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Report

NOx Fund supported NOx abatement from 2008 to 2011 User experience

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TITLE

NO_X Fund supported NO_X abatement from 2008 to 2011
User experience

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ABSTRACT

This report is a summary of work done to gather the user experience from a set of abatement technologies implemented and run in the marine sector during the 2008-2011 periods. It is based on interviews with crew who are close to the operation of, and with first hand knowledge on, the abatement system on board - typically chief and second engineers.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	NO_X abatement	NO_X reduksjon
GROUP 2	User experience	Brukererfaring
SELECTED BY AUTHOR		

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1. Introduction

The NO_X Fund Agreement has since 2008-2010 played a major role in reducing the emission of nitrogen oxides (NO_X) in the Norwegian maritime sector. The fund has since the start up supported the implementation of NO_X reducing measures adding up to an impressive 18000 ton of NO_X reduction at the end of 2010. An agreement for a second period lasting from 2011- 2017 is now operative. The goal is to improve the efforts by supporting the use of NO_X abatement technologies that are cost effective in a broader perspective. The overall sustainability of a measure is a keyword in this respect, which include compliance to:

- high NO_X reduction efficiency
- not effecting fuel efficiency negatively
- easy to implement and operate
- minimum of consumables
- long lasting without unacceptable need of follow-up and maintenance

Knowledge and experience has been gained during the first period of agreement which will be useful in evaluation of new measures for support in the current agreement period. This report is a summary of work done to gather the user experience from a set of abatement technologies implemented and operated in the marine sector during the 2008-2010 period. The report is based on interviews with crew who are close to the operation of, and with first hand knowledge on, the abatement system on board, typically chief engineers and second engineers.

2. Objective

The NO_X fund has so far focused on the basic figures for estimating the NO_X emission tax. In order to fully evaluate a NO_X reduction measure in a broader perspective, the operational aspects also have to be considered. The main objective of this work has been to gather relevant information and experience from vessels where the abatement technology has been in use for some time.

NO_X reduction efficiency of a technology is of interest, not only for newly installed and tuned systems but also after some time in operation. The necessary measurements for such verification are not included in the scope of work for this project.

The interviews were focused on collecting user experience related to:

- implementation of system in the vessel
- operation of the systems involved
- maintenance needs
- malfunctions/failures causing downtime on system
- effect on operability of engine(s) or other side effects
- training and follow-up from supplier
- impression in general, possible improvements etc.

3. Scope of work

- Choice of representative vessels for gathering user experience
- Prepare interviews with vessel crews. Focus on firsthand information from crew members close to the operation and maintenance of the installed NO_X reduction measure
- Perform interviews
- Prepare and run a web based questionnaire to vessel owners
- Report and summarize findings

4. Method of work

4.1 Interviews

In this part of the work, focus is put on collecting user experience on the NO_X measures supported by the NO_X-fund from 2008 to 2011. The selection of users and technologies should be representative for the majority of those in operation and is focused on the marine sector only. The technologies looked at are:

- SCR
- Engine Low NO_X modification
- Gas-fuel
- EGR
- Water based technologies

The experience from use is collected from hands-on interviews of personnel onboard the vessels. A checklist for each interview is used as guidance and for reporting.

4.2 User questionnaire

As a separate exercise and in parallel to other activities in gathering operating experience, a schematic web-based questionnaire is made and submitted to the vessel-owners. A variety of the implemented NO_X reduction technologies are covered. As the technologies are quite different in nature, a separate questionnaire was made for each as given in Appendix 1 (a link for each type of questionnaire). An overview has also been given of the companies asked and their respective technology in service.

The response to the questionnaire has been sparse and diverse. A summary of answers are given in table 1 below:

Table 1: Number of answers to questionnaire pr. 01-09-2012

Status of answer	SCR	Low-NO_X	Gas	Humid
Complete	14	6		-
Partly		1	1	-
Incomplete	2	1		-

Where information of value (additional from interviews) is gathered for the questionnaire it is included in the sections describing the interview findings. The web-based questionnaire is still active.

4.3 Selection for interview

The data reported to the NO_x-fund until midyear 2011 was initially systematized in Excel sheets to:

- categorize type of vessels using the same technology
- get an overview of NO_X reduction efficiency for different technologies
- get an overview of cases with significant deviations in reported data
- sort out interview objects

The list of visited ships for interviews is shown in table 1, including all together 21 ships (ship A to U). The table covers type of ship, year built, NO_X reduction technology installed, when installed and some comments. Vessels A to H cover SCR technologies, vessels I and J utilizes EGR, vessels K to N use LNG as fuel while vessels O to R have engines with low NO_X modification. Of the remainder three ships, ship S utilizes HAM with water injection in the intake manifold, ship T uses water emulsified fuel while ship U has performed test with some special type of catalytic filter.

Prior to the ship visits and the interviews with involved engineers, checklists were worked out as guides for the interviews. And since the actual NO_X reduction measures are quite varied, the checklists were adapted each kind of measure. The checklists cover subjects regarding ship technical data, kind and make of equipment, operation period in addition to experience from operation, possible influence on system performance, maintenance, service, consumables, operation costs, verification on NO_X reduction, reporting etc. The actual check lists are only available in Norwegian, and are included in Appendix 2.

From the systematized data further analyses and comparisons are made. From the analysis on SCR, the major abatement technology implemented so far, quite significant differences are seen among the vessels with regard to NO_X reduction efficiency, even for the same type of NO_X reduction measure.

Table 1 Ship matrix object for interviews

Ship	Ship type	Year build	NO_x red. mean	When installed	Comments
A	Fishing vessel	1998	SCR	Retrofit 2009	
B	Offshore vessel	2010	SCR	New build	
C	Fishing vessel	2004	SCR	Retrofit 2009	
D	Offshore vessel	2007	SCR	New build	
E	Fishing vessel	1999	SCR	Retrofit 2008	
F	Offshore vessel	2008	SCR	New build	
G	Offshore vessel	2006	SCR	New build	
H	Offshore vessel	2007	SCR	New build	
I	Offshore vessel		EGR	Retrofit 2009	Terminated 2011
J	Crane vessel		EGR	Retrofit 2009	
K	Product carrier	2007	LNG dual fuel	Retrofit 2011	
L	Offshore vessel	2003	LNG dual fuel	New build	
M	Offshore vessel	2009	LNG dual fuel	New build	
N	Ferry	2011	LNG lean	New build	

			burn		
O	Fishing vessel	1987	Low NO_x mod.	Retrofit 2008	
P	Offshore vessel	1985	Low NO_x mod.	Retrofit 2010	
Q	Offshore vessel		Low NO_x mod.	Retrofit 2009	
R	LPG carrier	1999	Low NO_x mod.	Retrofit 2008	Slide valves
S	Fishing vessel	2011	HAM	New build	Water inj. manifold
T	Bulk carrier	1990	Water emulsion	Retrofit 2009	
U	Coastal express	1996	Catalytic filter	Retrofit 2011	Terminated 2011

5 Summary of interviews

5.1 SCR – interviews

Principally all SCR systems comprise the same set of components; urea storing tank, urea injection system and mixing zone and the catalyst section. In addition necessary instrumentation and sensors, valves and control cabinet are included. The main variation between the system makes are shape and composition of the catalyst and the complexity of the process control system. For the simple control solutions the dosage of urea is based on registered engine power, while more complex control regimes contain continuous exhaust gas analyzer to measure NO_X content at exhaust outlet. The catalyst reaction is dependent that the exhaust exceeds a certain temperature, normally in the range 280 – 320 °C. Due to the sulphur content in the fuel ammonia sulphates can be formed as undesired byproducts of the SCR reaction from SO_3 and NH_3 at too low temperatures. A minimum cut-off temperature has to be selected to avoid formation and deposits of ammonia sulphates on the catalyst surface. All investigated SCR systems have automatic start of plant and urea injection when exhaust temperature reach the actual temperature level, and similar shut down when the temperature decrease below same set value.

A total of 8 vessels with SCR have been visited to get hands on experience from the operation of this kind of equipment. The crew on three fishing vessels has been interviewed, while the remaining five vessels are various offshore service vessels for stand-by, supply- and anchor handling purposes. Most of the vessels have diesel electric propulsion. All three fishing vessels have retrofit installations while for the offshore vessels the SCR plants were installed when the vessel was built.
Five different SCR suppliers are represented with the NO_X-fund registered vessels:

- H+H Umwelt- und Industrietechnik GmbH
- D.E.C. Marine AB
- Johnson Matthey / Argillon
- Yarwil AS
- Mecmar
- Ecoxy (catalytic filter combined with NO_X catalyst)

H+H is by far the maker most widely represented, and of the 8 vessels visited 6 have this type of make while D.E.C. and Johnson Matthey are represented by one vessel each. Yarwil and Mecmar are fairly new in the market, each have some few units installed however with short time of operation, and hence less thorough experience are gained so far.

The system installed onboard ship U is not a traditional SCR system but a prototype catalytic filter meant to collect and use particulate matter as a reactant for NO_X reduction (mainly the NO_2 part) on a catalytic surface. The system has shown a performance far from expected even after efforts for improvements. The NO_X reduction efficiency is low and pressure drop is unacceptable. Further comments on this concept are not given herein.

5.1.1 Findings

The overall impression from the vessel visits and from interviews with involved Chief engineers and crew representatives is that the SCR plants function according to intentions without any major need for maintenance or time out of order. Most vessels have service agreements with local representatives for the suppliers, this seems important for trouble-free operation. The service personnel are recognized as efficient and highly skilled, they also make up for insufficient training, or lack thereof, regarding system operation and maintenance.

When put into service some vessels experienced corrosion in the urea storage tanks due to faulty coating. After correction this problem was solved.

None have experienced any problem related to urea quality. The urea is bunkered from tank trailers, and due to short notice regarding time and place for port calls for the off-shore vessels they would prefer urea bunker facilities at the bunker terminals.

All visited vessels have automatic start/stop of plant according to exhaust gas temperature level, and this operation seems problem-free.

Most of the visited vessels were equipped with NO_X analyzer for control of urea injection. This more complex control strategy is reported to function well, and should ideally secure specified NO_X reduction efficiency and keep control of the NH_3 slip. However the NO_X analyzer involves need for calibration and maintenance, change of filter in sample line etc. and it is still no guarantee of the NO_X measurement accuracy. There are examples that the way of installing the sample filter affects the measurement quite significantly. Proper training is thus of vital importance.

For most vessels with continuous NO_X analyzer the NO_X level may be read at a display at the control cabinet, however few/none of the crew members have a conscious relation to the figures or making records. There is also an issue regarding long term stability of the online NO_X sensor, need for calibration as well as the consequences of this regarding urea dosage and reduction efficiency.

There is a need for a simple way for the crew to compare present NO_X readings (and the related amount of urea injected) versus a known "as new" value (i.e. new catalyst and everything well-tuned). A graphic illustration of NO_X on a display (the present versus the "as new" value or as curves), as function of load, could be a helpful easy way to evaluate whether the system is operating ok or if something is wrong.

The main source involving some maintenance is the urea injection system, covering change of urea filter and cleaning / blasting of urea injection line prior to closing down to avoid crystallization in the injection line/valve.

Most systems are equipped with nozzles for soot blasting with pressurized air, automatically operated when the pressure drop over the catalyzer reaches a set limit. The air consumption is fairly high, ship A for instance has installed additional air compressor. The suppliers state that need for soot blasting is dependent on fuel quality, with MGO there is less need for soot blasting.

Lifetime for the catalyst as given by the suppliers are 20 000 – 30 000 operating hours or five years. Both ship D, G and H are approaching this limit without experienced change in behavior; however NO_X reduction efficiency should be analyzed to verify condition.

5.1.2 Highlights of findings

- General impression is that the SCR plants function according to intention
- Service agreement with well qualified local agents from supplier seems important regarding efficient and trouble free operation

- Training in operation of the SCR plant is generally sparse, but good local agents contribute to training during performed service onboard
- At exhaust temperatures below 280-320 °C the catalyst loses efficiency, and urea injection is shut down automatically to avoid ammonia sulphate formation (dependent of the sulphur content in the fuel)
- Dosing of urea was controlled from engine power reading on ship B (possibly also ship C and H), or in more complex systems according to NO_X analyzer in the exhaust outlet, ship A, D; E; F; G. As exhaust gas analyzers involve some maintenance and calibration, cost-efficiency of this added complexity should be investigated.
- Some of the visited vessels are approaching catalyst lifetime stated by supplier, without experienced change in operational behavior, such as pressure drop and NO_x reading. However NO_x reduction efficiency should be analyzed to verify condition for one or more systems.

5.1.3 Comments and recommendations

A simple way for the crew to check if the NO_X reduction is according to specification during operating (SCR system is working properly) should be considered, i.e. as a check against the "as tuned" value for NO_X and urea flow at given loads. This could be visualized in control panel display by a "as new/as tuned" versus a "as run" (curves or tabulated). A significant deviation is then a warning that something is not working according to specification. A record of pressure drop versus number of operating hours could also be of interest. Some feedback to the crew on SCR performance could help motivations for best possible care and operating of the system.

For catalysts with 10000 running hours or more re-verification of NO_X reduction efficiency would have been of interest.

According to regulations the NO_X factor shall be approved by Norwegian Maritime Authority. However some of the vessel owners mention that they have a different operation profile than that assumed in the NO_X factor calculation, hence they use a different NO_X factor in their reporting. The dispute normally applies to the 25 % power point, which more often is without SCR plant in operation due to exhaust temperature limitation. Calculations can be done on this to illustrate the effects of the operating profile on the NO_X factor calculation.

The reporting is done half-yearly and covers documentation of fuel and urea consumption together with operation hours for the period. For most of the vessel owners this reporting is done from the vessel owner office, based on received information from the vessels. General impression is that these procedures function well.

A general comment regarding SCR is that the diesel engine manufacturers seems to accept the need for exhaust after treatment to meet the coming strict NO_x and PM emission level, and the SCR are likely to be the after cleaning technology. By employing SCR as engine component, optimization of lower fuel consumption is possible as the NO_X emission can be controlled by the SCR system. This is comparable to the trend for Heavy Duty vehicle producers for land transport.

5.2 EGR - interviews

The number of EGR installations in operation is few and so are the accumulated running hours. Ship I had the EGR system onboard more as a prototype for test purpose, and not supported by the NO_X fund. The information about it was gathered during a SCR interview with the vessel owner who had the EGR system onboard in one of his other vessels. The system had been onboard for about two years, but is now removed.

Regarding ship J the EGR system has been in ordinary operation for more than one year (installed nearly two years ago) and is still in operation.

The EGR systems have a two-filter system where one filter is in operation while the other is in "cleaning mode" with heated air. The switch-over between the filters is done automatically according to a preset sequence.

5.2.1 Highlights of findings

- Contamination of the engine has caused severe operating problems, increased maintenance and is thus one of the reasons for removing the system.

- For the system in operation the tendency is deposit in compressor, receiver and cylinder head inlet, especially at low loads (quite significant smoke and PM from the engines, 30 years old). To avoid this contamination the system is now turned on manually at higher loads which for the actual vessel is a minor part of its operation. Major mechanical or electrical problems with the system have not been experienced. After an initial phase with some modifications, tuning etc. the system is now in an ordinary operation phase. An updated NO_X verification would have been of interest.

5.2.3 Comments and recommendations

The few cases with EGR report challenges related to engine contamination. EGR as an add-on component from a third party is not recommendable as it influences negatively on engine performance. The EGR system should be supplied by the engine manufacturer. Another factor for better performance is fuel quality. Clean distillate fuel oil or natural gas provides much better operation conditions for an EGR system.

5.3 Gas fuelled engines - interviews

Altogether four gas fuelled vessels have been visited with interview of chief engineer and other involved crew members. Ship K is a product tanker, ship L and M are offshore supply vessels while ship N is a car and passenger ferry. Both supply vessels have four Low Pressure Dual Fuel (LPDF) engines driving generators, and with electric motor propulsion. The product tanker is the only retrofit gas installation from October 2011 and she has two LPDF engines with reduction gear driving propellers and shaft driven generators. The car and passenger ferry has three pure gas Lean Burn Spark Ignited (LBSI) engines driving generators, in addition to one diesel driven generator, and with electric azimuth propulsion.

The LPDF engines can operate with two fuels, either on pure diesel or on gas. In gas mode the engine needs a small amount (app. 1 % at full load) of diesel for pilot diesel ignition. It can also operate on combined diesel and gas fuel. However, on part loads below 10 – 15 % most LPDF engines have automatic close down of gas supply and switch to pure diesel operation.

The Lean Buren Spark Ignited gas engine (LBSI) implies operation on a lean gas air mixture, normally approximately twice the amount of air compared to stoichiometric combustion. Medium speed LBSI engines will normally use pre-chamber with enriched gas as amplifier of the spark plug.

For all the gas fueled ships the gas is bunkered and stored onboard as Liquefied Natural Gas (LNG) in vacuum/perlite insulated storage tanks at a pressure of 4 - 8 barg. Normal operating pressure is approx. 5 barg. Other important equipment is the gas evaporator system and the gas conditioning unit and gas pressure control. LNG is bunkered at LNG terminals or by LNG tank trailers.

For both engine types, LPDF and LBSI, the gas is injected during the air suction stroke and the air and gas is premixed before combustion. This implies that some small amounts of unburned methane will be emitted, called methane slip, due to small crevices in the combustion chamber where combustion is hampered. By dedicated design of the combustion room this methane slip can be minimized. Further it is important to control the gas lean rate at all engine loads, steady state and during load variation. Too rich mixture may cause knocking while too lean will increase unburned gas and methane slip.

5.3.1 Findings

The supply vessels have the longest experience, one with more than 9 years operation. When put in service it was a pilot installation for LPDF engines in supply vessel, and for several years they experienced a series of problem regarding burned exhaust valves, problems with pilot valves and gas injection equipment, change of cylinder heads etc. However, improvements are achieved, lessons learned and today maintenance is today comparable with that of diesel engines. The second supply vessel has three years operation and experienced only minor initial problems. For the remainder two vessels the gas operation experience are rather short, four and two months respectively, but both vessel owners are satisfied so far.

All involved crew members were given courses and trained by engine manufacturer prior to taking over the LNG systems, but in some cases the Chief would like a more systematic training of new crew members who are inexperienced with gas operation.

However, all the gas related equipment has good instruction manuals, both papers based and electronic.

LPDF engines shut down gas injection at part load below 10 – 15 % of MCR. All the actual vessels with LPDF engines report the engine load to be above this margin at all actual points of their operation profile, and hence that operation in diesel mode is rare except for start and stop of engines.

All the actual gas engines are equipped with knocking sensors and all vessels with LPDF engines experience knocking from time to time. This occurs when operating in heavy seas with large and rapid load variations, or during load increase after long periods of low part load operation. The first is helped by decrease of engine load, the last by very controlled load increase to burn out accumulated soot and particles. The sensors, including the automatic anti-knock engine control system, operate well and thus automatic change to diesel operation occurs infrequently. Some leaking gas inlet valves have been observed, resulting in richer gas mixture and hence cylinder knocking.

The actual vessel owners operate their gas vessels in the same way as for diesel fueled vessels, but the ferry company use special superintendents for their gas fueled ferries. Wärtsilä has own engineer onboard the product tanker during the time of guarantee.
For the DF engines all maintenance intervals are similar to that for diesel engines; for pilot- and gas injectors each at 6000 – 8000 hours. The same is valid for the LB engines except inspection of gas injection valve and change of spark plug, each at 2000 hours. Compared to diesel engines the lube oil consumption is less, approximately 0.5 g/kWh, and the cylinders stay cleaner. For LPDF engines fouling of piston crown and exhaust valves is experienced, especially after long periods of low part load operation. This might be connected to the actual lube oil type, TBN etc.

One of the four vessels on delivery experienced some minor gas leakage inside the double walled high pressure piping system in engine room, with release of gas alarm. All vessels are satisfied with bunkering procedures. Bunkering from LNG road tanker takes some more time than from LNG terminals or bunkering fuel oil.

Regarding reporting routines towards NO_X fund etc., none of the vessels are directly involved. Most vessels practice monthly reporting to company office, covering fuel consumption, running hours together with routine vessel/engine reports. Reporting towards NO_X fund etc. is handled by the company office.

In general all crews are satisfied by their gas fueled machinery, and several express that they will never revert to a diesel fueled vessel. Engineers with experience from first generation of gas fueled vessels also express satisfaction with improvements on the latest generation machinery.

5.3.2 Highlights of findings

- All vessel owners express perfect satisfaction with their LNG fueled vessels. The supply vessel delivered in 2003 experienced some initial problems which are claimed to be solved by now. Later delivered plants have experienced just minor fault / adjustments
- All involved crew members have been properly coursed and trained, and good instruction manuals exist for all gas related equipment. Some chiefs miss more systematic coursing of new crew members un-experienced with gas operation
- DF engines shut down gas injection at part load below 10 – 15 % of MCR. All the actual vessels report the engine load to be above this margin at all actual parts of their operation profile
- From time to time knocking is experienced (quick power demand /on-loading the engines). The knocking sensors function well, and also the automatic anti-knock engine control system
- For all visited vessels the reporting towards NO_X fund etc. is handled by the company office. Most vessels practice monthly report to company office, and any conflict regarding NO_X factor and weighting is unknown onboard.

5.3.3 Comments and recommendations

All the visited gas fuelled vessels went through thorough exhaust gas measurement when put in operation, covering 25 %, 50 %, 75 % and 100 % engine load. However, none cover HC gas measurements in the exhaust. This is an important characteristic for these engines with premixed combustion. The amount of HC is increasing at low/medium loads when still aiming to keep a low NO_X emission. None of the vessels has instrument for NO_x measurement.

It is recommended to include THC measurements when doing the NO_X verification measurements. The extra cost for such is marginal.

It is recommended to look into the bunkering procedures (incl. rules/regulations) to reduce the methane release to atmosphere.

5.4 Engine Low NO_X modification - interviews

Regarding engines with Low NO_X modification altogether four vessels are part of this study. Of those vessels O, P and Q cover comprehensive change of components and adjustments and medium speed trunk engines while for ship R the effort is limited to change from conventional to slide type fuel valves on a slow speed crosshead engine.

The principle behind the more comprehensive type of modification is to depress zones with the highest temperatures during combustion by retarding start of fuel injection, and to compensate consequence of reduction in efficiency by increased compression ratio and rate of injection. The actual modification normally involves change of piston crowns, cylinder heads, injection pumps and valves, eventually also camshaft, turbocharger etc. Of these vessels two are supply vessels while the remainder is a fishing vessel / fillet trawler. All modifications are retrofit and performed in 2010, 2009 and 2008 respectively.

5.4.1 Findings

The operational experience for the three vessels with Low NO_X modifications differ somewhat. One vessel reports that all engine characteristics are unchanged, both regarding operation, power and engine parameters, but with a reduction in consumption of 2-4 %. One vessel experienced some initial problems with broken high pressure fuel pipes due to increased injection pressure. This was solved by a new piping design.

The third vessel has experienced more serious problems, especially in the initial phase. It took extremely long time to run in new piston rings, and during this time severe blow-by, raised crank case pressure and increased lube oil consumption were reported. Of permanent change is increased smoke level, especially at part load, a small increase in fuel consumption and elevated exhaust gas temperatures. This vessel also reports some increased maintenance, more oil leakage from crank case, soot and need for engine room cleaning.

Regarding reporting regime towards the NO_X fund this is generally done from the vessel owner office, and based on data reported from the vessels. Some super intendants express need for simplification.

Regarding ship R and change to slide fuel valves the registration is not based on visit and interview onboard, but on a ship service report from the engine manufacturer provided by the actual ship owner. A NO_X reduction of 27 % is reported by comparing to standard engine NO_X emission, but emission levels for the actual engine prior to change of fuel valves are not registered.

5.4.2 Highlights of findings

- Two of three modified vessels report that all engine characteristics are unchanged, both regarding operation, power and engine parameters
- One modified vessel has registered a reduction in fuel consumption of 2-4 %
- One modified vessel has experienced serious problems, especially in the initial phase. During run in of new piston rings severe blow-by, raised crank case pressure and increased lube oil consumption were reported
- For one vessel the NO_X emission before modification is measured to133 kg NO_X/ton fuel, which is above realistic level
- Regarding reporting regime some super intendants express need for simplification

5.4.3 Comments and recommendations

For one of the actual vessels the NO_X emission before modification is measured to133 kg NO_X/ton fuel, and respectively 40 kg/ton fuel after performed modification. This represents a 70 % reduction which is far from realistic. Most probably the error is with the extreme high level measured before modification.

5.5 Water based technologies - interviews

Regarding humidification technologies two vessels have been visited, ship S which are equipped with water injection directly in the engines air manifold, Humid Air Motor, HAM, while ship T utilize water dosage in the fuel and mixing to emulsion by means of a fuel homogenizer.

The vessel with water emulsion operation is a handy size bulk carrier delivered in 1990, and the equipment for water injection and homogenizer was retrofit installed in 2009. The actual machinery is a slow speed crosshead diesel engine directly coupled to the propeller. However, the homogenizer has been broken for several long periods and was repaired and restarted prior to the visit onboard. By todays operation the water injection is turned on in transit in open sea, and closed down manually when engine load decreases below a set value for engine load (engine temperature restriction). There is no instrumentation or procedures for reporting / documentation of the water in fuel operation.

The vessel with the HAM operation is a factory fishing vessel delivered in October 2011, and with diesel electric propulsion. Energy production is by three medium speed diesel generators operating at fixed engine speed. The propeller is driven by two electric motors, the propeller is of variable pitch type, but operated at fixed pitch. The HAM technology was installed when the vessel was built. The quality criterion for the injection water is rigid so water cannot be bunkered from shore, but is produced by two evaporators specially installed for the purpose. There is no instrumentation or procedures for reporting / documentation of HAM operation.

5.5.1 Findings

Ship T, the bulk carrier with water emulsion functioned properly the first two years of operation according to the captain who has been onboard for many years. The vessel changed owner in January 2011, and interview onboard indicate that the new owner lacked proper information regarding the fuel emulsion installation, and hence purchase of needed emulsifier. Trigged by our request to make interview in February this year, emulsifier was purchased and the process restarted. After short time of operation the homogenizer broke down. During the visit onboard in May a new homogenizer was installed and service personnel came onboard for retuning of the plant.

The fuel – water emulsion is started and stopped manually, but equipped with alarm for shut down. Vessel super intendent will investigate with supplier if operation window might be widened regarding part load.

Ship S, the fishing vessel with HAM technology entered service in October 2011, hence the period of experience is fairly short. So far the impression is entirely positive both regarding operation simplicity and lack of problems. The HAM unit is fully automated with operation window within 30 – 95 % engine power.

The bulk carrier travels a fixed roundtrip always inside NO_X tax zone. The fishing vessel reports continuous operation of HAM also outside the zone.

None of the vessels are aware of any alteration in engine behavior, power or consumption with operation with or without water, but none of the vessels have instrumentation for more detailed investigation. For the engines with HAM the exhaust temperature is measured to be 5 - 7 °C lower with water injection in operation.

Except for un-sufficient battery backup capacity which has resulted in loss of logged data and mentioned lack of emulsifier, none of the vessels have experienced other operational problems. Except for the mentioned action regarding restart of the emulsion plant onboard the bulk carrier the follow up from shore office is limited to questions when visiting the vessels.

The water injection equipment has not caused problems for any of the vessels, but as mentioned above the water emulsion system has been out of operation for longer periods since January 2011. No external training during operation has been offered, but fairly good technical manuals have been supplied. None have had any follow up from equipment suppliers.

Both vessels are satisfied with the registered NO_X reduction. For the bulk carrier with water emulsion the established reduction is approximately 20 % while for the fishing vessel with HAM technology a reduction of 80 – 85 % is claimed. These figures should be investigated since they far exceed other available sources. MARINTEK measurements regarding HAM onboard "Mariella" indicate reduction in the range of 60 % while MAN and Wärtsilä indicate reduction potential in the range 40 – 50 %.

None of the crews had insight in the NO_X reduction verification measurements or the weighting compared to operation profile. Such matters are handled by the shore office. For both vessels the reporting towards NO_x fund and the Directorate of Customs and Excise is handled by the shore office based on fuel consumption figures from vessel voyage reporting. And both crews miss a log regime for documentation of operation of the plant. The water emulsion plant comprise a logging unit, but lack of 24V power supply and un-sufficient battery backup result in loss of data, and since no one asks for this kind of information no proper logging is performed.

The HAM plant has no logging unit, but the chief engineer for his own part logs start and stop of the plant in the machinery log. He proposes installation of flow meter for injection water, and use of this to record the HAM system operation, much similar to urea consumption for SCR installations.

5.5.2 Highlights of findings

- Both investigated water based technologies, HAM and water emulsion seems to function according to intension
- None of the crews are aware of any alteration in engine behavior, power or consumption with operation with or without water, but none of the vessels have instrumentation for more detailed investigation
- Both vessels are satisfied with registered NO_X reduction. For the water emulsion plant the established reduction is approximately 20 % while for the HAM technology a reduction of 80 – 85 % is stated. This last figure should be investigated since it far exceeds that of other available sources
- No external training during operation has been offered, but fairly good technical manuals have been supplied. None have had any follow up from equipment suppliers.
- For both vessels the reporting towards the NO_X fund and the Directorate of Customs and Excise is handled by the shore office based on fuel consumption figures from vessel voyage reporting. Both crews miss a log regime for documentation of operation of the plant

5.5.3 Comments and recommendations

It is recommended to re-verify NO_X reduction by onboard measurements.

6 Summary and comments

SCR:

- Information gathered from the interviews has not uncovered severe weaknesses of a general character. Where initial start-up faults/problems are encountered they are solved together with the system supplier.
- For a well-tuned plant the NO_x reduction efficiency is according to what the supplier specifies.
- Some installations have reported high pressure drop across the catalyst even when running frequent soot blasting. The amount of soot and particulate from the engine is certainly of importance (i.e. from transient operation) when it comes to clogging. The catalyst soot oxidizing capacity (V_2O_5), module size (cross section of flow channel in catalyst element) and urea quality are other parameters.
- The initial training of the crew can be improved. A close follow-up from the supplier, as to some degree practiced today, is recommended.
- Solutions to help the crew in a simple way to check or monitor the SCR system performance should be looked into.
- It is not possible to define a definite lifespan of a catalyst element as it depends quite much on the overall operating conditions. Figures given by suppliers are typically 10000 - 20000 operating hours. There is still an open question regarding the actual efficiency of the catalyst as a function of number of operating hours. A survey, by measure, on selected SCR plants with considerable time in operation, is recommended. Valuable information about marine SCR capability and sustainability could then be added.

EGR:

- To fully utilize the potential the EGR system has to be a well-tuned integrated part of the actual type of engine, developed and tested by engine makers.
- The main challenge with EGR is the particulate matter (PM) and contamination of the engine. A PM optimized combustion and filtration is essential.

Gas fuelled engines:

- The crew on gas driven vessel is in general satisfied with their machinery. The problems encountered initially on some of the first vessels are now claimed to be solved.
- To compare gas only and the dual fuel vessels is not meaningful as the gas only vessel interviewed was brand new with only a few running hours. The two concepts are in a way complementary as they cover a wide range of marine applications. As gas engines together with mechanical drive are now offered the range of applicability also increases.
- Gas operation is regarded as sustainable not only because of the significant with NO_X reduction but also for reducing harmful emissions such as SO_X, PM, and CO_2. The technology may in addition last the whole lifespan of the vessel.
- It is recommended to continue development on engine transient control in order to increase margin to knock and reduce methane slip.
- Verification measurement on vessels should also include THC measurements.

Engine Low NO_X modification:

- There are varied experiences from the different vessel interviewed, all with modifications done as retrofit. The problems reported are to some degree surprising as the technology used is mature and well proven. A factory delivered low NO_X diesel engine is probably more trouble free.
- Low NO_X modification has a potential as NO_X reduction measure, even if the efficiency is limited to about 20-30%. It is a technology based on design and tuning which is meant to last over the lifespan of the engine. A premise is that the fuel consumption does not suffer significantly due to the modification.

Water based technologies:

- The number of vessels with such technologies is low and the information gathered from the interviews is thus not a proper basis for definite conclusions.

The vessel with water emulsion claims about 20% NO_X reduction (amount of water unknown), however without any documented effect on fuel consumption. The plant has also from time to time been out of operation.

The vessel with HAM claims an unrealistically high NO_X reduction efficiency, which should be documented together with water and also fuel consumption.

- None of the vessels have a record on operating hours of the system (run in proper condition). Some tracking should be possible.

Appendix 1

TOTAL report:
- Link: https://system.enalyzer.com/redirect.asp?pubID=c5resatar7
- Password: "NOXFOND" (med store bokstaver)

Tentative report – Humid
-Link: https://system.enalyzer.com/redirect.asp?pubID=qasis7b6pa
- Password: "Vannbasert"

Tentative report - SCR
- Link: https://system.enalyzer.com/redirect.asp?pubID=pifa2k2g5s
- Password: "scrscr"

Tentative report – Rebuild of engine
- Link: https://system.enalyzer.com/redirect.asp?pubID=f5nuc5ref5
Passord: "Motorombygning"

Tentative report - Low-NOx rebuild of engine
- Link: https://system.enalyzer.com/redirect.asp?pubID=mus3r6k3n2
- Passord: "Lavnox"

Appendix 2 Interview check-list.

NÆRINGSLIVETS NOx-fond

DNV

MARINTEK SINTEF

BRUKERERFARING – SCR

<u>Brukerfaringsdataene er delt inn i 6 kategorier:</u>
1: Tekniske data for fartøy
2: Informasjon om SCR-anlegg
3: Drift av SCR anlegget
4: Vedlikehold og service
5: Måling og verifikasjon
6: Urea

1. FARTØYSTEKNISKE DATA

- Navn og IMO nummer på fartøy:
- Til stede:
- Fartøystype:
- Lengde / bredde / dybde riss:
- Bygget (år):
- Maskineri:
- Ytelse:
- Fuelforbruk:

2. SCR ANLEGG – TEKNISKE DATA

- Leverandør av anlegg:
- Retrofit / Nybygg:
- Hvem utførte ombyggingen:
- Installert heater for bruk på lavlast:
- Oksiderende katalysator:

3. DRIFT AV SCR ANLEGGET

- Hva er maskinistenes inntrykk av det installerte anlegget?:
- Hvem er ansvarlige og for hva rundt drift av anlegget?:
- Hva er rutinene rundt drift av anlegget:
- Hva er sett verdiene for operasjon av anlegget (Eksostemperaturer, svovelinnhold, motorlast evt andre)?:
- Bruk utenfor avgiftsbelagt område?:
- Hva slags opplæring ble gitt?:
- Brukes bypass av anlegget ved enkelte driftsforhold?:
- Er det registrert endringer i fuelforbruk som kan spores til SCR anlegget?:
- Problemer med eksosmottrykk?:
- Er det opplevd problemer med ammoniakk lukt i maskinrommet?:

- Eventuelt andre problemer?:
- Hvordan fungerte anlegget i oppstartsfasen, var det mye startproblemer?:
- Hvordan følges anlegget opp av onshore organisasjonen i rederiet?:

4. VEDLIKEHOLD OG SERVICE

- Hva er vedlikeholdsrutinene?:
- Hva slags problemer oppleves i forhold til SCR anlegget? (Belegg, korrosjon, plugging osv):
- Er anlegget preget av mye nedetid?:
- Hva er rutinene for blåsing av SCR anlegget?:
- Hva er levetiden på det katalytiske materialet? Rutinene rundt bytte av kat. materiale?:
- Hva er prosedyrene når man opplever driftsproblemer?:
- Hva er den mistenkte årsaken til driftsproblemene?:
- Hva er rutinene for å ha oversikt/bekrefte at anlegget fungerer?:
- Er mannskapet klare over faren for ammoniakk slipp?:
- Hvordan følges systemet opp fra leverandørsiden?:

5. MÅLING OG VERIFIKASJON

- Hvilke data blir registret og hvor ofte? (oppetid, ureaforbruk):
- Hvordan blir registrerte data brukt og hvor rapporteres de oppsamlede data?:
- Er installert NOx måleutstyr for kontroll og regulering av SCR anlegget?:
- Er det gitt opplæring i bruk av måleutstyr?:
- Hvordan forholder mannskapet seg til de målte dataene, har de et forhold til hvilke verdier som er fornuftige? Stoler de på måledataene?:
- Har det vært eksterne måle firmaer inne for å måle/sjekke anlegget (utenom de første verifiseringsmålingene? Gjøres dette rutinemessig?:

6. UREA

- Hvem har ansvar for ureabestillingen?:
- Hva slags spesifikasjon er det som brukes for bestilling av urea?:
- Er det problemer knyttet til urea leveranser?:
- Er det noe regime for kvalitetssikring av ureakvaliteten?:
- Hva er konsentrasjonen av urea i løsningene som kjøpes?:
- Varierer konsentrasjonen fra bestilling til bestilling?:
- Påvirkes doseringen av urea av konsentrasjonen?:
- Må konsentrasjonen mates inn i styringssystemet?:
- Hvor store er ureatankene? Er de store nok?:

7. GENERELT

- Rapportering til NOx-fondet, hva medfører dette for rederiet?:
- Forslag til endring i rapportering?:
- Synet på vekting for å beregne NOx faktor?:

BRUKERERFARING – GASSDRIFT

Brukerfaringsdataene er delt inn i 7 kategorier:

1: Tekniske data for fartøy
2: Informasjon om motor og gassanlegg
3: Drift av motor anlegget
4: Vedlikehold og service
5: Måling og verifikasjon
6: Gass systemet
7. Generelt

1. FARTØYSTEKNISKE DATA

- Navn og IMO nummer på fartøy
- Bygget (år)
- Maskineri
- Gas only eller dual fuel:
- Fuelforbruk

2. GASS-ANLEGG – TEKNISKE DATA

- Leverandør av motor
- Leverandør av gasstank/fuelsystem
- Retrofit / Nybygg

3. DRIFT AV MOTOR ANLEGGET

- Hva er maskinistenes inntrykk av det installerte anlegget ?
- Opplevd bank i den grad at effekt må reduseres ?
- Dual-fuel: kjøres i gass-mode på alle lastpkt ?
- Hva slags opplæring ble gitt ?
- Følges gassdriften opp annerledes enn dieseldrift av onshore organisasjonen i rederiet?

4. VEDLIKEHOLD OG SERVICE

- Hva er vedlikeholdsrutinene?
- Opplevd nedetid pga uforutsette hendelser (stempel/foring, eksosventiler, tenningssystem, pilotinjektorer, gasstilførsel ?
- Hva er rutinene for bytte plugger ?

- Hva er rutinene for bytte pilot injektorer ?
- Oljeforbruk versus dieseldrift ?

5. MÅLING OG VERIFIKASJON

- Utførte avgassmålinger ?
    - etter idriftsettelse av båt
    - etter et gitt antall driftstimer
- Ble det målt på flere lastpunkter ?
- Ble det målt HC ?
- Er installert NOx måleutstyr ombord ?

6. GASS SYSTEMET

- Oppleves tankvolum som stor nok ?
- Er det opplevd problemer med gasstilførsel ?
- I tilfelle hvilke problem ?
- Opplevd gasslekkasjer ?
- Opplevde lekkasje alarm ?
- Bunkring og prosedyre for dette, hvordan oppleves ?

7. GENERELT

- Hvordan oppleves rapporteringen ?
- NOx-faktor vekting versus aktuell driftsprofil ?
- Annet ?

NÆRINGSLIVETS NOx-fond

DNV

MARINTEK SINTEF

BRUKERERFARING – MOTORTEKNISK OMBYGGING

Brukerfaringsdataene er delt inn i 6 kategorier:

1: Tekniske data for fartøy
2: Informasjon om ombyggingsomfang
3: Effekt av ombygging
4: Vedlikehold og service
5: Måling og verifikasjon

1. FARTØYSTEKNISKE DATA

- Navn og IMO nummer på fartøy:
- Til stede:
- Fartøystype:
- Lengde / bredde / dybde riss:
- Bygget (år):
- Maskineri:
- Ytelse:
- Fuelforbruk:

2. OMBYGGING - TEKNISKE DATA

- Leverandør av ombyggningskomponenter:
- Hvem utførte ombygging:
- Ombygging foretatt:
- Omfang av ombyggingen:

3. DRIFT ETTER OMBYGGING

- Hva er maskinistenes inntrykk av den foretatte ombyggingen?
- Er motorens driftsegenskaper eller prestanda endret?
- Eventuelt andre endringer, forbedringer eller problemer?
- Var det barnesykdommer etter ombyggingen?

4. VEDLIKEHOLD OG SERVICE

- Innebærer ombyggingen endringer for motorens drift eller vedlikehold?
- Er det gitt opplæring i h.h.t. disse endringer?

- Er motorens ytelse eller forbruk endret? ?
- Er motorens avgasstemperaturer, ladelufttrykk eller partikkelutslipp endret?
- Hvordan følges motorombyggingen opp fra leverandørsiden?

5. MÅLING OG VERIFIKASJON

- Er en fornøyd med oppnådd NOx reduksjon?
- Er en tilfreds med opplegg og gjennomføring av verifikasjonsmåling, vekting av driftskondisjoner etc.?
- Har det vært eksterne måle firmaer inne senere for å kontrollere utslippsnivå?

6. GENERELT

- Rapportering til NOx-fondet, hva medfører dette for rederiet?
- Forslag til endring i rapportering?
- Synet på vekting for å beregne NOx faktor?

BRUKERERFARING – VANNTILSETNING

Brukerfaringsdataene er delt inn i 6 kategorier:

1: Tekniske data for fartøy
2: Informasjon om ombyggingsomfang
3: Effekt av ombygging
4: Vedlikehold og service
5: Måling og verifikasjon

1. FARTØYSTEKNISKE DATA

- Navn og IMO nummer på fartøy:
- Til stede:
- Fartøystype:
- Lengde / bredde / dypgående:
- Bygget (år):
- Maskineri:
- Ytelse:
- Fuelforbruk:

2. VANNTILSETNING - TEKNISKE DATA

- Leverandør av vanntilsetningsutstyr:
- Nybygg / retrofit / når installert?:
- Form for vanntilsetning, vanninjeksjon, emulsjon, HAM?:
- Omfang av ombyggingen:

3. DRIFT ETTER OMBYGGING

- Hva er maskinistenes inntrykk av aktuelt utstyr?:
- Hvem er ansvarlig for hva rundt drift av anlegget?:
- Rutiner rundt drift av anlegget?:
- Hva er sett verdier for drift av anlegget (ytelse / dellast / avgasstemperatur / annet)?:
- Bruk utenfor avgiftsbelagt område?:
- Er motorens driftsegenskaper eller prestanda endret?:
- Eventuelt andre endringer, forbedringer eller problemer?:
- Var det barnesykdommer etter ombyggingen?:
- Hvordan følges anlegget opp av rederikontor?:

4. VEDLIKEHOLD OG SERVICE

- Innebærer ombyggingen endringer for motorens drift eller vedlikehold?:
- Spesielle rutiner eller driftsproblem med vanntilsetningsutstyret?:
- Er anlegget preget av mye nedetid?:
- Er det gitt opplæring i drift av utstyret?:
- Er motorens ytelse eller forbruk endret?
- Er motorens avgasstemperaturer, ladelufttrykk eller partikkelutslipp endret?
- Hvordan følges motorombyggingen opp fra leverandørsiden?

5. MÅLING OG VERIFIKASJON

- Er en fornøyd med oppnådd NOx reduksjon?
- Er en tilfreds med opplegg og gjennomføring av verifikasjonsmåling, vekting av driftskondisjoner etc.?
- Har det vært eksterne måle firmaer inne senere for å kontrollere utslippsnivå?

6. GENERELT

- Rapportering til NOx-fondet, hva medfører dette for rederiet?
- Forslag til endring i rapportering?
- Synet på vekting for å beregne NOx faktor?
- Annet?: