle holder, fuel oil pumps, injection pipes, camshaft arrangement from short to long camshaft)
- New turbo charger arrangement

Recorded reductions:

NO$_x$	**30 - 40 %**
Fuel	**7 - 10 %**

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Possible conversions

Following Wärtsilä engines are possible to upgrade to LowNOx:

- Wichmann AX/G – AXA/G
- Wichmann 28 A, B
- Wärtsilä 25 (Nohab)
- Wärtsilä F20/F30
- Deutzh: D616, D620
- Wärtsilä Vasa 32
- Wärtsilä SACM UD30
- Wärtsilä 38
- Wärtsilä 46
- Zulzer ZAS40
- Wärtsilä 20 (under development)
- Wärtsilä F30 (under development)
- Wärtsilä 32 (under development)

Engine type	As Built	LNU	SCR	Product company
Diesel engines				
ZAS	Tier I	Tier II	Tier III	Wärtsilä Italy
AX		Tier II	Tier III	Wärtsilä Norway
AXA		Tier II	Tier III	Wärtsilä Norway
28	Tier I	Tier II	Tier III	Wärtsilä Norway
28C	Tier II		Tier III	Wärtsilä Norway
WN25 - 750 rpm		Tier I	Tier III	Wärtsilä Sweden
WN25 - 1000 rpm		Tier II	Tier III	Wärtsilä Sweden
F20 750-825 rpm		Tier I	Tier III	Wärtsilä Sweden
F20 900-1000 rpm		Tier I	Tier III	Wärtsilä Sweden
F30 - 750 rpm		Tier I	Tier III	Wärtsilä Sweden
F30 - 1000 rpm		Tier II	Tier III	Wärtsilä Sweden
F240 - 700 rpm	Tier I		Tier III	Wärtsilä Netherland
F240 - 1000 rpm	Tier I		Tier III	Wärtsilä Netherland
SW280	Tier II		Tier III	Wärtsilä Netherland
D616	Tier I	Tier II	Tier III	Wärtsilä Netherland
D620	Tier I	Tier II	Tier III	Wärtsilä Netherland
D628	Tier II		Tier III	Wärtsilä Netherland
W38A	Tier I		Tier III	Wärtsilä Netherland
UD30 - 600 rpm	Tier II		Tier III	Wärtsilä France
UD30 - 1500 rpm			Tier III	Wärtsilä France
W200			Tier III	Wärtsilä France
14/24			Tier III	Wärtsilä Finland
W 20 B		Tier I	Tier III	Wärtsilä Finland
W 20 C,C2, C3, D, D2	Tier I	Tier II	Tier III	Wärtsilä Finland
W 20 C5	Tier II		Tier III	Wärtsilä Finland
22			Tier III	Wärtsilä Finland
22/26			Tier III	Wärtsilä Finland
32		Tier I	Tier III	Wärtsilä Finland
32LN	Tier I		Tier III	Wärtsilä Finland
W32	Tier I	Tier II	Tier III	Wärtsilä Finland
W46 (<1995)		Tier I Tier II	Tier III	Wärtsilä Finland
W46 (>1995)	Tier I	Tier II	Tier III	Wärtsilä Finland
Gas engines				
W220 SG	Tier III			Wärtsilä France
W25 SG	Tier III			Wärtsilä Sweden
WN25 DF	Tier III			Wärtsilä Sweden
W28 SG	Tier III			Wärtsilä Sweden
W32 DF	Tier III			Wärtsilä Finland
W34 SG	Tier III			Wärtsilä Finland
W50 DF	Tier III			Wärtsilä Finland

LNU = with Low NO_x Upgrade

SCR = with SCR

Available today:
Tier I
Tier II
Tier III

Under development:
Tier I
Tier II

EIAPP certificate can be issued for these engine types after conversion.

Wärtsilä engines from Finland - possibilities

Wärtsilä 32

- Designed and delivered as LowNO$_x$ engine.
- Engines produced later than 2000 have or can have EIAPP certificate.
- For older engines a check has to be done (some components are missing the IMO code).

In development (as a service product):

- A service upgrading to reduce emissions will be released October 2008.

- By this modifications the Wärtsilä 32 will meet the IMO TIER I (-10% to -20%)

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Wärtsilä engines from Finland - possibilities

Wärtsilä Vasa 32

- Engines produced after 1997 are LowNO_x engines.
- Engines produced before 1997 can be upgraded by renewing the following components.
  - New piston crowns, modification of cylinder head
  - New fuel injection nozzles
  - New piston rods, new guiding pin
  - Anti-polishing ring in cylinder liner
- Result: 1-2% fuel oil reduction and 25-30% NO_x reduction
- EIAPP certificate

Wärtsilä engines from Sweden - possibilities

Wärtsilä Nohab 25

- Engines can be upgraded by renewing the following components:
  - New pistons, modification of cylinder head
  - New fuel oil nozzle (new spray angle)
  - New fuel oil pipes with leakage alarm
  - New piston rods, new guiding pin
  - Anti-polishing ring in cylinder liner

- Result: 1-2% fuel oil reduction and 25-30% NO_x reduction

- EIAPP certificate

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Primary methods:

”Wet package”

Wet Low NOx Technologies

NOx reduction due to:

- Lower combustion air temperature through vaporization of the liquid water prior to and/or during combustion
- Increased heat capacity of the cylinder charge, which reduces the temperature increase during combustion
- Dilution of oxygen concentration in the cylinder charge

Three Wetpac technologies <u>have been developed/tested</u>:

Humidification	Direct Water Injection	Water-fuel-Emulsions
Wetpac H	Wetpac DWI	Wetpac E

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Wet Low NOx Technologies for 4-stroke Engines

Wetpac H (Humidification):

- Humidification of the combustion air by injecting (and evaporating) water after the turbocharger compressor
- NOx reduction potential: 40%
- Water-to-Fuel ratio typically: 1.3 - 2
- Flexible system – control of water flow rate
- Two field installations in operation

Wetpac DWI (Direct Water Injection):

- Injection of water directly into the combustion chamber
- NOx reduction potential: 40% sometimes up to 50%
- Water-to-Fuel ratio typically: 0.7
- Flexible system – control of water flow rate and injection timing
- Several field installation

Wetpac E (Emulsion):

- Water-in-Fuel emulsion
- NOx reduction potential typically: up to 20%
- Water-to-Fuel ratio typically: 0.3
- Reduced smoke formation especially at low load
- Laboratory tested technology but no field installation (=> no long term experience)

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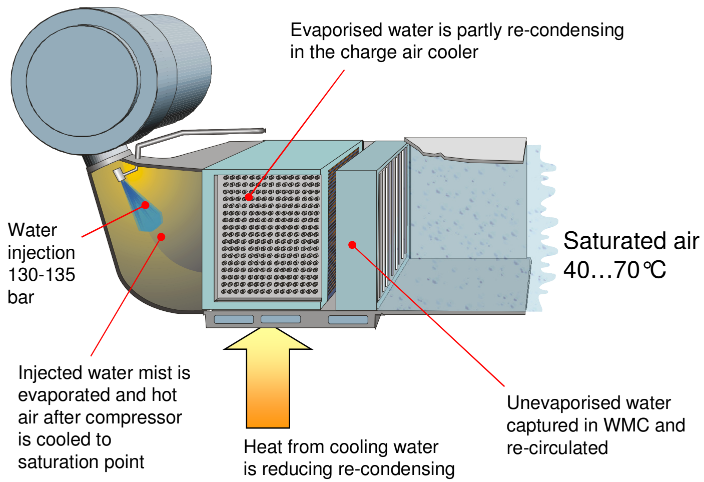
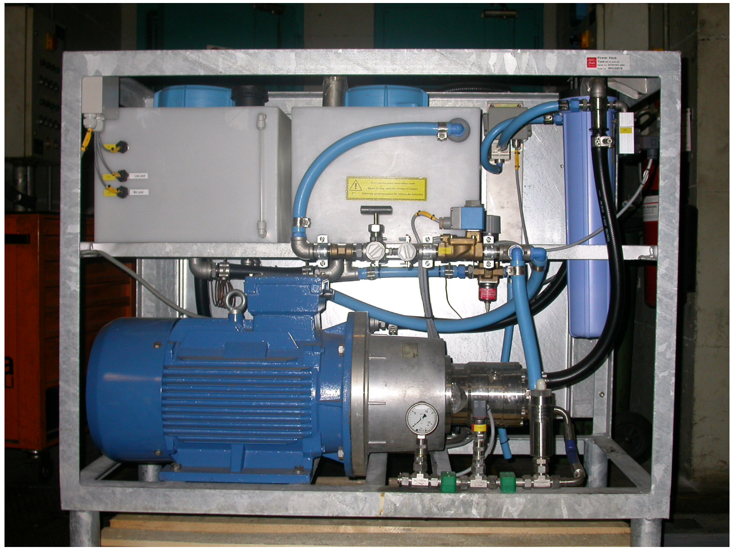
Wetpac H (Humidification)





Standard Wetpac H unit

Strengths

- Only marginal increase of SFOC
- Less complicated/expensive system compared to DWI
- Flexible system – control of water flow rate and switch off/on

Weaknesses

- Lower NOx reduction (20-40%) compared to DWI (50%)
- High water consumption compared to DWI
  - Very clean water is required in order to avoid fouling/corrosion of CAC and air duct system
  - Major change in heat recovery possibilities - less cooling water heat available for production of clean water
- Turbocharger speed increase and drift towards compressor surge line due to increased rec. temp. and high water flow
  - By-pass is required (anti-surge device)
    - Not possible together with pulse charging systems
  - Full NOx reduction (40%) can not normally be achieved at full engine load and low loads
- Increased smoke formation especially at low loads
  - Remedy: switch off or less water at low loads
- Limited long term experience
  - Unacceptable corrosion observed in the air duct system including CAC on 500h endurance test with high sulphur fuel (3%)
  - Encouraging lab and field experiences (rather few hours) with low sulphur fuel and low NOx reduction levels (about 30%)

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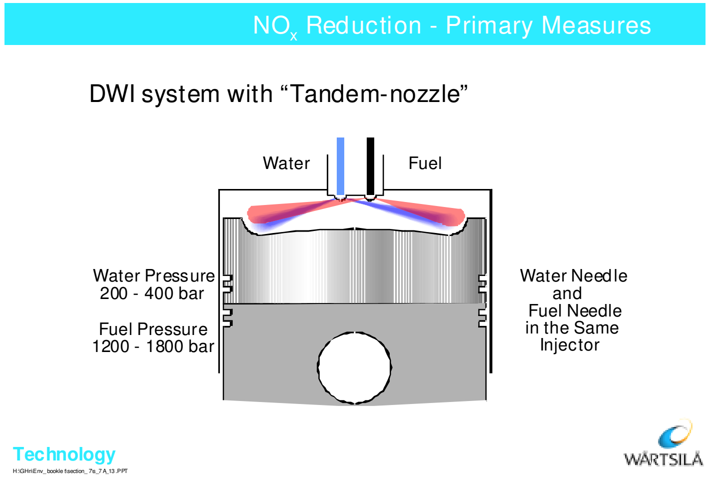
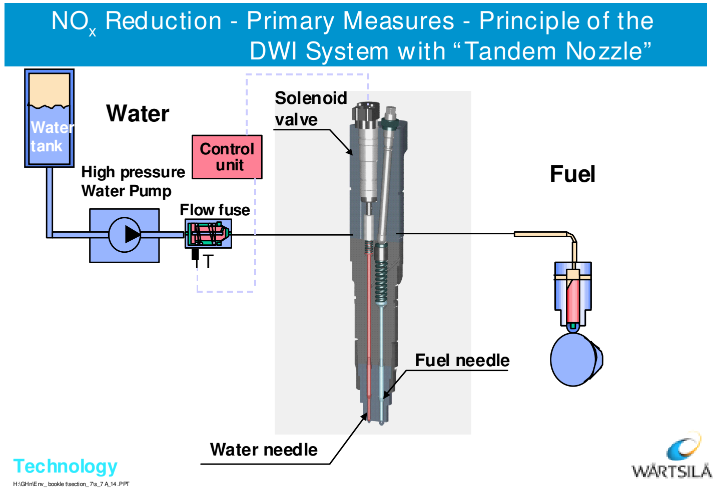
Wetpac DWI (Direct Water Injection)





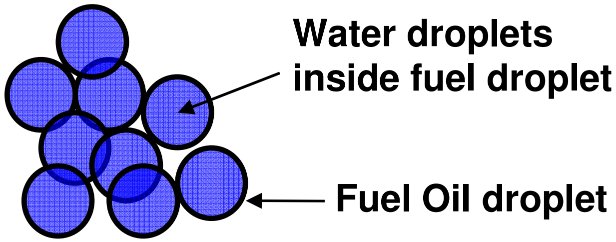
Strengths

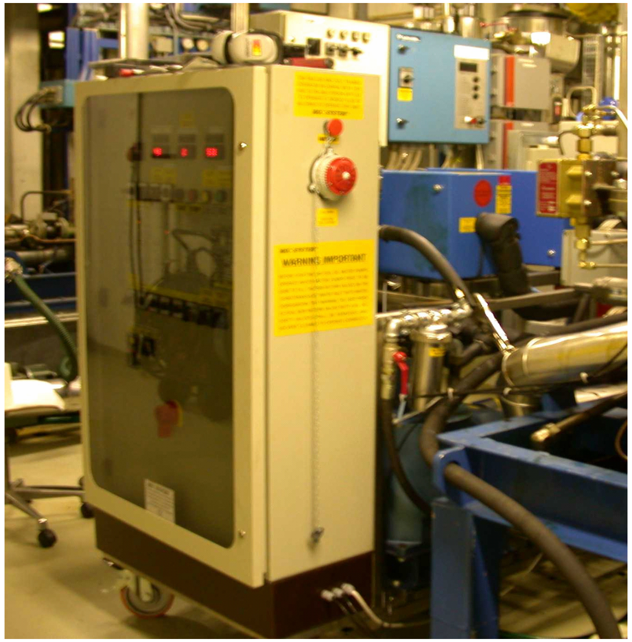
- High NOx reduction level achievable: 50%
- Low water consumption compared to Humidification
- Water quality is less crucial compared to Humidification
- Air duct system can be left unaffected – no risk for corrosion/ fouling of CAC, etc
- Flexible system – control of water flow rate, timing, duration and switch off/on
- Less increase of turbocharger speed and less drift towards compressor surge line compared to the Humidification method due to no increase of rec. temp. and less water flow – high engine load can be achieved and high (50%) NOx reduction also at full engine load
- No major change in heat recovery possibilities
- Good long term experiences with low sulphur fuels (<1.5%)

Weaknesses

- High fuel consumption penalty
- Increased smoke formation especially at low loads
    - Remedy: switch off or less water at low load
- More complicated/expensive system compared to Humidification
- Challenges in terms of piston top and injector corrosion with high sulphur fuels (>1.5%)

Wetpac E (water-fuel Emulsions)





Strengths

- Only marginal increase of SFOC
- Reduced smoke formation especially at low load
- Low water consumption compared to Humidification
    - Almost similar to that of DWI, but due to low NOx reduction the water consumption is low
- Water quality is less crucial compared to Humidification
- Less increase of turbocharger speed and less drift towards compressor surge line compared to the Humidification method, due to no increase of rec. temp. and less water flow – high engine load can be achieved
- No major change in heat recovery possibilities

Weaknesses

- Low NOx reduction potential (15-20%)
- Rule of thumb: 1% added water reduces emissions with 1%
- Limited flexibility
    - Increased smoke formation and poor engine performance due to too large nozzles in case of switching off the system
    - Increased mechanical stress on the fuel injection system in case ”standard” nozzles are used
- Limited long term experience
    - 400h endurance test showed extreme turbine nozzle ring fouling
        - Root cause was very bad water quality

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Secondary methods:

Selective Catalytic Reduction (SCR)

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Wärtsilä Secondary method:

Wärtsilä SCR – system:

- High activity over a wide temperature range (280-510°C)
- High selectivity for the SCR process
- Extreme low SO2 → SO3 conversion rate
- High mechanical stability and chemical resistance
- Low back pressure and low risk of clogging
- One size honeycomb for all modules

Performance	NOx reduction	80 - 90%
	HC reduction	20 - 40%
	Soot reduction	20%
	Sound Attenuation	20 dB (A)
Operation	Temperature Span	300 - 500 °C
	Fuel	MGO/MDO/HFO/GAS

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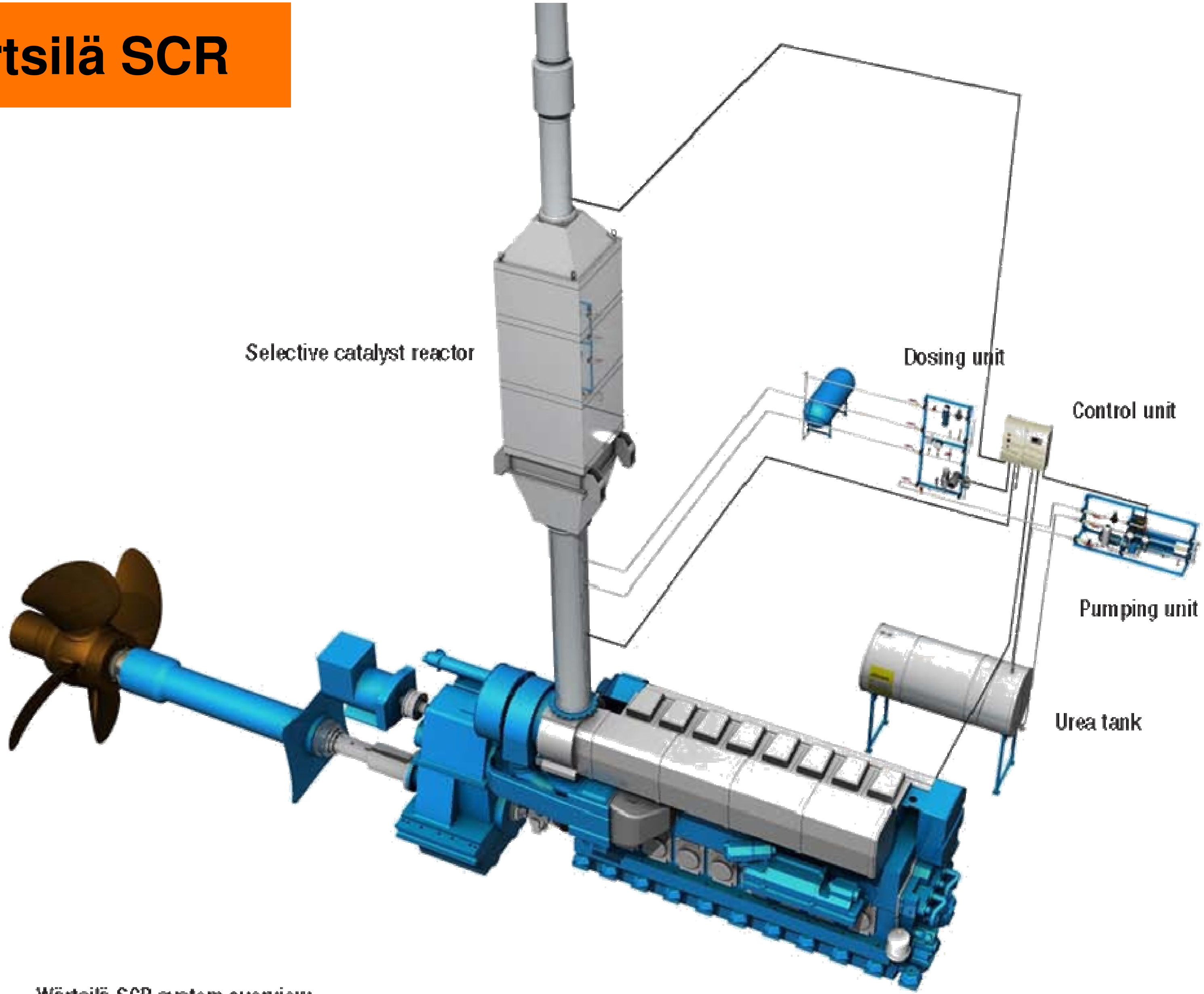
Wärtsilä SCR



Wärtsilä SCR system overview.

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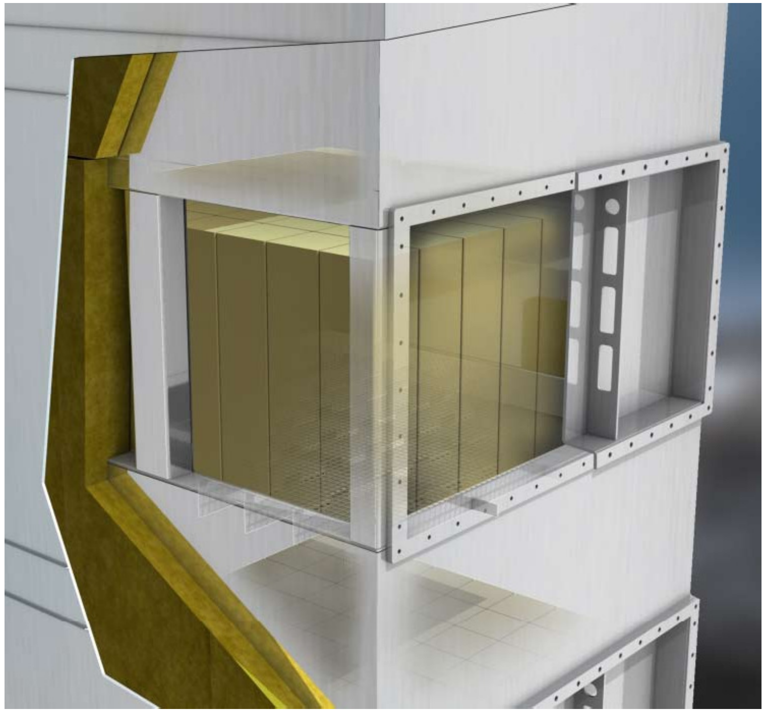
Wärtsilä SCR

Size	H mm	W mm	D mm	Ø1 mm	Ø2 mm
1	4590	1414	1414	800	500
2	4790	1725	1570	1000	700
3	5170	1885	2035	1200	900
4	5690	2350	2350	1450	1000
5	6050	2665	2665	1700	1200
5.1	6950	2665	2665	1700	1200



- Urea consumption is about 20 l/MWh
- Operational cost 6 €/MWh
- Investment cost 25-50€/kW

4. Experience from Wärtsilä Norway Conversions.

Short summary

WNO running Engine base

- We have following engine volume:

Engine Type	Engines in op.	NOx upgraded	Production year
Wichmann 28	124	26	1984 - 1998
Wichmann AX	374	39	1970 - 1985
Wichmann AC	171	-	1965 - 1973
Wichmann DC	26	-	1960 - 1970
Wichmann DM	1	-	1960 - 1970

- Total 65 engines upgraded pr 01/05-08.
- 61 of these engines have been Service upgraded either by our Ships service in Rubbestadneset, or by WNO Fieldservice in Norway or World Wide. 4 engines delivered as LowNOx engines (in 1998).
- Recon-engines are delivered as LowNOx engines.

Status conversions in Norway

Upgradings done by Wärtsilä Norway:

- A total of 65 WNO engines (Wichmann) are converted as of 01/05-08
- Wärtsilä Engines: 3 x Vasa32, and 9 x W25 engines (to be completed).

- *In WNO Service order book for 2008* (from 03/04-08 ⟶)
  - *4 x Wichmann AXAG,*
  - *3 x Wichmann 28,*
  - *4 x Wärtsilä Vasa 32,*
  - *4 x Wärtsilä F30.*

Annual reductions obtained:

(Theoretically, based on 5,000 h/year – WNO Engines 65 pcs)

NO_x	**3 000 tons**
CO_2	**18 360 tons**
Fuel	**5 780 tons**

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5. Other environmental solutions from Wärtsilä.

Short introduction

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Environmental solutions

OWS

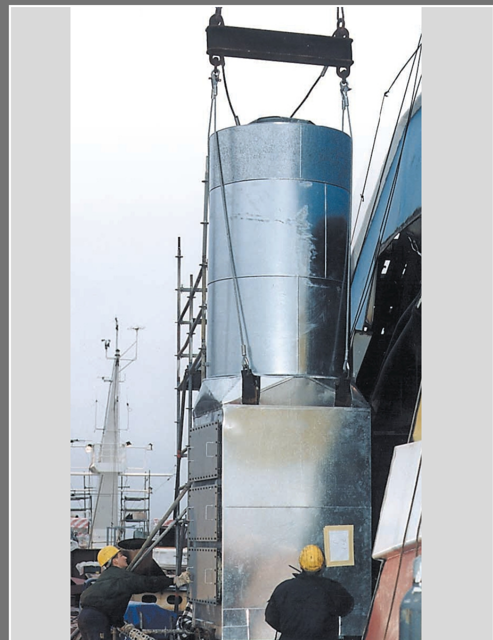
MS FinnClipper
RoRo Passenger, Finnlines

SOx

MV Suula
Product Carrier, Neste Oil

NOx

Birka Princess
Cruise Ferry, Birka Cruises



Gas Engine Alternative
Dual-Fuel Engine Characteristics

Wärtsilä 6L50DF

- **High efficiency**
- **Low gas pressure**
- **Low emissions, due to:**
  - High efficiency
  - Clean fuel
  - Lean burn combustion
- **Fuel flexibility**
  - Gas mode
  - Diesel mode
- **Two engine models**
  - Wärtsilä 32DF
  - Wärtsilä 50DF

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