

NO_x abatement solutions

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The Norwegian government has been at the forefront of developing emissions regulations for shipping. Wärtsilä has been actively leading marine engine research addressing both the Norwegian and global abatement demands.

Already back in the early 80's the Norwegian government started to focus on emissions from shipping. In parallel to this, the IMO began defining rules and regulations for NO_x emissions from new ships. By the end of the 80's this environmental focus had increased, and a number of political resolutions with white papers ("stortingsmeldinger") on the reduction of emissions from existing coastal vessels in Norway, were published. The main target became coastal vessels as they represented the biggest source of emissions, and because NO_x modifications on these vessels were rather cost-effective and easy to conduct.

Development process of Low NO_x technology by Wärtsilä

With about 60% of coastal car ferries equipped with Wichmann engines, Wärtsilä in Norway started development work on upgrading packages for these existing installations.

Through co-operation with the Norwegian Government, Wärtsilä was able to get funding to start research and development on a one cylinder Wichmann 28 engine. In this Wärtsilä was assisted by Marintek in Trondheim. The study was terminated in 1990.

In 1991, Wärtsilä in Norway continued with a parameter study on production engines to see if the results from the test engine were comparable with results on production engines. The first field tests were conducted, in co-operation with The Norwegian Directorate of Transport, in 1992 on two ferries.

After evaluation of the results, the next step was defined as being the implementation/development of the same technology for the older engines (Wichmann AX) manufactured in the 1970s. From 1995 to 1997, all test results (from both field and laboratory tests) were evaluated. Detailed design and specification work was carried out so that upgraded packages for the different Wichmann 28 and AX engines series would actually be available.

The complexity of the conversion was dependant on the specific age of the engine, but in general terms it consisted of modifying the fuel system, the combustion chamber, and in some cases, the turbocharger system. Two pilot tests, on the Wichmann 28 and Wichmann AX, were carried out in the autumn of 1997. A reduction in NO_x of some 30% was achieved, as were reasonable fuel savings of 8% on the Wichmann AX and 4% on the Wichmann 28 engine.

At about the same time that Wärtsilä in Norway was getting the first results, the Norwegian Government signed the Gothenburg Protocol in 1997, which committed Norway to reducing their NO_x emissions from 215,000 tons to 156,000 tons (28.5%) by 2010. To match these requirements, a subsidy system was established for owners/operators that lasted

for five years. This so-called NOXRED programme fund covered up to 100% of the cost of upgrading, and about 30 engines were converted during that period.

From 1st of January 2007, the Norwegian Government introduced a NO_x fee for vessels operating in Norwegian waters. This fee was introduced in order to attain the reductions that Norway had committed to in the Gothenburg Protocol of 1997. The fee is set at 15 NOK/kg NO_x.

New NO_x funding for Norwegian owners/operators

On Wednesday 23rd of January 2008, there was a press conference held by the Norwegian Ministry of the Environment. The reason for the press conference was to announce the establishment of a new NO_x fund articulated around the following five main points:

- 1) The agreement, valid from 1st of January 2008, is between the Norwegian Government and 14 industry organizations, and is subject to European Surveillance Authority (ESA) approval. Until formal approval is confirmed, operators will have to pay the NO_x tax as before, but NO_x tax paid in 2008 will be refunded (upon application for refund) following final approval of the agreement. NO_x tax paid to the Norwegian Government in 2007 is not refundable. The fund is only applicable to Norwegian customers.
- 2) In accordance with the new agreement, operators joining the fund are obliged to initiate NO_x reducing actions. When appropriate action has been carried out, the amount of NO_x tax will be reduced from today's 15 NOK/kg NO_x down to 4 NOK/kg NO_x (the 4 NOK/kg NO_x is paid into the fund - not to the Norwegian Government). This rule applies to all vessels/installations except for offshore vessels/installations, for whom the fee is 12 NOK/kg NO_x →

payable into the fund. All matters regarding calculations, measurements etc., are as set out before.

- 3) Those operators/owners who sign an agreement with the fund before 1st of July 2008 will have priority as regards funding of a conversion or upgrading of an installation. Operators who opt not to join the fund (or who do not fulfil the obligation if they do join) will have to pay 15NOK/kg NO_x to the Norwegian government (and the indication is that this figure will increase in the years to come).
- 4) The industry organizations will manage the fund and also evaluate the NO_x reducing initiatives. The most cost-effective initiatives will be prioritized. Two main solutions have already been identified and evaluated as being the most reliable: Low NO_x modifications and SCR (where this is feasible).
- 5) This fund will be established for the coming three years and will have a value of approximately 1.5 billion NOK (about 190 MEUR), equally spread over three years, i.e. 500 million NOK (about 63 MEUR) per year. The results from the upgradings/modifications will be monitored by the Norwegian Ministry of the Environment. In case the target level reduction of ~30,000 tons of NO_x per year isn't reached, the agreement will come to an end and the NO_x tax will be reintroduced.

Dry Low NO_x technology

The Wichmann diesel engines are medium speed, 2-stroke loop-scavenged, valveless, turbocharged, intercooled, and with direct fuel injection. The engine output varies from 700 kW to 4680 kW.

Wichmann engines are equipped with an auxiliary blower to obtain a good operational profile at low loads.

Wärtsilä's "primary method" upgrading package focuses on optimizing the combustion process.

The main elements are:

- Higher combustion air temperature at injection start. This results in considerably reduced ignition delay.
- Constant pressure during the combustion process (increased compression pressure).
- Later injection start and up to 30% shorter injection time. The injection point is decreased from ~11 deg BTC to 4 deg BTC. The opening pressure of the injection nozzles was also increased from 280 bar (on a standard engine) to 720 bar.
- Improved fuel oil atomization and matching of combustion chamber with fuel spray to get a better air/fuel mixture.
- For the oldest engines the technology comprises a turbo charging system, reducing the SFOC by up to 10-12%.

Field results from upgraded installations

The following are all real measured values carried out onboard during sea trials after conversion, in accordance with ISO 8178. Power, consumption, and emissions were also measured. Table 1 highlights the different upgrading packages per engine families.

Most of the conversions have been performed at Wärtsilä's ship services facility in Norway. They can also be carried out by Wärtsilä field service personnel anywhere. Normally, such upgrades take about 14 days, including two days for final testing, i.e. sea trials with the necessary

engine adjustments.

As of January 2008, a total of 53 engines have been upgraded and the resulting corresponding annual reductions are as follows (based on a theoretical base of 5000 annual running hours):

- NO_x 2400 tons/year
- CO₂ 15630 tons/year
- Fuel 4930 tons/year

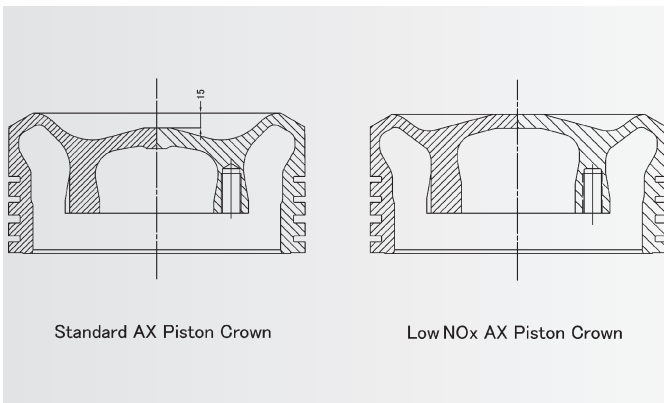
Wet NO_x reduction methods

Abatement methods can be categorized by the location of the abatement (in the engine or along the exhaust gas duct), the technology used (dry, wet, catalytic, etc.), the abatement level they can achieve, or the main application (new buildings or retrofitting).

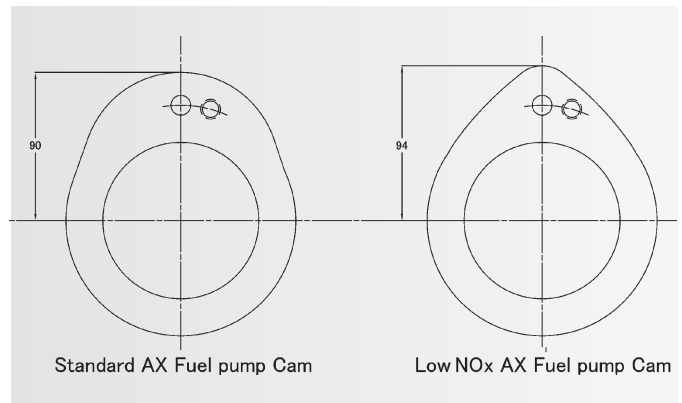
The solutions previously explained in this article are known as primary dry methods, or 'dry package' in Wärtsilä's terminology. This is usually a modification of the engine combustion cycle, similar to what has been described in the previous chapters, aimed at limiting the combustion temperatures and, as a consequence, the formation of NO_x. Depending on the starting point, this method can give NO_x reductions in the range of 20-30%. It is applicable to existing engines, as it requires only engine modification, but no major changes in engine room layout or to the main workings of the ship are necessary.

The wet methods family takes a different approach to perform the same task, i.e., to reduce the combustion temperature. This is achieved by evaporating water into the inlet air or combustion space. Wärtsilä has developed three different packages named:

- WETPAC E, based on the water to fuel emulsion principle,
- WETPAC H, based on the



■ Fig. 1 – Two cylinder head profiles together (standard vs. Low NO_x).



■ Fig. 2 – Two different cam profiles (standard vs. Low NO_x).

air saturation principle,

- WETPAC DWI, with direct water injection into the cylinders.

As regards the **WETPAC E** method, Wärtsilä has developed an external unit that creates a stable emulsion between fuel and water, which thus behaves as a single-phase liquid. This enables it to be pumped and injected into the engine without the drawbacks occurring with only fuel. The system efficiency in NO_x abatement is limited to the amount of water we can add to the system. Usually we can achieve NO_x reductions in the range of 20%. Before applying this method, the engine needs to undergo some verifications and calculations on fuel pump capacity, injection nozzles, torque, temperature development, etc.

WETPAC H is a technology aiming to achieve NO_x reductions via air saturation. Water is injected immediately after the compressor where, because the compressed air is hot, it evaporates. Due to the large amount of water injected, the scavenge air is completely saturated. This method requires a small external pumping unit but very limited modifications to the engine. NO_x reductions as high as 40% can be achieved.

WETPAC DWI, on the other hand, injects water directly inside the cylinder at almost the same time as the fuel is injected. As a separate injection system is used, this method is not limited by the quantity of water to be injected. This abatement can achieve almost 50% reductions in NO_x emissions. Some modifications are required at engine level to introduce

Engine Family	Upgrading	Components	EIAPP	Results
Wichmann AX/AXG	Low NO _x	- Cylinder liners - Cylinder covers - Piston crowns - Complete fuel system (i.e. new camshaft, pumps, injectors, pipes, etc.) - New turbocharger	YES	NO _x = 8.5 g/kWh Reduction: 30–40% SFOC= 205 g/kWh Reduction: 8–12% Weighted E2
Wichmann AXA/AXAG	Low NO _x	- Piston crowns - Fuel oil nozzles - Fuel oil pipes - Cams - New turbocharger	YES	NO _x = 8.5 g/kWh Reduction: 30–40% SFOC= 195 g/kWh Reduction: 5–7% Weighted E2
Wichmann 28 A/B	Low NO _x	- Cylinder covers - Fuel oil nozzles - Fuel oil pipes - Cams	YES	NO _x = 8.3 g/kWh Reduction: 30–40% SFOC= 192 g/kWh Reduction: 2–3% Weighted E2
Wichmann 28 A/B/C	Low NO _x + Power increase (300 → 390 kW/cyl)	- Cylinder covers - Fuel oil nozzles - Fuel pumps - Fuel oil pipes - Cams - Turbocharger - Charge air cooler	YES	NO _x = 7.8 g/kWh Reduction : 30–40% SFOC= 188 g/kWh Reduction: 4–5% Weighted E2

■ Table 1. – Different upgrading packages per engine family.

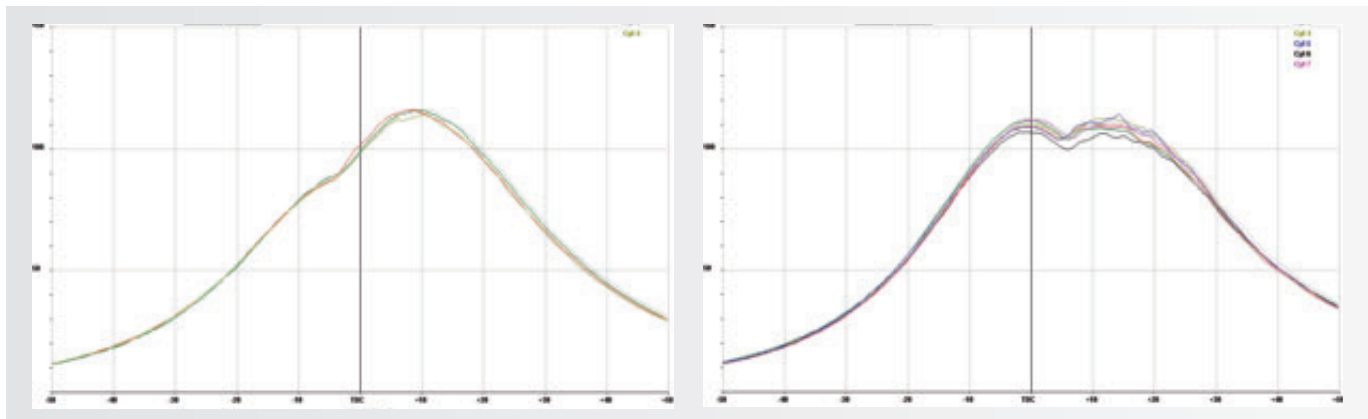
this additional injection system. All wet methods require a limitation in fuel sulphur content, as it can combine with the water to form sulphuric acid.

Aftertreatment, secondary technology

The most powerful technology currently available for reducing NO_x is Selective Catalytic Reduction (SCR). It is an aftertreatment method capable of cutting

NO_x emissions by 85–95%. It consists mainly of a catalytic converter (the reactor) located along the exhaust pipe, (after the turbocharger on 4-stroke engines and before the turbocharger on 2-stroke engines), control system, urea injection system, and a urea storage tank.

The catalytic material in the reactor converts NO_x back to nitrogen and water using urea-originated ammonia as a →



■ Fig. 3 – Real measured firing pressures (standard vs. Low NO_x).

reductant. Wärtsilä offers an SCR solution for new building and retrofits, which can be fitted to both Wärtsilä and non-Wärtsilä engines. The retrofit solution has a compact design that enables replacement of the existing silencer without sacrificing the sound attenuation properties of the system. Wärtsilä's SCR solution makes it possible to comply even with the most stringent emission limits at sea.

Gas engines and gas conversion

Gas engines are intrinsically green. Because of their combustion process, they emit about 85-90% less NO_x than today's diesel engines burning HFO. When burning gas the mixture is lean, and when the gas burns it does not reach the high temperatures usually seen at the hot spots when running on liquid fuels. As a result, the amount of NO_x produced during combustion is controlled.

At the same time, CO₂ emissions are 30% less than with liquid fuel burning. This goal is achieved thanks to the low amount of carbons in the fuel molecule. The Hydrogen to Carbon ratio of gas fuels is rather high when compared to liquid fuels; this gives a high amount of water and a low amount of carbon dioxides in the exhaust gases.

The final positive effect in burning gas is that there are virtually no SO_x gas emissions. This is because the gas contains no sulphur. The small amounts of sulphur that could be present in the gas come from the lubricant oils of the compressors used to compress the gas in the pipeline. ●

NOTE: For further information regarding NO_x compliance solutions or a customized analysis of your equipment, please contact us at NOx@wartsila.com.

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 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

■ Table 2 – Available NO_x compliance solutions.

REFERENCE: NORWEGIAN COAST GUARD VESSELS



■ Fig. 1 – KV Andenes during operation in the Arctic.

KV Nordkapp, KV Senja and KV Andenes are all fitted with four Wichmann 9AXAG engines delivered in 1981 and 1982. As the vessels were planned for full operability up till 2020, the Norwegian Navy decided to upgrade their engines with Wärtsilä's LowNO_x solutions.

In December 2007, KV Andenes arrived at Wärtsilä's ship service premises in Rubbestadneset. The upgrading of all four engines was done in five weeks, along with other planned maintenance work. After the retrofit, NO_x emissions were reduced by about 30%. Fuel consumption was reduced by about 8.5%, as were the CO₂ emissions.

By mid-March, all three coast guard vessels (12 engines) had undergone the conversion, and all met the contractual regulations concerning emissions.