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Maritime Conferences

# • The Maritime Environment •

## International Conference and Exhibition

## "Treatment Technologies for Gaseous Emissions from Ships"

18st – 19st October 1999

Holiday Inn Brussels City Centre

Brussels, Belgium

**The Conference is sponsored by:**




20010430 052



AQ F01-1418

# REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | 1999 | Conference Proceeding |

4. TITLE AND SUBTITLE

The Maritime Environment. International Conference and Exhibition. Treatment Technologies for Gaseous Emissions from Ships. 18th-19th October 1999, Brussels, Belgium.

5. FUNDING NUMBERS

**N00014-99-1-1xxx**

6. AUTHOR(S)

Multiple

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Eule & Partners
International Consulting S.P.R.L.
Leeuwerikenlan 21
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research International Field Office
PSC 802 Box 39
FPO AE 09499-0039

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

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12b. DISTRIBUTION CODE

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12. ABSTRACT (Maximum 200 words)

The conference objectives were the following: Provide a forum for discussion and information exchange on the latest technologies and alternatives for the reduction of air pollution from ships caused by exhaust gases, emissions from thermal waste treatment processes, ozone depleting substances and other greenhouse gases in the maritime environment. Discussion of national and international policies and regulations for IMO compliance and the implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry. Presentation of advanced gaseous waste treatment technologies.. The conference was divided into four session topics: Session 1 – Requirements and Policies for the Reduction of Air Pollution from Ships. Session 2 – Emissions from Thermal Waste Treatment Processes – Treatment Technologies and Alternatives. Session 3 – Reducing Ozone Depleting Substances and Other Greenhouse Gases – Impact of the Implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry. Session 4 – Exhaust Gases from Engines and Power Generators – Treatment Technologies and Alternatives.

13. SUBJECT TERMS

Air pollution; Waste management; Greenhouse effect; Ships, Agreements, Conference proceedings

15. NUMBER OF PAGES

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

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# •THE MARITIME ENVIRONMENT •

# "Treatment Technologies for Gaseous Emissions from Ships"

## Objectives of the Conference

## Conference Objectives

- The conference shall provide a forum for discussion and exchange of information on the latest technologies and alternatives for the reduction of air pollution from ships caused by exhaust gases, emissions from thermal waste treatment processes, ozone depleting substances and other greenhouse gases in the maritime environment.
- Discuss national and international policies and regulations for IMO compliance and the implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry.
- Discuss current requirements and trends for future maritime air pollution abatement standards.
- Present and discuss advanced treatment technologies, future research and adaptation of current and future technologies for ship systems.
- Devise recommendations for latest technology for shipboard and harbour applications.
- Provide recommendations to industries and governments for policies and international collaboration.

**The Conference is sponsored by:**



# Summary of the Conference on "Treatment Technologies for Gaseous Emissions from Ships" in Brussels, Belgium on 18 –19 October 1999

The International Conference on "Treatment Technologies for Gaseous Emissions from Ships" was held on 18th –19th October 1999 in the Holiday Inn Brussels City Centre, Brussels, Belgium.

The Conference had been initiated and was organized by Eule & Partners International Consulting SPRL, Tervuren, Belgium.

**The Conference was sponsored by the US Office of Naval Research Europe (ONR Europe) in London, UK.**

ONR Europe is committed to fostering and facilitating collaboration in Science, Technology, Research and Development between the United States and their professional counterparts in Europe, Africa and the Middle East. ONR Europe liases with international scientists and engineers through conferences, workshops, visits and personal research to identify key opportunities in S&T, to assess S&T activities and accomplishments and to exchange information and ideas in areas of mutual interest.
ONR Europe is based in London.

The Conference objectives were the following:

- The conference should provide a forum for discussion and exchange of information on the latest technologies and alternatives for the reduction of air pollution from ships caused by exhaust gases, emissions from thermal waste treatment processes, ozone depleting substances and other greenhouse gases in the maritime environment.
- Discussion of national and international policies and regulations for IMO compliance and the implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry.
- Discussion of current requirements and trends for future maritime air pollution abatement standards.
- Presentation and discussion of advanced treatment technologies, future research and adaptation of current and future technologies for ship systems.
- Recommendations for latest technology for shipboard and harbour applications.
- Recommendations to industries and governments for policies and international collaboration.
- Exhibition of gaseous waste treatment technologies applicable to ship board employment.

50 Experts in this area from 11 different Nations (Belgium, Canada, Denmark, France, Germany, Netherlands, Norway, Poland, Sweden, the United Kingdom and the United States) attended the conference. They represented the whole range of interested groups in this field, i.e. Cruise Lines and Shipping Industry, Shipyards, Navies, System Engineering Companies, Equipment Manufacturers, Port and Regulation Authorities.

The Conference was organized in four Sessions:

Session 1 – **Requirements and Policies for the Reduction of Air Pollution from Ship**
Session Chairman *Capt. Cornelius de Keyzer,* Rotterdam Port Management, NL

Session 2 – **Emissions from Thermal Waste Treatment Processes - Treatment Technologies and Alternatives**
Session Chairwoman *Dr. Fiona Winterbottom,* AEA Technology, UK

Session 3 – **Reducing Ozone Depleting Substances and other Greenhouse Gases - Impact of the Implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry**
Session Chairman *Dipl.-Ing. Volker Behrens,* NOSKE-KAESER, GE

Session 4 – **Exhaust Gases from Engines and Power Generators - Treatment Technologies and Alternatives**
Session Chairman, *Dr.Peter Sunn Pedersen,* MAN B&W Diesel A/S, SE

**The keynote address was presented by Dr. Keith L. Gardener, Deputy Assistant Secretary General for Scientific and Environmental Affairs, NATO,** offering some insight into the methods and benefits of "Expert Networking in NATO". The conference noted that this subject had a much broader relevance than only for the NATO environment. Actually this conference was seen as providing just the kind of networking addressed by Dr. Gardner. The key benefits of such networking were a durable relationship amongst the experts and increased visibility of the subjects being dealt with.

The conference discussed the implementation of the MARPOL Annex VI. Although nations have recognised that global implementation will still take some years, several nations (e.g. USA, Australia, Japan) and alliances, like the European Union, have put regulations in place that actually implement the Annex VI goals far earlier. The implementation process and its compliance by ship owners is being supported by incentives, like variable harbour fees.

The Crude Oil Industry is already producing compliant low sulphur fuel and the Engine Manufacturers have developed more efficient and economical engines in accordance with the Annex VI goals. Industry is further improving engine efficiency through technology developments of exhaust treatment equipment. The Classification Societies have put verification and certification processes in place.

The result is that, although MARPOL Annex VI has not yet been implemented, industrialised nations have realised the importance of measures against global warming and further depletion of the ozone layer that they have started to adhere to the values set by Annex VI and even become more restrictive in certain areas.

The Port Authorities who would have to guard and enforce compliance have conducted a worldwide inquiry to evaluate where and how ports would be affected by the implementation of MARPOL Annex VI. They have found that a selective implementation by individual Port States would have a negative economical impact on those ports and would reduce their competitiveness with others who were not implementing Annex VI. They feel that the implementation needs to be simultaneous worldwide and also that further studies are needed to investigate the technical implications for ports.

Regarding the treatment of exhaust gases and odors two interesting technologies were presented, i.e. non-thermal plasma treatment and bio technical filtration. Both technologies are currently undergoing a demonstration phase.

The very interesting series of presentations continued addressing reduction and replacement of ozone depleting substances and global warming. Significant research and technology has gone into the replacement of CFCs for refrigeration. Technology is well advanced in this area. The replacement of HALON for fire suppression is still a challenge, as is the simultaneous reduction of $CO_2$ causing the global warming effect.

A large part of the conference was devoted to the discussion of $NO_x$ reduction of engines.

Meanwhile mature technologies to reduce $NO_x$ internally to the engine are available, e.g. Low $NO_x$ nozzles for fuel injection and water injection techniques and engines have been built, tested and operated with these technologies. Further reduction has been reached through the application of exhaust gas treatment using a Selective Catalytic Reactor and scrubbers.
Also the very interesting approach to humidifying the intake air in the Humid Air Motor concept was presented generating a higher degree of efficiency in reducing $NO_x$. This technology uses sea water which is pre heated by excess heat from the motor to saturate the intake air with water vapour before being injected in the motor again.

Reduction of $SO_2$ (by 90%) and soot (by 80%) has been tested through after-treatment of engine exhaust using a pilot wet scrubber. Full trials will be conducted in the near future.

All presentations have demonstrated that technologies in these areas are operational, however it was noted that ship owners will only introduce these measures if they are forced to do so, as these technologies just cost more money.

Thus one of the main conclusions of the conference was that the implementation of these technologies and the enforcement of Annex VI values have to be assessed very carefully. It has to resolve the conflict and find a compromise between the necessary environmental goals set out in Annex VI, the application of technology to meet these goals and the economics to implement them in an economically highly sensitive and competitive global environment.

But the conference has also shown that we are on the move to achieving that goal for the preservation of our maritime environment.

Being at the end of this conference I would like to thank the Chairpersons of the Sessions for their guidance and contribution to very interesting discussions.

Further thanks go to our Sponsor the US Navy Office of Naval Research represented by its Assistant Director, Dr Igor Vodyanoy, for its support of the conference.

Finally I would like to express my thanks to my Partner, Mrs. Elke Lonicer, who has made a major contribution to the preparation and the smooth running of this conference.

Organizationally and socially the conference worked well. The Holiday Inn Brussels City Centre in Brussels offered very good conference facilities and support.

The Participants also used the conference extensively to conduct business discussions.

In summary the conference was very well received by the Participants, who expressed their desire, to take part in future conferences in the area of environmental technologies for ships and other maritime applications.

## Keynote Address
## DR. KEITH L. GARDNER

Ladies and Gentlemen,
I am very proud to announce that our conference will be opened by the keynote address of the Deputy Assistant Secretary General for Scientific and Environmental Affairs, NATO HQ,
by Dr. Keith Leroy Gardner.

Dr. Gardner studied physics at the Brigham Young University, University of Southern California and at the University of Arizona.

He worked as civil servant at the Naval Weapons Centre, China Lake, California, for 15 years before he joined NATO HQ Brussels in 1985.
He served as Staff Officer and Head of the Defence Research Section.

In July 1998, Dr. Gardner was named as the Deputy Assistant Secretary General for Scientific and Environmental Affairs. In this position, he has been involved in the development of the new structure for the NATO Science Programme, approved by the North Atlantic Council in November 1998.

Dr. Gardner is a member of the Sigma-Xi Physics Society. He is the author of a number of technical reports, and is the holder of seven patents.

Dr. Gardner, we are very happy that you are here and we feel honoured that you will open this conference.

# Expert Networking in NATO

*Dr. Keith L. Gardner*
*Deputy Assistant Secretary General for Scientific & Environmental Affairs*
*18 October 1999*

# The Content

- What do we mean by "Networking in NATO"?
- Opportunities and benefits
- Limitations
- Costs and commitments
- Conclusions

# NATO Expert Networks (1 of 2)

- Task-oriented associations of experts from different nations
  - Knowledge exchange in groups and workshops
  - May conduct cooperative projects
- Under NATO legal umbrella
- Using NATO support structure
  - Groups
  - Staff support
  - Publication and organizational resources

# NATO Expert Networks (2 of 2)

- Voluntary participation by nations and individuals
  - Self-funded
  - Bottom-up process in most cases
- Characterized by close international linkages based on trust
  - Extremely durable relationships
  - Foundation for closer national linkages
- NATO bodies fostering expert networking
  - CNAD Main Groups (MAGs and RTO)
  - CCMS

# Opportunities & Benefits (1 of 2)

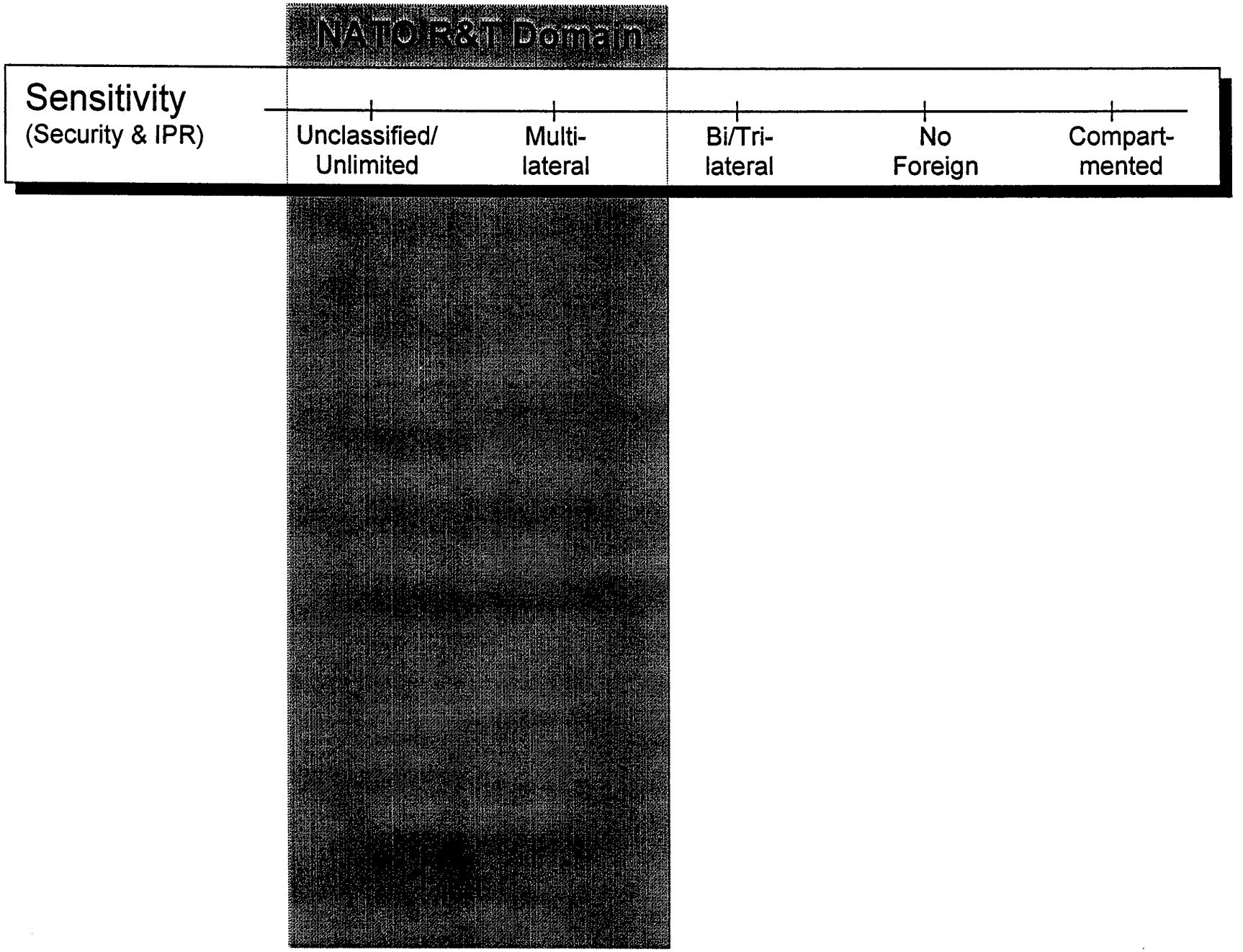
- Rapid response network for addressing problems
- Synergy
  - Whole is greater then parts
- Visibility
  - International activity provides added weight
- Vertical connectivity
  - NATO's "steep ladder"

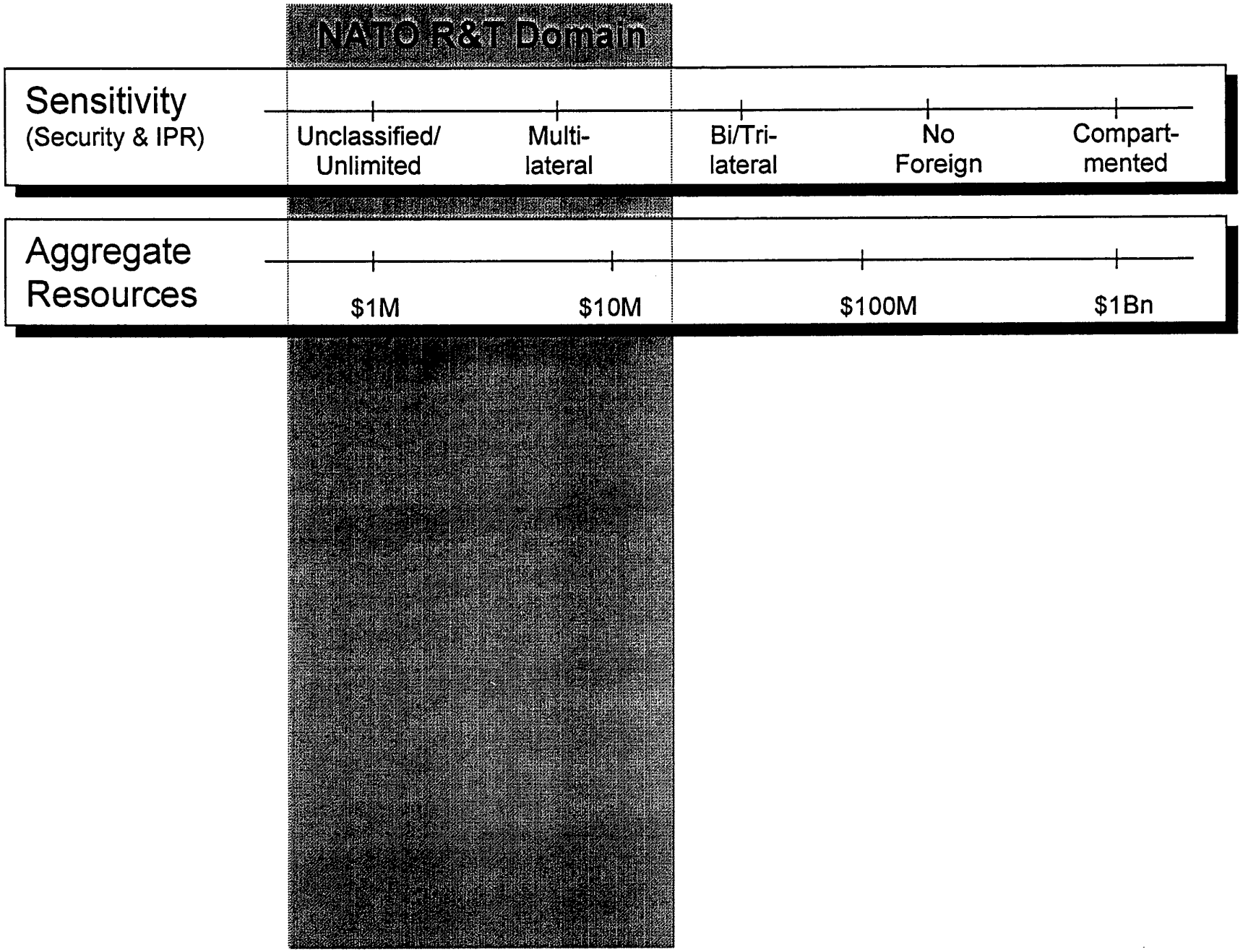
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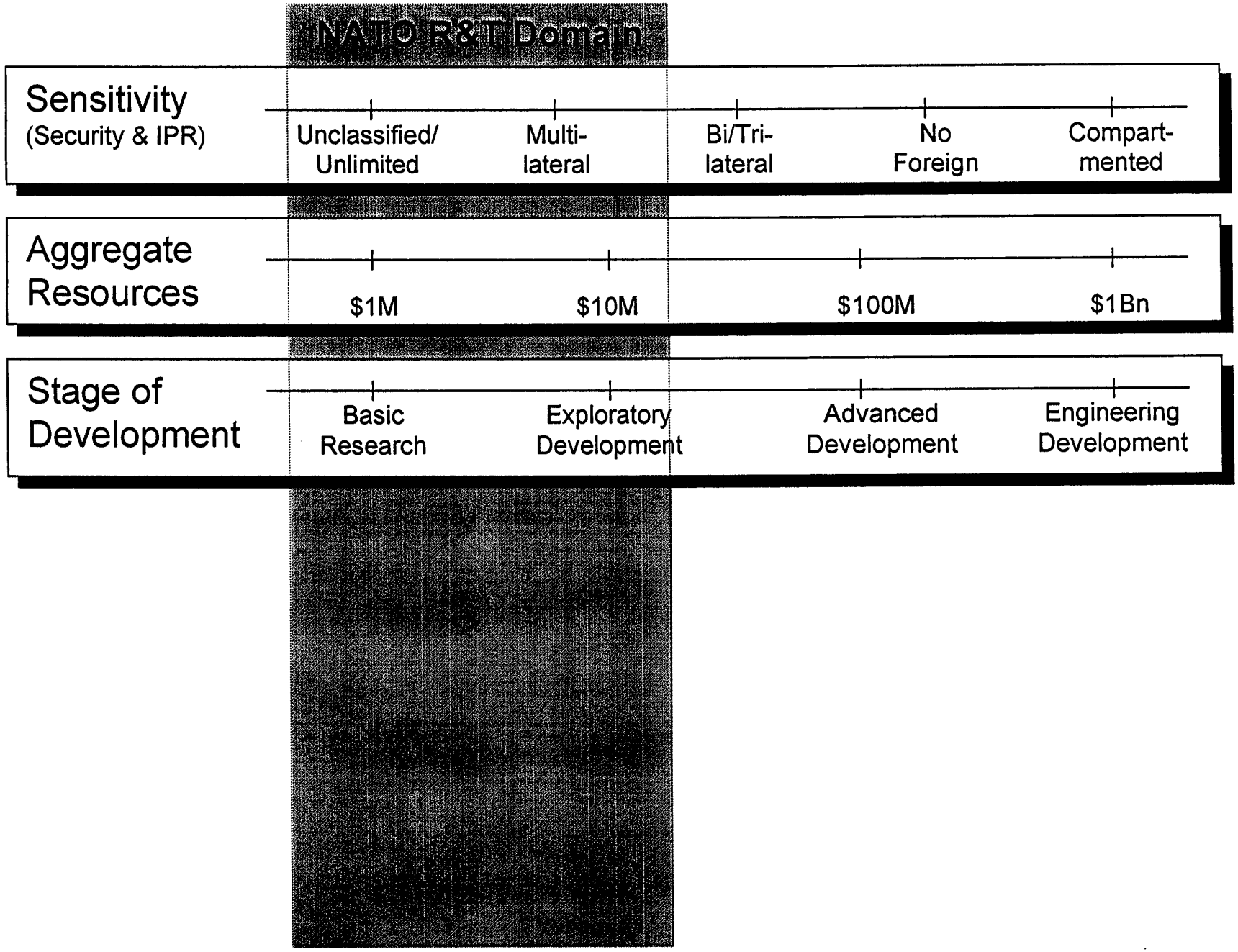
- Environment for free and open exchanges
  - No competition among participants for national funding
- Fertile ground for generating new activities
  - Both inside and outside NATO
    - Bi-lateral arrangements
- Opportunities for Alliances
  - Among NATO groups
    - SWG/12 and CCMS
  - With other national and international groups

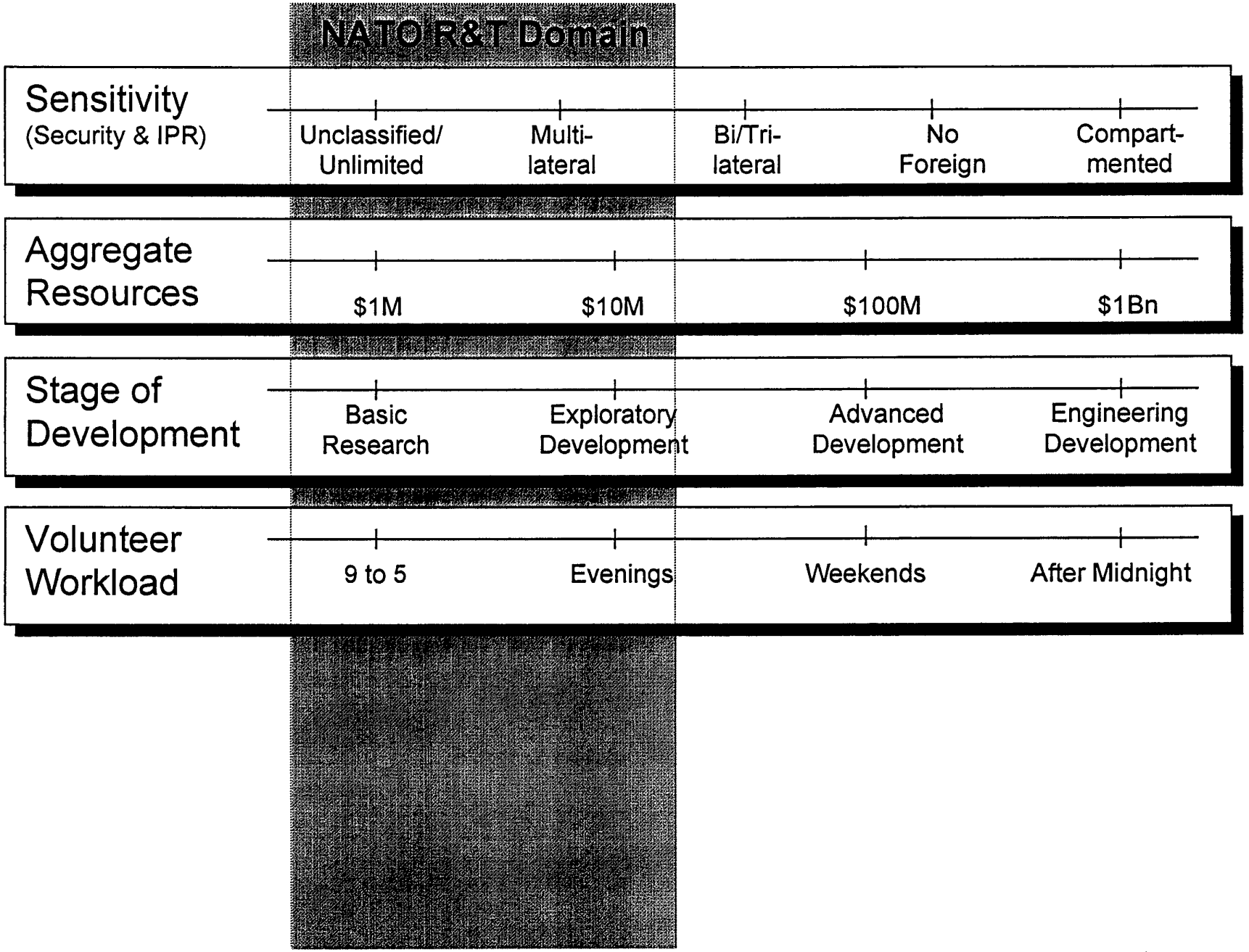


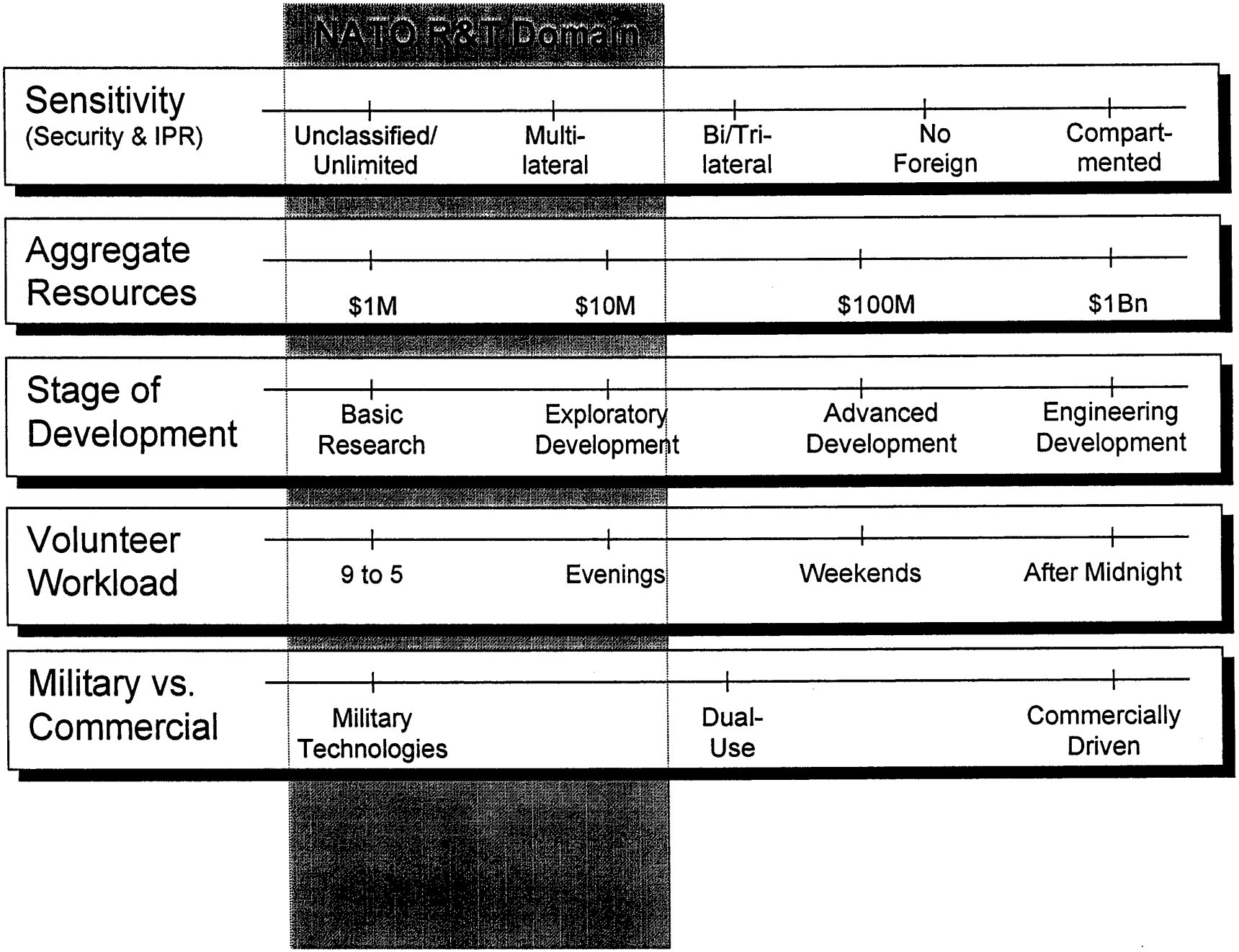

NATO SST ARW --- Novosibirsk, Russia, Sept. 1999 (Bioweapon Defence)

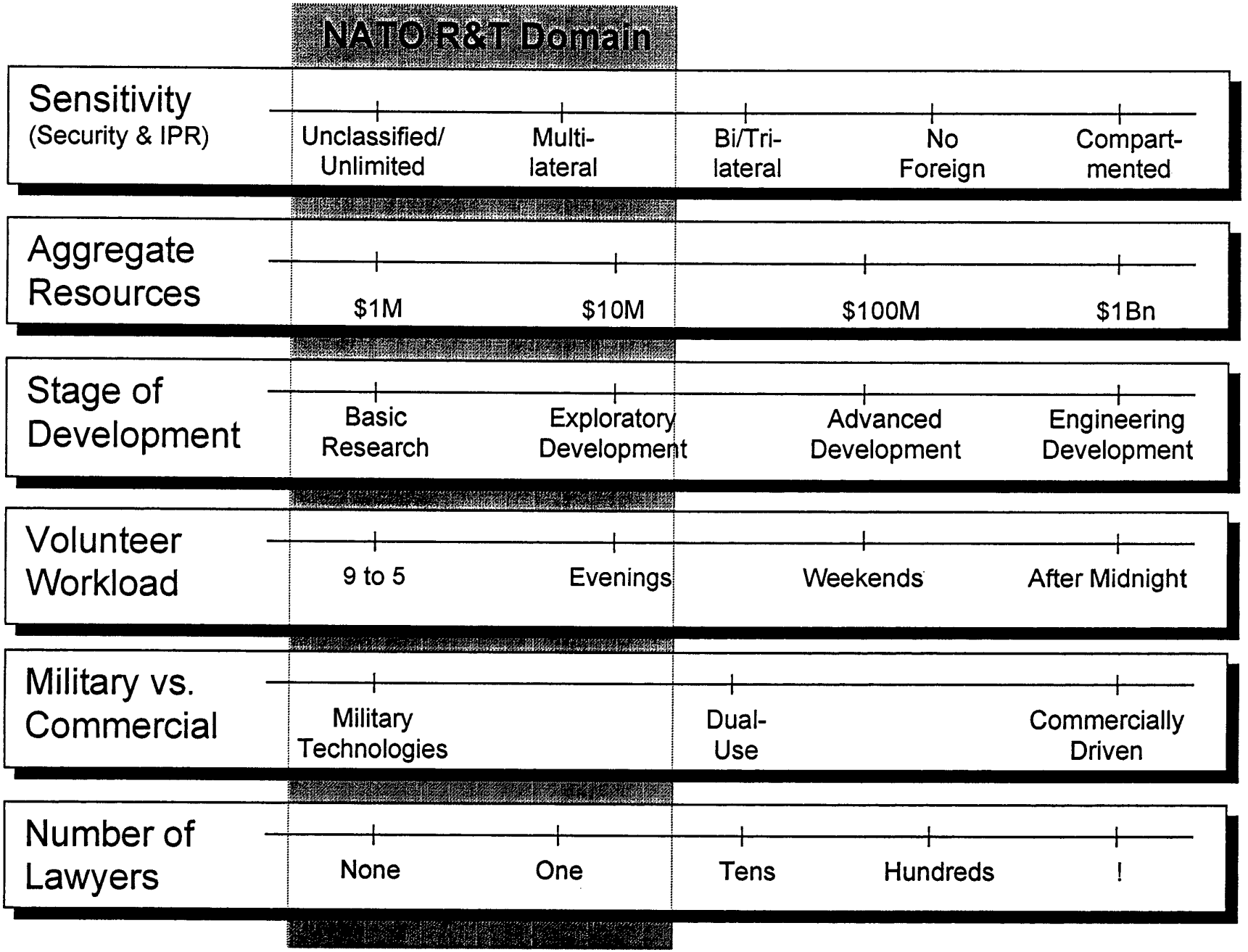

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NATO R&T Domain
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Stage of Development
Basic Research
Exploratory Development
Advanced Development
Engineering Development
Volunteer Workload
9 to 5
Evenings
Weekends
After Midnight


NATO R&T Domain
Sensitivity
(Security & IPR)
Unclassified/ Unlimited
Multi-lateral
Bi/Tri-lateral
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Compart-mented
Aggregate Resources
$1M
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9 to 5
Evenings
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After Midnight
Military vs. Commercial
Military Technologies
Dual-Use
Commercially Driven


NATO R&T Domain
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$1Bn
Stage of Development
Basic Research
Exploratory Development
Advanced Development
Engineering Development
Volunteer Workload
9 to 5
Evenings
Weekends
After Midnight
Military vs. Commercial
Military Technologies
Dual-Use
Commercially Driven
Number of Lawyers
None
One
Tens
Hundreds
!

# Costs & Commitments

- Nations must provide their "best" people
  - For cooperative projects: long-term commitment
- Participants and supervisors must secure resources
  - Can require considerable effort in some countries
- Disciplined fulfillment of commitments
- Periodic heavy workload
- NATO must provide a minimum level of full-time support

# Conclusions

- NATO networks can be of great benefit to the participating nations and individuals
  - Durable fora for stimulating ideas and activities
  - Knowledge exchange
  - Increased visibility and impact
- Need to concentrate most efforts within domain of practicality
- Requires a level of sacrifice by participants
- Need to give credit to the NATO networks
  - Provide NATO staff with examples of "successes"

# Experiences from the Swedish incentive scheme on NOx and SOx-emissions from ships

**Stefan Lemieszewski**
**Head of Environment Division**
**Maritime Safety Inspectorate**

The Swedish Maritime Administration would like to bring the following information to the attendees of the conference on the so far gained expencience on the application of the incentive scheme to reduce emissions of SOx and NOx from ships calling upon Swedish ports. Sweden introduced from the 1st of January 1998 the voluntary incentive scheme of environmental differentiated fairway and port dues.

As until the 1st of November 1999, 1335 ships have attested their continuos operation on only low sulphur fuel and become registered in the scheme, for ferry's less than 0,5 % S m/m and cargo ships less than 1,0 % S m/m. A control program is at hand for random sampling of the fuel oil in all tanks of the controlled ships. As a condition high sulphur fuel is not allowed to be kept in any fuel tanks onboard. Only a few offenders have so far been caught.

As from effective NOx-reducing measures 11 ships mainly of high power output have become certified for various emissions levels between 10 and 0,5 g NOx/kWh. Some 40 ships are known to be in the process of installing SCR catalysts. Also other technologies are applied such as HAM and Direct Water injection. The reason for this rapid development is the incentive scheme in combination to market forces out of environmental competitiveness and the restitution from paid fairway dues by the Swedish Maritime Administration. This until the ending 31st of December 1999 40 % of the investment cost is covered within a 5 year period. From 1st of January year 2000 until 31st of December year 2001 30 %, and from year 2002 0 %. This restitution is possible to gain for any ship regardless of flag provided it is calling at Swedish ports.

The incentive scheme has so far shown to be extremely effective. According to the gentlemen's agreement between the Swedish shipowner association and the Swedish Maritime Administration and the Swedish Harbours and Stevedoor association the goal was set at a 75 % reduction of NOx as well as SOx, until year 2003. Basis year for SOx was 1990 and for NOx year 1995. A rough estimation shows that so far around 60 % reduction of SOx have been achieved and from ongoing installations of effective NOx reducing measures a reduction of NOx by around 40 % may be achieved by the end of year 2000. However, reduction achieved until the end of 1999 based on the consumption of urea (reducing agent) is some 3500 tons NOx reduced.

Norway will likely introduce a differentiation scheme from year 2000 pending on a final political decision and also the autonomous islands of Åland, a part of Finland will do likewise.

The European union DG VII and DG XI have jointly assigned a consortium of consultants to carry out a feasibility study on the implication and consequences of applying i.a. the Swedish incentive scheme in the entire European union. This study was announced to the finalised in the beginning of October 1999.

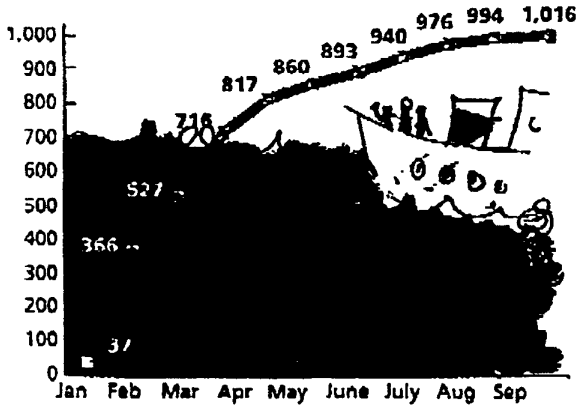
The Swedish Maritime Administration has been very active to internationally inform on this way of dealing with ships related environmental problems with the aim of having followers due to the extreme cost-effectiveness of measures taken in ships compared to elsewhere in transportation and industry.

Also the EPA of U.S. and representatives from Canada has shown interest.

The aim of Sweden is to initiate a proliferation in other nations of this measure making investments in emission reduction technology worthwhile from point of economics to the ship owners.

Achieved results are more than promising and substantial emission reduction is achieved at a minimum of cost to the society. The system is in addition decent to handle from administrative point of view. By incentives shipping are in the position to become the entirely outstanding means of transport from environmental point of view in a few years of time.

**Number of vessels using low sulphur oil**




## THE TRIPARTITE AGREEMENT

The Swedish Maritime Administration, the Swedish Shipowners' Association and the Swedish Ports' and Stevedores' Association made a principle agreement in April 1996 to employ vigorous measures in order to decrease ship generated air pollution, particularly in the form of emissions of nitrogen oxides and sulphur. The parties to the agreement set as a goal that these emissions should be decreased by 75% by the beginning of the next century.

In order to reach this goal, the parties agreed to apply economic incentives in the form of environmental differentiated fairway and port dues. Reduced dues would primarily stimulate the ferry traffic and other frequent maritime traffic to and from Sweden, regardless of the ships' flag state, to take measures which would benefit the environment, such as using catalytic converters or making other technical improvements, which would decrease the nitrogen oxide emissions and promote the use of low-sulphur bunker fuel.

## THE NEW FAIRWAY DUES

The environmental differentiated fairway dues, which has entered into force from 1 January 1998, comprises a two-part fee, which supersedes the current light dues and fairway dues on goods. One portion, which corresponds to the previous light dues is based on the size of the ship, computed on the gross tonnage. The other portion is based on the volume of cargo being transported by the ship and corresponds to the previous fairway dues on goods. The portion being based on the gross tonnage is environmentally differentiated according to the ships' emissions of nitrogen oxides and sulphur.

The level of the new fairway dues will be such that it will result in the same total cost of shipping to and from Swedish ports as earlier. There will be no general increase in incomes received from the fairway dues. There will, of course, be a distinction between individual ships, so that ships which have taken environmentally protective measures will be charged reduced dues, while ships with higher emission levels will pay higher dues. This is the whole idea of the differentiation and means that the polluter pays principle is applied.

That portion of the fairway dues which is based on the size of the ship measured as the gross tonnage will be charged a maximum of 12 times per year for a cargo ship and 18 times per year for a passenger ferry or a railway ferry.

## ENVIRONMENTAL DIFFERENTIATION

The environmental differentiation means that the ship based portion of the fairway dues is differentiated according to the ship-generated emissions of nitrogen oxides and sulphur. If the level of emitted nitrogen oxides is 12 g/kWh or more the dues for tankers carrying a cargo of mineral oil products in bulk will be SEK 5.30 per unit gross tonnage, and for other ships SEK 5.00. If the level of emissions is lower, the dues will be rebated, so that a ship which has attained an emission level of a maximal 2 g/kWh will be billed SEK 3.70 or SEK 3.40 respectively. Dues for other degrees of cleansing will be rebated according to a linear scale.

An oil tanker carrying a cargo of mineral oil products in bulk which has attained an emission level of maximum 2 g/kWh will be charged a maximum amount of SEK 100,000. Following a linear scale, with an increasing rate of SEK 6,000 per g/kWh, the amount for an emission level exceeding 12 g/kWh will be SEK 160,000. For other vessels the amounts are SEK 60,000 and SEK 100,000 respectively with an increasing rate of SEK 4,000 per g/kWh.

In order to encourage the installation of catalytic converters, which give the highest degree of purification, the Swedish Maritime Administration will reimburse the fairway dues being paid for a five year period. The cost of installations, which qualify for the reimbursement, can be as high as 40% of the investment cost if catalytic converters are installed before the year 2000, and up to 30% for installations thereafter.

In addition to differentiating the fairway dues according to emission levels of nitrogen oxides, the ship will be given an additional rebate of SEK 0.90 per unit of the ships' gross tonnage, if the sulphur content of the bunker fuel is lower than 0.5 percent of weight for passenger ships and 1.0 percent of weight for other ships.

## DIFFERENTIATED PORT DUES

About 20 Swedish ports have already introduced rebates in their dues, based on environmental meassures regarding NOx and sulphur reductions.

# Incentives to boost environmental shipping

AFTER ONE YEAR of environmentally differentiated shipping dues, 1,100 vessels have attested guarantees that they are only using oil with a low sulphur content in their traffic on Sweden. "This is more than twice the number we had calculated for during the first year," Stefan Lemieszewski

TRANSPORT

says, Head of Environmental Affairs at the Swedish Maritime Administration.

Measures for nitrogen oxides reduction are also being developed. Three major passenger ferries and three cargo vessels that carry goods for the forest industry have been certified for nitrogen oxides reduction. Three more forest company vessels, some passenger ships and two vessels that will transport cargo for Volvo, are next in line.

The less air pollution a vessel can prove it emits, the lower the fairway and port dues it has to pay. For the cleanest vessels, this can be a matter of halving their dues. For those that install catalytic nitrogen oxide reduction (SCR), investment subsidies are also available. This is regardless of nationality of the ship.

"This is truly cost-effective environment measures. The environmental benefit of reducing nitrogen oxides emissions is estimated at about SEK 40 (EURO 4.3) per kilo. The total cost for vessels to reduce their emissions of nitrogen oxides by one kilo is only between SEK 3 and SEK 7.5", Mr Lemieszewski points out.

The European Commission is currently in the process of compiling an impact assessment on how these incentives would affect transport and trade if applied in the Baltic, the North Sea, the Mediterranean and the North-East Atlantic.

"The incentive scheme is neutral as regards competition. It is therefore both politically and practically more easy to implement this kind of economic instrument than to develop viable and strict common rules. Strictly regulated emission limits might be unfair to a country's own fleet compared to vessels from other countries which will not have to face the same demands", Stefan Lemieszewski states.

The differentiated fairway dues entered into force on 1 January 1998. There is no general increase in total income received from fairway dues, but of course there is an distinction between individual ships.

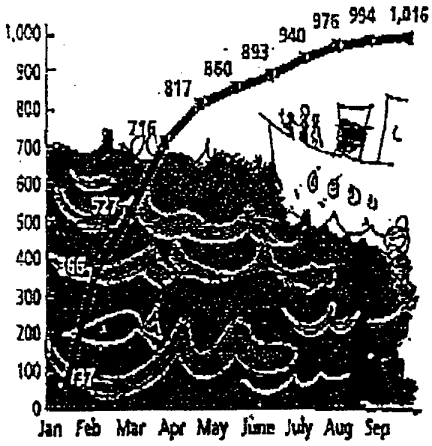
Fairway dues drop from SEK 5 to SEK 4.10 per unit gross tonnage for vessels that operate on only low-sulphur oil (Maximum 0.5 per cent sulphur content in ferries and maximum 1 per cent in cargo vessels). With also the most efficient nitrogen oxide reduction measures applied and verified, the dues fall to SEK 2.5 per gross tonnage.

"Port dues bring in about four times as much income as fairway dues. Until now, about half of Sweden's 52 ports have introduced or are in the process of introducing environmental differentiated harbour dues, and the rest will most likely follow suit in the very near future," Mr. Lemieszewski says.

## New technologies are being tested

As an additional incentive, there is an investment subsidy for those who install catalytic nitrogen oxide reducing equipment and qualify before year 2000. This is equivalent to 40 per cent of the installation cost, in the form of reimbursement of fairway dues. Two years thereafter, the reimbursement will be equal to a maximum of 30 per cent of the installation cost. From year 2002 there will be no investment subsidy. The reimbursement is independent of the ship's nationality, but frequent visitors to Swedish ports will of course be reimbursed more quickly.

Number of vessels using low sulphur oil




The most commonly used technique so far, selective catalytic reduction (SCR), reduces nitrogen oxides emissions by up to 80-95 per cent using urea as a reducing agent. The costs for urea are equivalent to1-2 per cent of fuel costs, depending on engine factors. The HAM-technique (Humid Air Motor) is also currently being adapted to fit marine vessels and reduces emissions by 50-80 per cent, using seawater and with no increased running costs.

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Swedenvironment

Swedenvironment (SE), with environmental news and views from Sweden, is a joint publication from the Ministry of the Environment, the Environmental Protection Agency and the National Chemicals Inspectorate in Sweden.

Swedenvironment is published bimonthly both in printed form and on the Internet, www.swedenvironment.environ.se

For free subscription by e-mail, comments and further information, please mail us at Swedenvironment@environ.se or write to us at Swedenvironment, Swedish Environmental Protection Agency, SE-106 48 Stockholm, Sweden.
Editor: Katrin Hallman ISSN 1403-4735

SWEDAC
magasinet

En tidskrift från SWEDAC, Styrelsen för ackreditering och teknisk kontroll

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# Sweden leads the world in environmental work at sea

PAGE 8-9

Sweden is one of the countries that have come furthest in the world in reducing emissions at sea. One of the methods by which this has been achieved is the use of the new environmentally-differentiated channel fees that were introduced at the beginning of 1998. Their effect is that, for example, by installing modern flue gas cleaning equipment, an ordinary Finland ferry can save over SEK 150 000 each time it enters harbour.

Emissions of NOx and sulphur from the diesel engines of cargo and passenger vessels presents a serious environmental problem at sea and on land.

– The emissions are carried a long way by the wind. In an average wind speed of 10 m/s, nitric oxide has a half-life of 30 hours and sulphur has a half-life of 30 hours. Emissions on the North Sea have repercussions as far north as the Kola Peninsula, says Stefan Lemieszewski, the National Maritime Administration's environmental manager.

## Serious in Scandinavia

– The acidification problem is particularly serious for us in Scandinavia. Most of the countries consist of igneous rocks which, being difficult to dissolve, provide no help in neutralising acid precipitation.

Work is in progress at the international level on tackling these sources of air pollution. But, says Stefan Lemieszewski, the agreements that have been reached so far are ineffective.

– The 4.5 % by weight limitation for sulphur in marine fuels, agreed in the international MARPOL framework, is completely meaningless, bearing in mind that the average sulphur content of present-day marine fuels is 2.9 %.

Sweden has therefore decided unilaterally to go a step further, through the agreement on environmentally differentiated channel fees reached between the National Association of Shipowners, the Harbour Workers and Stevedores Association and the National Maritime Administration. This new system of fees, which was introduced at the beginning of the year and which applies to all cargo vessels and ferries entering Swedish harbours, has already meant that over 1000 vessels have changed to the use of low-sulphur fuel.

– A qualified forecast, based on current and planned activities in the shipping sector, shows that emissions of NOx from vessels in the Baltic and the North Sea travelling to or from Sweden will be reduced by about 20 000 tonnes by the end of the century, explains Stefan Lemieszewski.

The economic incentives incorporated in the system provide an important explanation for the successes that have been achieved. Shipowners can save considerable sums by changing to low-sulphur oil and by installing new technology such as selective catalytic cleaning, which reduces the emissions of NOx.

Vessels that have taken no action at all have to pay a charge of SEK 5 per gross register tonne (a measure of volumetric capacity, equivalent to 2.5 $m^3$). The use of low-sulphur fuel, containing not more than 0.5 % (for ferries) or 1.0 % (for cargo vessels) of sulphur by weight, reduces the charge by 90 öre.

Installing equipment that reduces emissions of NOx to less than 12 g/kWh reduces the charge by a further SEK 1:60. In total, therefore, the original charge can be halved. This means that, for example, a Finland ferry of 65 000 grt saves over SEK 150 000 each time it enters a Swedish harbour. However, a maximum ceiling to the reductions has been introduced, equivalent to 18 entries per year for ferries or 12 for cargo vessels.

Not only do the channel fees fall in step with the reduction in emissions, but vessels that install catalytic flue gas treatment also receive a refund of their channel fees amounting to up to 40 % of the investment cost of catalytic cleaning equipment (30 % after 2000).

## A profitable investment

– There's no question that investing in environmental technology doesn't pay. The rule of thumb in Swedish industry is that all investments below about SEK 40-45 per kilogram of reduced NOx emissions are profitable. The investments that we're talking about here within shipping cost only about SEK 3:50-7:00, says Stefan Lemieszewski.

Not surprisingly, the Swedish system of differentiated channel fees has aroused considerable international interest. The EU Commission, for example, has issued a preliminary call for tenders for a consequence analysis of the application of similar systems throughout the Baltic, the North Sea, the Northeast Atlantic, the Irish Sea and the Mediterranean.

– Bearing in mind how cost-efficient the system is, there can't be much doubt about the conclusions that will be drawn from the analysis, says Stefan Lemieszewski.

## *Analysis requires accreditation*

One of the requirements for a reduction in channel fees is that the sulphur analysis has been performed by a laboratory accredited by SWEDAC. This applies also to the measurements of NOx emissions, which have to be repeated every three years. It is expected that about five companies will be accredited for this work by the end of the year.

– Those who are accredited are mainly laboratories that have already been accredited for some years for measurements in accordance with the Environmental Protection Agency's regulations for NOx emissions from combustion, explains Mats Hansson, of SWEDAC's Chemical Technology Division in Borås. However, the accreditation requirements differ in that the calibration requirements for the equipment are stricter in the National Maritime Administration's regulations. In addition, the National Maritime Administration regulations specify the exact method of analysis that is to be used.

– SWEDAC is planning a round robin comparison within this sector. We shall be sending out a calculation example, with given input data, to check the quality of the laboratories' measured results, says Mats Hansson.

## *Measurements can take several days*

IVL, the Swedish Environmental Research Institute, possesses one of the laboratories accredited for the measurement of NOx emissions in accordance with the National Maritime Administration's new regulations. The measurements are made at sea, and can take from half a day to up to two weeks, depending on the extent of the work, says David Cooper, IVL's project manager.

– We follow the international ISO 8178 standard and the IMO's NOx technical code. In some cases, the work may involve just a simple indicative measurement of NOx emissions at a given engine load, while in other cases it may involve a considerable amount of work, such as performance testing of selective catalytic cleaning, with measurements being made on different engines at different loads.

IVL started with marine measurements in 1989. According to David Cooper, they have played a considerable part in reducing emissions, not least by providing a basis on which the right decisions could be made.

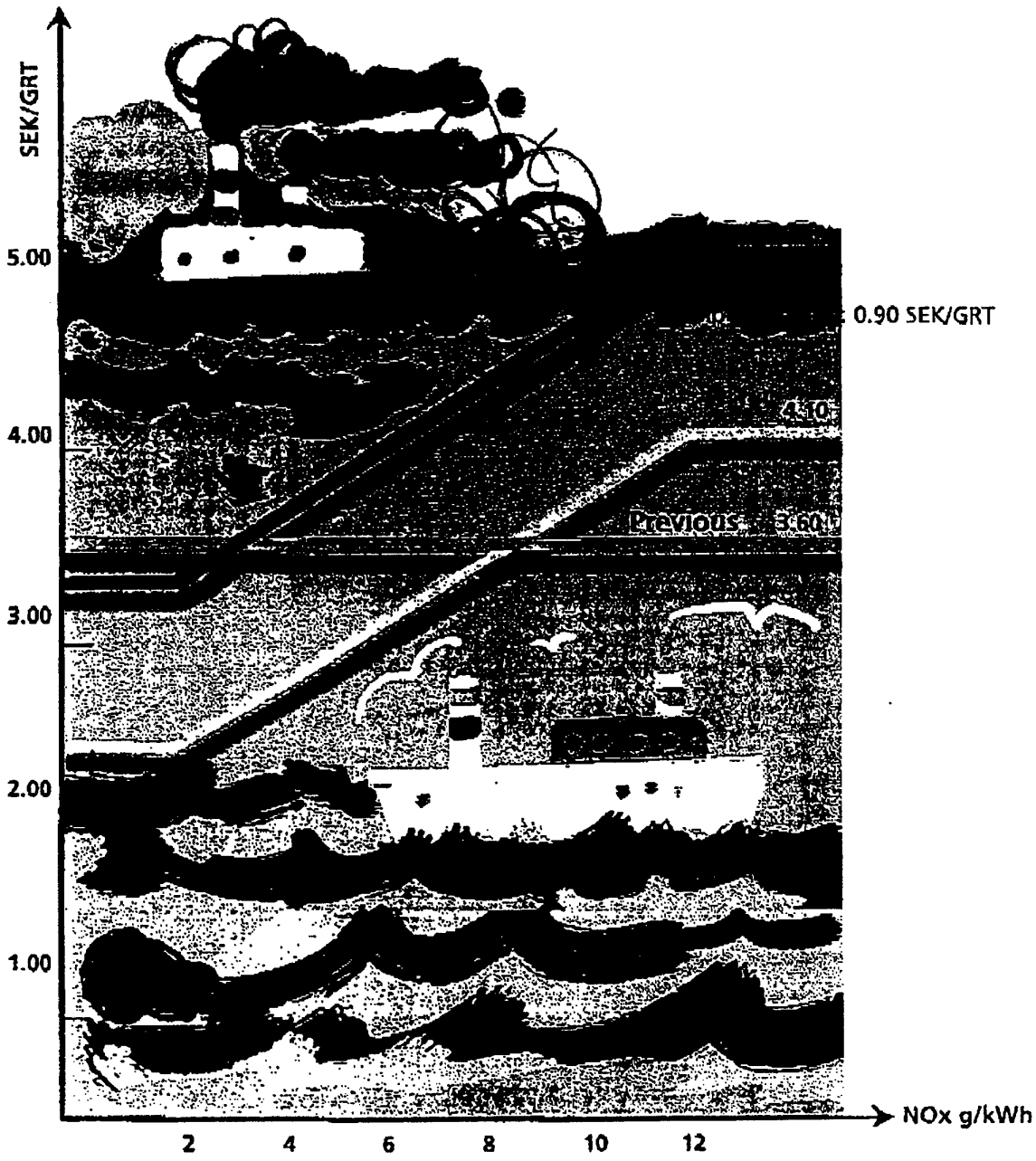
– Much has happened in the shipping sector since we started. There's new technology for reducing NOx emissions, an ISO standard on how to make the measurements and various national regulations.

David Cooper is in favour of the new system with differentiated channel fees:

– It's good to know that something radical is finally being done in order to deal with emissions at sea.

# $NO_x$- and S-rebate

## Ferries and other vessels




**SCR-TECHNIQUE**
SCR (Selective Catalytic Reduction) reduces NOx-emission up to 80–95% by using urea. This method require low sulphur bunker oil of good quality and exhaust temperature above 300° C. There will be no increased oil consumption. The method requires investment in installations and increased running costs due to the urea consumption.

**HAM-TECHNIQUE**
HAM-technique (Humid Air Motor) prevents the production of NOx during the combustion through adding water steam to the engine's combustion air. The method is insensitive to the oil quality and the engine's work load. Sea water can be used for the process and NOx-reduction will be between 50 and 80%. There will be no increased fuel consumption. The method requires investment in installations, but very limited increased running costs.

**WATER INJECTION**
Water injection in the combustion room prevents and reduces NOx-emission with 20–50%. The method requires rebuilding of the engine and fresh water without salt. Increased fuel consumption occurs in proportion to the NOx-reduction. The system is today technically complicated.

**WATER EMULSION**
Water emulsion in the fuel prevents the production of NOx. The method needs simple installation but can cause problems with quick stop and manouver. Stability problem with water/oil emulsion requires special measures. The method increases fuel consumption at higher NOx-reduction levels. The method is insensitive to

# • The Maritime Environment •

## "Treatment Technologies for Gaseous Emissions from Ships"

## Session 1

### Requirements and Policies for the Reduction of Air Pollution from Ships

**Session Chairman:** *Capt. Cornelius De Keyzer*, **Rotterdam Port Management, NL**

Chairman Session 1
Captain Cornelius de Keyzer

Ladies and Gentlemen,
I am very happy to welcome the Chairman of the Requirements and Policy Session: Captain Cornelius de Keyzer.
He is well known to many of us. For those who meet him the first time I should like to explain that Captain de Keyzer has been involved in the shipping business for 35 years. After graduating from the Nautical Academy Rotterdam he went to sea on Dutch, Liberian and Canadian merchant ships. After 11 years he signed off and joined Furness Shipping Agency as marine cargo superintendent and liner manager.

In 1974 he exchanged private enterprise for public service and was 13 years involved in vessel traffic- and port control management at Pilot Maas, Europoort and the Harbour Co-ordination Centre respectively.

Since 1987 he is working for the Port of Rotterdam. Today he is holding the position of a (senior) advisor Nautical, Safety & Environmental policy for the Directorate Shipping of the Rotterdam Municipal Port Management.

Capt. de Keyzer is also assigned bunker-coordinator for the RMPM. In 1996 he was elected a counsellor of the IBIA, the International Bunker Industry Association.

Welcome again!

Captain de Keyzer is going to present his paper:
Air Pollution and the EROS Demand for Shipping
"To be reduced and how to be reduced"
Global, EU wide, Regional, National and Local

# Air pollution and the EROS demand for shipping

## "To be reduced and how to be reduced"

Global, EU wide, Regional, National and Local


**Capt. Cornelius de Keyzer**

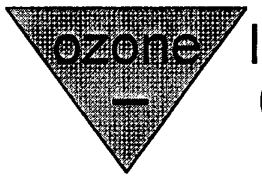
Senior Policy Advisor

Directorate Shipping


IBIA Council Member

# Climate and air quality problems

affecting

- Greenhouse effect (global warming) → Climate, Bio diversity
- 

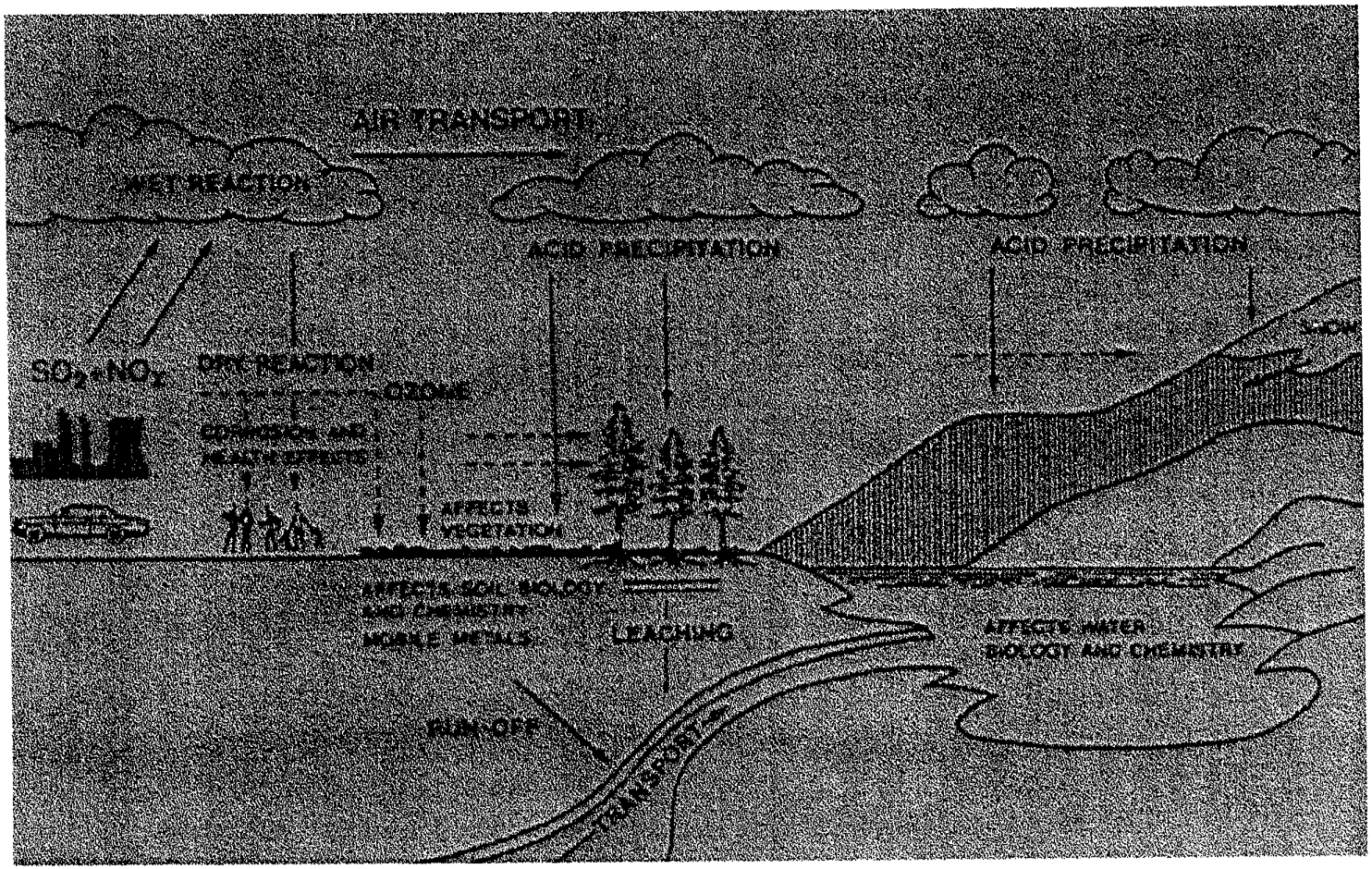
layer depletion (u.v. radiation) → Health, Vegetation
- 

ground level (smog) → Bad smell, Visibility
- Acidification (Acid Deposition) → Aquatic life, Corrosion

# Index Shipping Related Emissions

| **Originators** | $SO_x$ | $NO_x$ | VOCs | $CO_2$ | CFCs | Halons | $CH_3Br$ |
|---|---|---|---|---|---|---|---|
| Greenhouse effect | | | | X | X | X | |
| ODS-Stratospheric | | | | | X | X | X |
| Ozone-ground | | X | X | | | | |
| Acid rain | X | X | | | | | |
| **Linked-up with:** | | | | | | | |
| Fuel combustion | X | X | X | X | | | |
| Cargo handling | | | X | | X | | X |
| Ship's equipment | | | | | X | X | |
| Incinerators | X | X | | X | | | |

# Acid pollution chain



# The Question:

- To be reduced or not to be reduced

  = outdated !

- To be reduced and how to be reduced

  That is the EROS question !

- EROS = Emission Reduction Objectives
- EROS = EURO's

# EROS originators

- Climate conferences
- UN FCCC (United Nations Framework Convention on Climate Change)
- OECD (Organization for Economic Co-operation and Development) and Annex I countries
- Vienna Convention and Montreal Protocol
- IMO-MEPC's Marpol Annex VI
- EU Gasoline Directive
- EU Sulphur Directive
- EU Acidification Strategy

# $SO_x$, $NO_x$ and $CO_2$ emission-scope

- Global marine fossil fuel consumption = 6% of the annual liquid energy demand
- 1997 consumption:
  - 115 Mts HFO/IFO
  - 25 Mts MDO/MGO
- Combustion is responsible for:
  - ± 2% of global $CO_2$ emissions (± 370 Mts $CO_2$/year)
  - ± 4% of global $SO_2$ emissions (± 8 Mts $SO_2$/year)
  - ± 7% of global $NO_x$ emissions (± 11,5 Mts $NO_x$/year)

# GHG ⟶ $CO_2$ emission reduction target

- Kyoto conference/UNFCCC
- FUELTAX in Annex I - OECD countries
- Introduction of a non-worldwide tax in the aviation- and shippingsector will create huge problems. The divertion behaviour is enabling the shipping industry to fuel elsewhere with the result that a non-worldwide fueltax will not or scarcely reduce ship's $CO_2$ emissions. Such a measure, however, will lead to an extensive shift of bunkersales to regions which are not levying taxes.

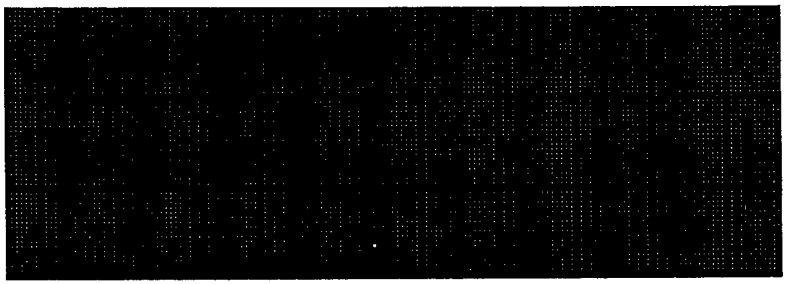
# EROS for ODS

MARPOL - CFC and Halons on board ships

Montreal protocol - $CH_3Br$ for cargo

- CFC's and Halons phased out - elimination in 2000
- Methylbromide, used for fumigation of agribulk cargoes and quarantine containers
- Unilateral measures in the Netherlands; creating improper and unfair competition
- Exorbitant safety distances and other discouraging measures promulgated by the "College Admission Pesticides"

# Two EROS approaches for both smog and acidification



Mainly caused by fossil fuel combustion and to a less extent by cargo-handling

1 The Global Approach

› IMO - MEPC's Marpol Annex VI

2 The E.U. approach

› EU Gasoline Directive 1994/63/EC

› EU Sulphur Directive 1999/32/EC

› EU Acidification Strategy 1997 -2010

# Marpol Annex VI

- Regulations for the prevention of air pollution from ships
- For any ship of 400 gross tonnage or above an IAPP certificate required
- Regulation 12 - ODS
  Regulation 13 - $NO_x$
  Regulation 14 - $SO_x$ and SECA requirements
  Regulation 15 - $VOC_s$
  Regulation 16 - Shipboard Incineration
  Regulation 17 - Reception Facilities
  Regulation 18 - Fuel Oil Quality

# Information to be included in the Bunker Delivery Note

## (Regulation 18 (3))

Name and IMO Number of receiving ship

Port

Date of commencement of delivery

Name address, and telephone number of marine fuel oil supplier

Product name(s)

Quantity in metric tons

Density at 15° C, kg/m3 *

Sulphur content (%m/m) **

A declaration signed and certified by the fuel oil supplier's representative that the fuel oil supplied is in conformity with regulation 14 (1) or (4)(a) and regulation 18 (1) of this Annex



---

* Fuel oil should be tested in accordance with ISO 3675

** Fuel oil should be tested in accordance with ISO 8754

# Marpol Annex VI

- "Emission" means any release of substances, subject to control by this annex from ships into the atmosphere or sea

- In force: not before 2003, 4, 5, 6, 7
- 12 month after 15 countries / 50 % world tonnage
- So far only: Norway and Sweden

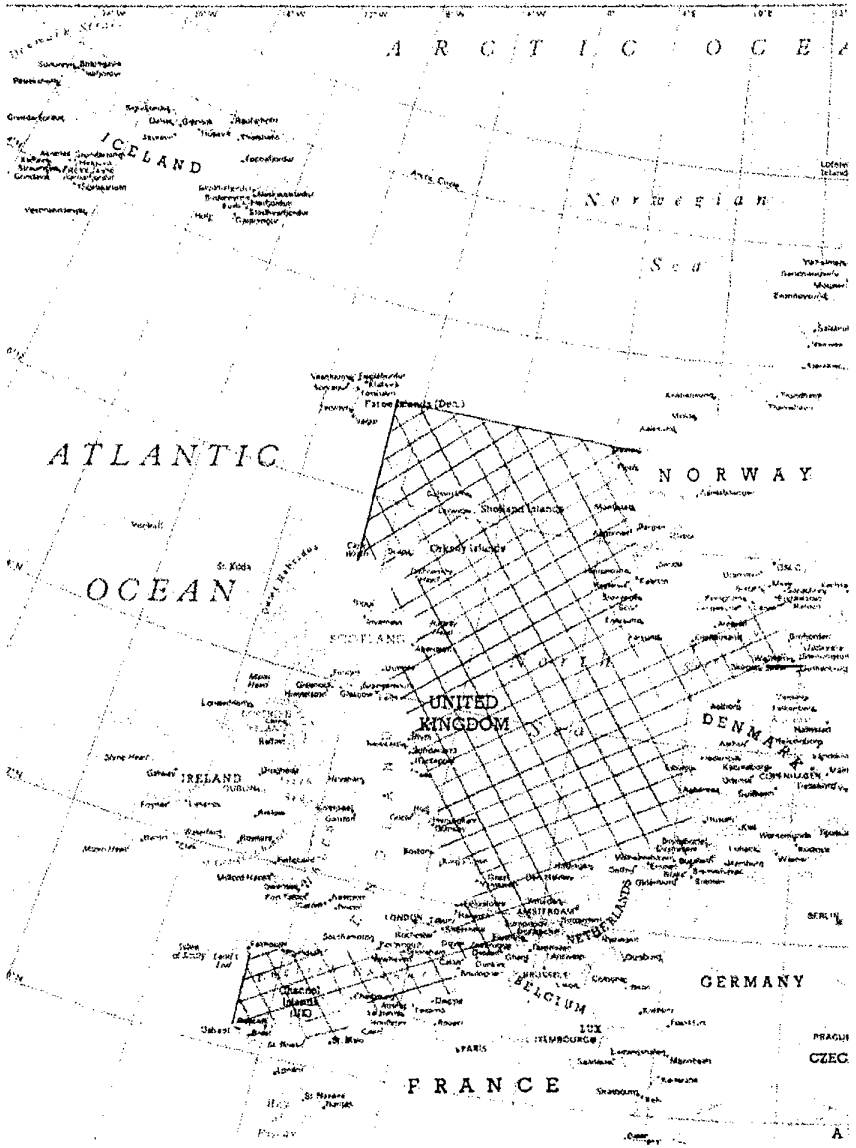
- However one consequence w.r.t. NOx and Incinerators
- New Engines and Incinerators installed after 1-1-2000 shall meet the standards of Annex VI - Reg. 13 & 16
- Existing ships under the grandfather clause

# Why $SO_x$ - emission - control areas ?

- Acid pollution deposition ashore
- Emissions far out sea partly absorbed/neutralised by seawater
- Fuel oil Sulphur content in Seca's max. 1,5% instead of 4,5%
- or after treatment exhaust gas cleaning resulting in max. 6,0 g $SO_x$ 1 kWh
- Baltic nominated, North Sea to follow
- Local: cold ironing in some ports

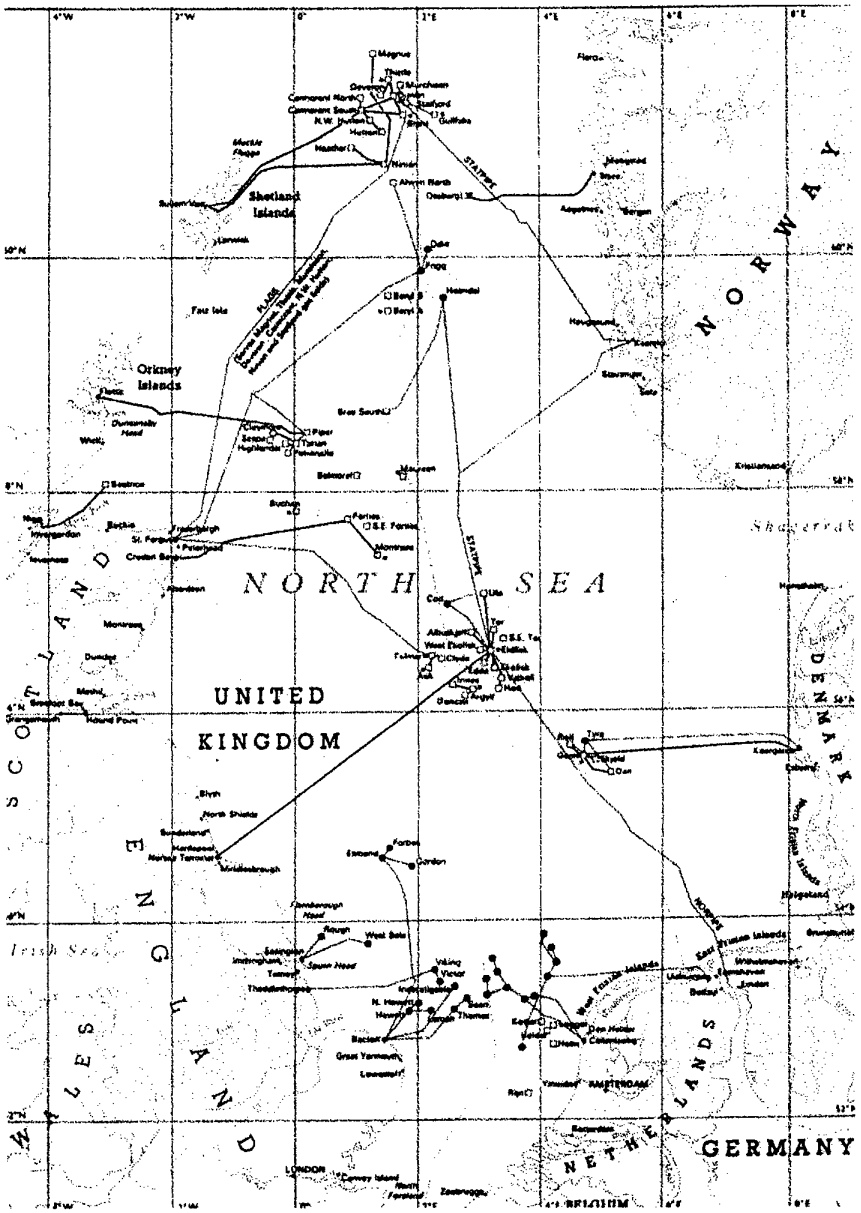
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# SECA Limits North Sea



# VOC - smog targets

- Marpol Annex VI - Regulation 15
- EU Gasoline Directive
  VEC for loading inland barges
- National VOC abatement programme HC 2000
- Local: Sture Statoil Terminal
  VRS with rebate for crudetankers
  Europoort CrudeVec with environmental license conditions
- Region: Restrictions under bad meteo codes
  no tank ventilation / slow loading rate


NORTH SEA
UNITED KINGDOM
Shetland Islands
Orkney Islands
NORWAY
DENMARK
GERMANY
NETHERLANDS
SCOTLAND
ENGLAND
WALES
Irish Sea
STATPIPE
FLAGS
LONDON
AMSTERDAM

53

# EU Directive on Sulphur in fuels

Formally adopted : april 26, 1999

Art.1

- The limitation on the S content for HFO / IFO (1% by mass, per 1-1-2003) shall not, however apply
  - to HFO / IFO used by seagoing ships and
  - to MGO used by ships crossing a frontier between a third country and a memberstate

- S content MGO
- max. 0,2 % by weight from 1-1-2000
- max. 0,1 % by weight from 1-1-2008



- To be controlled by representative and frequent taken samples

# EU-DGXI acidification strategy

Objective:

- Significant acidity reduction for sensitive ecosystem areas by 2010

Shipping:

- Designation of the Baltic and North Sea as so called $SO_2$ control areas with the aim to restrict HFO to 1,5 % sulphur

Considerations:

- The use of economic instruments

To investigate:

- a Sulphur fee
- differentiated shipping dues, in particular port dues
- exhaust gas projects
- regulated S content

New proposals:

- Before the end of 2000

# Best Acceptable Attitude

| | | |
|---|---|---|
| Be | **A**ware and | pro- **A**ctive |
| Stay | **A**lert and | **A**larmed |
| Act | **A**gainst if | **A**pplicable |
| But | **A**ccept Inescapable Irreversibility | |

Safeguard the balance between environment and economy
Keep eyes open for reality and on the horizon
Prevent distortion of environmental competition in ports
Do not create contra-productivity

**In our life re-examinations are possible**
**Climate does not have that second chance**

Session 1
Speaker Mr. Klaas Jan Bolt

I should like to introduce the next speaker which is Mr. Klaas Jan Bolt from the Ministry of Transport and Public Works, the Netherlands.

Mr. Klaas Jan Bolt graduated from the Nautical College as Master Mariner and served almost 20 years in the Merchant Navy as Deck Officer and Master on board different types of ships.

He than served as North Sea Pilot in the English Channel, the North Sea and the Baltic Sea.

After some years as a Professor at the Nautical College he became a civil servant working for the NL Ministry of Transport and Public works. His specialisation is the protection of the maritime environment in relation to shipping. He is active also in international maritime fields, both within the IMO and the European Union.

Mr. Bolt will now present his paper titled
"IMO – Annex VI of Marpol"

# HARMFUL EMISSIONS & THE IMPACT ON SHIP OPERATION AND EQUIPMENT MANUFACTURER

by: K. J. BOLT
Senior policy adviser marine environment
Ministry of Transport, Public Works and Water Management
Directorate-General for Freight Transport
Directorate Transport Safety
Traffic Management Division
The Netherlands

## Introduction

**In the last years important decisions on harmful emissions were taken in the international arena.**

**The Kyoto conference addressed six greenhouse gases and commits quite a few countries to reduction of the emissions of these gases by a certain percentage of the total of a reference year before a certain date.**

**The International Maritime Organization produced a new annex to the Marpol convention. The annex addresses several aspects of air pollution from ships. For some of the exhaust gases from ships, emission standards have been developed.**

**The similarity between these international instruments is that they both address gaseous emissions with the aim to protect the environment against adverse effects.**

**There are several differences between the instruments:**

- **"Kyoto" is not yet in force, but measures are imminent; e.g. on the basis of the deliberations in the EU environment council, Kyoto for the Netherlands means a reduction of 6% based on the level of 1990, to be achieved by 2010;**
- **Marpol annex VI is not yet in force, measures are not imminent but the instrument does influence engine manufacturers and shipowners and will be retro-active to a certain extent once it enters into force (in other words: its is pro-active in that it influences industry decisions prior to entry into force);**

- **Kyoto exclusively addresses the following climate gases: $CO_2$ , $CH_4$ , $N_2O$, HFC, PFC and $SF_6$**
- **Marpol addresses some climate gases (specifically ozone depleting substances); it also addresses other substances such as exhaust gases from engines and shipboard incinerators and volatile organic compounds; Marpol further addresses fuel oil quality;**
  **Marpol does *not* address emissions of $CO_2$**

- Kyoto addresses total loads on the global environment (at least in principle, failing the consent of quite a number of countries) and irrespective of the source;
- Marpol only addresses emissions from ships and either simply bans the use of certain compounds or prescribes measures that prevent emission; it further gives emission standards (notably for oxides of Sulphur and Nitrogen) that are expressed as limits, e.g. no fuel of over 4.5 % S may be used anywhere in the world; no more than 6g/kWh $SO_2$ (which is the equivalent of 1.5% S) may be emitted in an $SO_x$ emission control area. Marpol Annex VI does not address the total load emitted by a ship and thus does not restrain installed power or number of ships. In many respects Marpol will change trends in that it reduces the rate of increase of certain emissions. There is a resemblance with the EU-regulations that apply to cars; it is possible to regulate the emission standard, but a lot more difficult to regulate the number of gallons consumed by a particular car Controlling the number of cars that contribute to the total emission load would be an even greater challenge.

It should be recognized that Kyoto will affect total loads anyway and probably in every sector of industry that emits greenhouse gases. For shipping this may turn out to be a mixed blessing. On the one hand administrations may tend to dish out their reduction targets equally to every sector of society , on the other hand - in the transport sector- shipping may be the alternative mode of transportation that can absorb growth in the demand for transport while at the same time mitigating trends in over all emissions. This is particularly true for quite a few countries on the continent where indeed inland water transport can be a substitute for road transport, but it may equally apply to short sea shipping.

For the remainder of this paper issues related to Marpol and its annex VI will be addressed, but even though Marpol annex VI does not address $CO_2$ and other greenhouse gases, it is nevertheless linked to the outcome of Kyoto through two resolutions that were adopted at the Marpol conference held at IMO in London in September 1997.

## The new regulations of MARPOL annex VI: why and what do they affect?

## Why?

By the end of the eighties several countries in NW Europe but also elsewhere, became aware of shipping emissions to the atmosphere as a source of pollution to be considered when addressing pollution on land. For some of these countries the level of acidification of their soil is in excess of the critical load. The critical load is defined as "a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt,1988). It became clear that in order to close at least part of the gap between actual levels of acidification and the desired level on or preferably below the critical load, it would be necessary and cost effective to control emissions from ships.

Although there still is considerable disagreement about the necessity and the adequacy of the measures encompassed in Marpol Annex VI, most parties would agree on the benefit of an international instrument as opposed to regional or unilateral measures. For international shipping, different regimes in every port they call at is something of a nightmare. This is an

other reason why the new regulations are in a new annex to the Marpol convention and have been developed under the auspices of IMO.

The European Commissions' strategy to reduce acidification also encompasses ship's emissions. The Commission, although reluctantly, has accepted that IMO's attempts to develop and implement an international instrument should, at least for the time being, be given the benefit of the doubt. Failing timely entry into force of Annex VI however, the Commission may consider to develop an instrument of its own.

## What do the new regulations affect?

Marpol Annex VI, in regulating quite a number of issues, affects many parties, whether they are states, non governmental organisations or industrial enterprises. Annex VI creates obligations for the shipping industry and affects shipbuilders, engine manufacturers and manufacturers of equipment such as incinerators and exhaust gas cleaning components. It very much affects the oil industry and the bunker industry.

The issues addressed by Annex VI are the following:

- ozone depleting substances
- nitrogen oxides
- sulphur oxides
- volatile organic compounds
- shipboard incineration
- reception facilities
- fuel oil quality

The obligations created by Annex VI affects states and in some cases classification societies acting on their behalf in a statutory capacity. States will have to arrange their domestic legislation and enforcement. They will have to set up provisions for shore reception in the case of ozone depleting substances. If they want to control vapour emissions from ships they will have to provide the necessary shore side facilities for vapour return in order to accommodate these ships.

The shipping industry will have to comply with the new rules in that the equipment they install on their ships will have to be in conformity with annex VI. This affects fire fighting equipment, cooling and refrigeration, engines and incinerators. When they visit ports that require vapour emission control for ships that are being loaded with cargoes that emit volatile organic compounds, these ships will have to have the proper equipment for that purpose.

Many ships will have to be modified to enable operation in an $SO_x$ emission control area. These modifications sometimes will amount to the installation of additional fuel tanks and additional pumping and piping arrangements.

The engine manufacturers will need to build engines that can meet the standards for $NO_x$ emissions.

The oil industry must respond to the demand for low sulphur fuel from ships that operate in $SO_x$ emission control areas. Such demand will not only exist within these areas, but also elsewhere ships destined fro these areas will require a supply of low sulphur fuel.

The bunker industry will see the obligation to take samples of the product they deliver and will face customers that are in a stronger position than before in the case of conflicts about quality of bunker fuels.

## When will they come into effect?

Formally the measures will come into effect once Marpol annex VI enters into force, which is not to be expected before 2003. By that time hopefully 15 states with at least 50% of world tonnage among them will have ratified Annex VI and thus will have fulfilled the necessary conditions for entry into force. Some measures will cast their shadows ahead, such a the requirements for $NO_x$ emissions for new engines and the requirements for incinerators. For these the applicable regulations say that engines and incinerators installed on ships on or after 1 January 2000 shall meet the standards of Annex VI. Shipowners therefore would be wise to order engines and equipment for their newbuildings that can meet these standards. Failing that they may run into trouble once Annex VI enters into force. Supposing, for the sake of the argument, that this is the case in 2004, port states may wish to apply Annex VI to the full extent. They may inspect a ship that is built in 2001 and require that the engine of the ship comply to regulation 13, which imposes limits on the emission of nitrogen oxides.

The situation of today is that the necessary technology to meet these standards is available and that the difference in price for a ship that meets the standards from one that does not is only marginal.

## What is not covered by annex VI?

Greenhouse gases, particulates, organic micro pollutants and $NO_x$ emissions from existing engines are not or not directly covered by Annex VI.

IMO's Marine Environment Protection Committee, in accepting responsibility for ship's emissions to the atmosphere, has not given a restrictive interpretation to the notion 'marine environment'. Had this been the case, then emissions to the atmosphere would not even have been addressed. Even more significant is that IMO now has developed measures that are aimed at protection of the terrestrial environment, such as reduction of acidification of the soil. The Committee has however shown great reluctance to include $CO_2$ emissions in Annex VI. There are several reasons for this position. In the first place, many countries have pointed out that the contributions from shipping are relatively small and that shipping produces many tonmiles per ton of $CO_2$ emitted as compared to other modes of transport. In view of the fate of very ambitious proposals for instance regarding $SO_2$ emissions, states have shown increasing reluctance to propose reduction targets for $CO_2$. The issue of $CO_2$ has seen a number of submissions to MEPC on the basis of which some discussions took place, but which never have led to proposals for quantitative measures. Instead, in the context of the Marpol conference of September last year, two resolutions were adopted, which aim to address greenhouse gases. One of these non binding resolutions, in the case of $CO_2$ , seeks to study

possibilities to reduce the emissions from ships. The other one addresses PFC's and seeks a moratorium on its use followed by an amendment to the relevant instrument to prohibit its use in shipboard fire extinguishing systems.

Particulate and organic micro-pollutant emissions are not covered by Annex VI, because of lack of knowledge about proper possibilities to reduce them, but also and perhaps even more because of the notion that Annex VI should be a developing instrument, to be amended in due course. It was considered very important to make the instrument acceptable for as many countries as possible so as to enable timely entry into force. Another consideration is that growing insight and knowledge about air pollution from ships and abatement techniques may in future point at the issues to be included or amended in the annex.

In the case of $NO_x$ emissions from existing engines, the physical impossibility to install large exhaust gas cleaning plants and the cost associated with such measures, prevented that Annex VI covers these emissions. Technology develops fast though, and there are indications that not only techniques are emerging to reduce $NO_x$ emissions from new engines far more than the present levels in Annex VI, but also that some of these techniques may be applicable to existing engines without excessive costs.

## Measures to reduce harmful exhaust gas emissions

The exhaust gas emissions of ships by and large are proportional to fuel consumption. Any measure to reduce fuel consumption will reduce exhaust gas emissions. The exception sometimes made for $NO_x$ is only apparent, because although there may be an inverse relation between the specific fuel consumption in a given engine type and the $NO_x$ emission in g/kWh of that engine, the $NO_x$ emissions from that engine will still be proportional to the amount of fuel consumed.

Looking at factors that affect fuel consumption world wide and top down we find the following list.

- World economy
- Shipping efficiency
- Ship efficiency
- Propulsion efficiency
- Engine efficiency

Going down this list we find increased opportunity to influence fuel consumption with the decrease of scale. From the perspective of one country the possibilities to influence world economy are mostly limited, with the exception of some superpower(s) or large economic blocks. From the perspective of IMO: to influence shipping efficiency is already beyond the remit of that organisation: IMO has no instruments to achieve the goal that more cargo is transported with less ships consuming less fuel, other than perhaps saying publicly that this will be helpful in achieving environmental goals.

Market forces may indeed prove be more powerful than any regulatory attempt. In the past we have seen increased attention for efficiency, driven by high oil prices and we might see something similar again, e.g. in the case of an oil crisis. Present trends are just the opposite: fuel prices are very low and thus provide very little incentive for fuel economy. Nevertheless, there is an increased trend in the demand from shippers that their goods be transported in

**ships that are operated by certified companies and that these ships and their crews contribute to achieve high safety and environmentally standards. This is certainly an incentive for quality operators that nowadays still suffer from unfair competition from substandard operators and their equally substandard ships.**

**As regards the technical and operational possibilities to reduce harmful exhaust gas emissions: these are manifold and indeed start with increased efficiency, e.g. through total energy installations, sometimes even diesel-electric installations and in future perhaps through application of fuel cell technology.**
**Nowadays reductions of well over 10% in fuel consumption are certainly achievable and may at least temporarily be sufficient to let shipping do its bits in the reduction of greenhouse gas emissions.**

## Measures to reduce sulphur dioxide emissions

**Other than with $NO_x$ emissions, the fuel is the only source of sulphur dioxide emissions. The $SO_2$ emissions are directly proportional to the sulphur content of the fuel and the fuel consumption, whereas with $NO_x$ it is the engine properties and the combustion process that come with it, that determine the amount of $NO_x$ emitted per kWh generated.**

**Annex VI limits the maximum sulphur content of fuels to 4.5% but this will not bring any significant reduction as very little fuel exceeds this percentage. Only further reductions would bring significant reduction but this seems a far away and perhaps unnecessary goal. It has been said that 4% might have been achieved in the negotiations about annex VI but in reality only a percentage well below 3% would bring a significant reduction in $SO_2$ pollution world wide.**

**Cost considerations and strong opposition by the oil industry have prevented that one world wide standard of 1.5% was achieved by IMO. Shipowners do not oppose this, indeed they would benefit from better fuel quality, although this encompasses more than just a low sulphur percentage. Indeed from a shipping perspective one world wide standard for sulphur in fuel would be attractive and some eleventh hour attempts to change course in that direction have been seen, but came too late.**

**Failing the world wide uniform standard, countries in North West Europe have proposed $SO_x$ emission control areas for the Baltic and the North Sea or even the North West European waters, the latter stretching west of Great Britain and Ireland. (This area is now becoming a special area under annex I of the Marpol convention).**

**The Baltic is included in Annex VI, the North Sea isn't yet, but it may be expected that it will be part of Annex VI soon after entry into force.**

**In these $SO_x$ emission control areas a standard of 1.5% sulphur or exhaust gas cleaning systems that can reach 6 g/kWh or less shall apply. As the exhaust gas treatment plants are very large and cumbersome, it may be expected that shipowners would choose the option of applying low sulphur fuel, which requires some modification in the fuel systems and tanks on board.**

## Measures to reduce nitrogen-oxide emissions

**Such measures can be divided into two categories: engine design and exhaust gas treatment. Examples of the first are injection retard and water injection, so most of these are found in the fuel management; the second category encompasses selective catalytic reduction (SCR). Recently experiments in Sweden with the so called humid air engine may turn out to be another engine design option.**

**Annex VI for now only requires measures to reduce $NO_x$ emissions for new engines installed on or after 1 January 2000. The emissions standards that are applicable vary with the engine revolutions as follows:**

| | |
|---|---|
| **17** | **g/kWh when n is less than 130 rpm** |
| **9.8** | **g/kWh when n is 2000 rpm or more** |

**For intermediate values the following formula is applicable: $45*n^{(-0.2)}$g/kWh**

**These standards can be achieved by engine design alone, i.e. no after treatment of exhaust gases is required. Most of these design measures are based on the characteristics of fuel injection pumps and nozzles, the timing of injection, the addition of water to the fuel or in the cylinder and similar measures.**
**Far higher reductions can be achieved by SCR. This however requires large installations and a supply of consumable ammonia or urea, with the associated costs and risks (particularly in the case of ammonia). SCR also requires a better than average fuel oil quality to make it effective and reliable.**
**As mentioned before Annex VI only requires moderate reductions for new engines and none for existing engines, which means that the lead time to substantial reductions from the merchant fleet of the world will be an average ships' lifespan of 20 years. So we may expect some results by 2020. Some countries such as Norway and Sweden, who are more seriously affected by acidification than others, have proposed measures for existing ships as well. Failing such measures in Annex VI they have developed (or are in the process of doing so) a number of incentives to reduce these harmful emissions. By introducing differentiation in harbour- and fairway dues they promote installation of exhaust gas treatment, the use of low sulphur fuel and other measures that reduce emissions. In doing so they promote technology from which others may benefit in due course.**

## Fuel oil quality issues; engines, fuels & the environment

**The relation between engines, fuels and the environment can be depicted as a conflict triangle. Looking at the three elements two by two can help is find some of the conflicts and perhaps provide clues for solutions. In doing so we should however not overlook safety aspects associated with fuel quality. Poor quality fuel can either directly or indirectly jeopardize the safety of the crew and/or the ship.**

**Fuel quality and the environment:**

**Residuals fuel are an outlet for a waste product of the oil industry, but also for some industrial waste streams. This may result in additional combustion products, that may be harmful to the environment or human health. The effect on the environment of the exhaust gases has already been covered in the context of this paper. Fuel quality may however also have an impact on**

**the sea. Poor fuel quality may bring excessive formation of sludge, with operational problems in its wake, some of which may result in illegal discharges.**

**Fuel quality and the diesel engine:**

**Suffice it to say that the diesel engine can do without abrasive metals and acids that cause excessive wear, polypropylene that clogs filters and fuels that are incompatible with each other. Ask any diesel engine and it will say it prefers gasoil for quite a number of reasons, not least because that is what its' master, the chief engineer would prefer. Engine manufacturers have coped somehow with the problem to run their engines on fuel of steadily deteriorating quality, but there have been a number of cases in which the fuel quality was directly at the base of incidents or near incidents. Sampling and testing of fuels, preferably mandatory may hopefully be a useful tool in controlling the quality of fuel and in eliminating sub-standard suppliers.**

**The diesel engine and the environment:**

**There is room for improvement in this relation although it must be admitted that the diesel engine is in principle very efficient and therefore inherently environmentally friendly. How friendly it is depends very much on what it is fed with and how it is operated. Development of technologies to reduce harmful exhaust gases are also conducive to further improvement of efficiency and that in itself is one of the benefits of technology development driven by emerging environmental standards.**

## In summary

**Many of the measures summed up here are relatively easy to achieve at reasonable cost. Engines that meet $NO_x$ standards are only marginally more expensive than those that do not. There is progress in the development of alternatives for CFC's and Halons, although the alternatives are not quite satisfactory across the board. Measures to reduce $SO_x$ emissions may turn out the most expensive, particularly for ships that are operating continuously in $SO_x$ emission control areas . Low sulphur fuel may be 20 - 50% more expensive. For some operators it may turn out to be more attractive to run their ships on marine diesel or even gasoil, with the bonus of simpler operation, and less cumbersome fuel treatment and maintenance of fuel equipment.**

**Shipowners would be well advised to address these issues in time. Not only will they be in the clear once Annex VI enters into force, but even today they may contribute to the reduction of pollution by ships. In doing so they may find that they have a competitive edge with the increasing demand from shippers and cargo interests for ships that meet certified quality standards.**

**Shipowners would be equally well advised to consider their options now and not to wait until the entry into force of Annex VI is imminent. In doing so they will find out the potential frictions between legislation and shipping practice. The International Maritime Organization and indeed national administrations need such inputs from the shipping industry of today to be able to address the problems of tomorrow on a realistic basis.**

# Certification of Marine Diesel Engines and Ships According to the new IMO-NOx-Requirements

**Dr. H. J- Gätjens / C. Hadler, Germanischer Lloyd, GE**

## Abstract

The maritime industry is being forced to reduce the exhaust gas emissions of the merchant fleet. With the introduction of the "Technical Code on Emission of Nitrogen Oxides from Marine Diesel Engines", the IMO has presented the first requirements in this respect. With today's state of the art, marine diesel engines can achieve the NOx limitis without external exhaust gas treatment. Ships with NOx reduction plants based on selected catalytic reaction are already in service. The certification procedures and the measurement methods are defined; the first certificates for engines have been issued. The results and the first experiences will be presented.

Measures for a further reduction of sulphur oxides and particle emissions can be expected in the future. Particle and soot emissions represent only 0,02 % of the total mass emissions of a diesel engine. However, since they are visible and partly carcinogenic, measures for their reduction have to be developed. In the continuation of the R-D-Project CLEAN these aspects will be investigated. An overview of the project and new developments in the international legislation will be given.

Session 1
Speaker Dr.-Ing. H. J. Gätjens

I should like to introduce the next speaker which is Dr.-Ing Hans Jakob Gätjens, Germanischer Lloyd, Hamburg.

Dr. Gätjens studied in Flensburg and Hannover and graduated as Master of Science. After having served at sea on steam and motor ships as Marine Engineer he became Assistant Professor at the Institute for Thermal Powerplants and Marine Engineering of the Technical University Hamburg where he received his doctor degree.

For 8 years he worked for the German Shipyard "Howaltswerke Deutsche Werft AG (HDW)" as project manager and head of the "Project Department, Cost Estimation, Project Management, Research and Development of Merchant Shipbuilding".

He is now the Director of the Machinery and Electrical Division of "Germanischer Lloyd AG in Hamburg.

Dr. Gätjens will present his paper on
"Certification of Marine Diesel Engines and Ships according to the new IMO-Nox-Requirements"

# *IMO $NO_x$ Certification of Marine Diesel Engines*


## Department M

| | |
|---|---|
| **Dr. H. J. Gätjens** | Divisional Director Machinery |
| **Dipl.-Ing. C. Hadler** | Diesel Engines and Emissions |
| **Dipl.-Ing. H.-J. Götze** | Diesel Engines and Emissions |

# 1. Introduction

The Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) has developed a "Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines".

The $NO_x$ Technical Code is a mandatory guideline related to Reg. 13 of the new Annex VI to MARPOL. The regulations will come into force when the new amendments to the MARPOL protocol have been accepted by not less than 15 countries representing 50 % (in GT) of the world fleet. Provided that this formal procedure has been undertaken, all marine diesel engines built after 1st January 2000 will have to fulfil these requirements.

The major engine manufacturers have developed measures to ensure that their products meet the regulations of the IMO Technical Code. Governmental bodies and also the industry have a keen interest in reducing the emissions of marine diesel engines. Sweden has already introduced a system with different port fees depending on the $NO_x$ emissions of the ship. Within the framework of the ISO 14000 series, several companies oblige themselves on a voluntary base to reduce the exhaust emissions. The transport of the products is part of the environmental certification. At present, the forestry, paper and chemical industry have created new environmental requirements for shipowners and charterers. The shore-based industry has much stricter regulations - e.g. TA-Luft in Germany - regarding exhaust emissions. The EU is presently introducing new regulations for land-based transport. Therefore a considerable amount of pressure has been placed on the maritime industry towards reducing the exhaust emissions of its ships over the next few years.

According to the IMO, all engines installed on board ships with a power of 130 kW and above need an Engine International Air Pollution Prevention Certificate (EIAPP Certificate). Emergency diesel engines (generator, fire pump etc.) are excluded. These certificates provide the basis for the International Air Pollution Certificate (IAPP Certificate) for the ship, which is issued by the flag state authorities or organizations acting on their behalf. Several engine manufacturers and shipowners are already asking for certification of their engines. Therefore, guidelines have been introduced as an interim solution. The flag states can authorize organizations to witness the necessary tests during the certification procedures at the manufacturer's site and to issue for this engine a Statement of Compliance which may be automatically transformed into the EIAPP Certificate when the IMO $NO_x$ regulations come into force, provided that the $NO_x$ technical file was also approved during that process.

Germanischer Lloyd has been authorized by the administrations of several countries:

***Acknowledgements***

Flag States' acknowledgements (as of July,15th):

Australia, Bahamas, Barbados, Belize, Rep. of Cyprus, Denmark, Estonia, Fiji Islands, Finland, Germany, Greece, Hong Kong, Ireland, Isle of Man, Italy (not finally decided), Liberia, Rep. of Marshall Islands, Netherlands, New Zealand (not finally decided), Norway, Singapore, St. Vincent and The Grenadines, Sweden, United Kingdom.

Reply is soon expected from further shipping countries.

To date, the certification procedures have been carried out successfully for several "engine groups" and some single engines of different engine manufacturers.

## 2. Pre-certification at the engine manufacturer's shop

The limits of the IMO requirements (Fig. 1) can be achieved by modification of internal engine parameters, e.g. injection timing or breathing characteristics. With direct water or ammonia injection, a further reduction is possible.

The relevant tests regarding $NO_x$ regulations for these engines will be carried out at the manufacturer's site.

However, the best results regarding $NO_x$ reduction can be achieved by an exhaust gas treatment with selective catalytic reduction using urea or ammonia. Systems for external gas treatments have to be tested on board the vessel.

The $NO_x$ emissions are dependent on the operational profile of the engines. The test cycles (Fig. 2) are distinguished for various marine applications such as:

- Constant-speed marine engines for ship main propulsion, including diesel-electric drive and variable-pitch propeller sets - **test cycle type E 2** -
- Propeller-law operated main engines and propeller-law operated auxiliary engines
  - **test cycle type E 3** -
- Constant-speed auxiliary engines - **test cycle type D 2** -
- Variable-speed, variable-load auxiliary engines - **test cycle type C 1** -

The limits are represented by the Engine Speed / $NO_x$ Emission Limit Curve (Fig. 1), which results from the particular characteristics in the formation of $NO_x$ across the engine speed ranges.

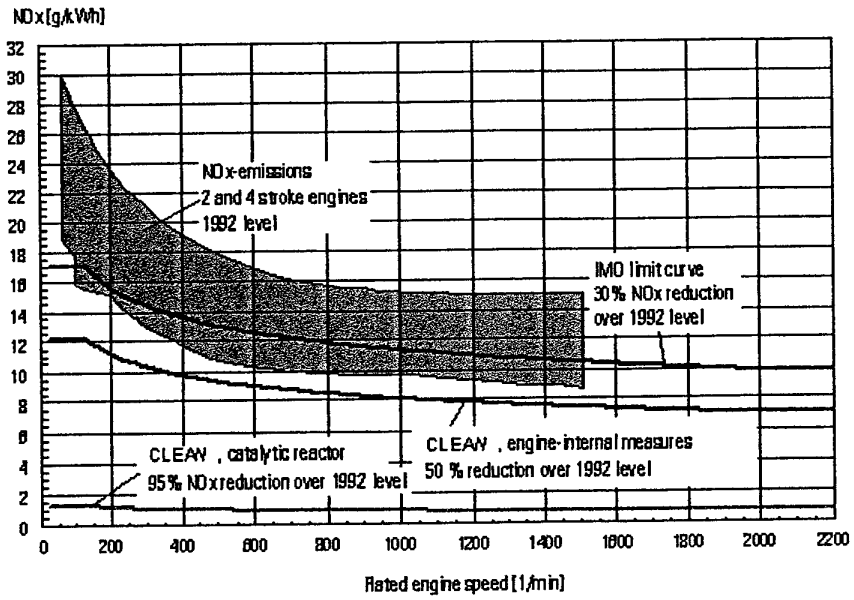



**Fig. 1** IMO NOx-emission limits

The total emission of NOx should be determined using the relevant test cycles (Fig. 3) and measurement methods, as specified in the NOx Technical Code. The test cycles are distinguished for different marine applications following ISO standard 8178 /3/.

- Constant speed operated main engines
- Propeller law operated main and auxiliary engines
- Constant speed operated auxiliary engines.

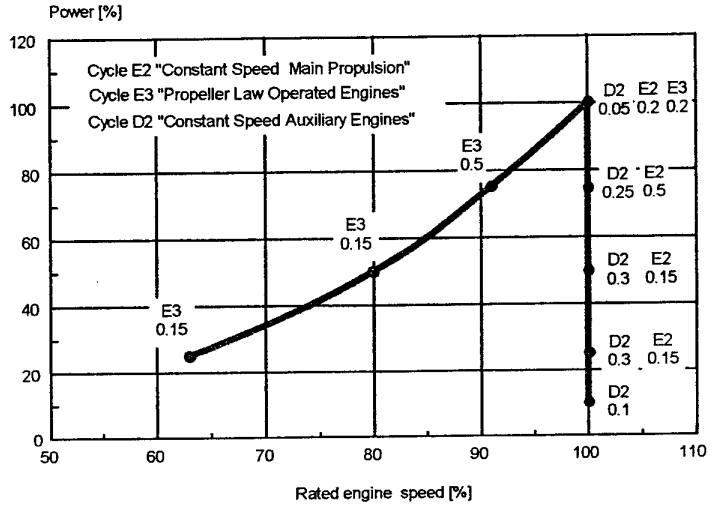



**Fig. 2** IMO Test-cycles and weighting factors

The $NO_x$ Code prescribes that each marine diesel engine shall be subjected to several surveys:

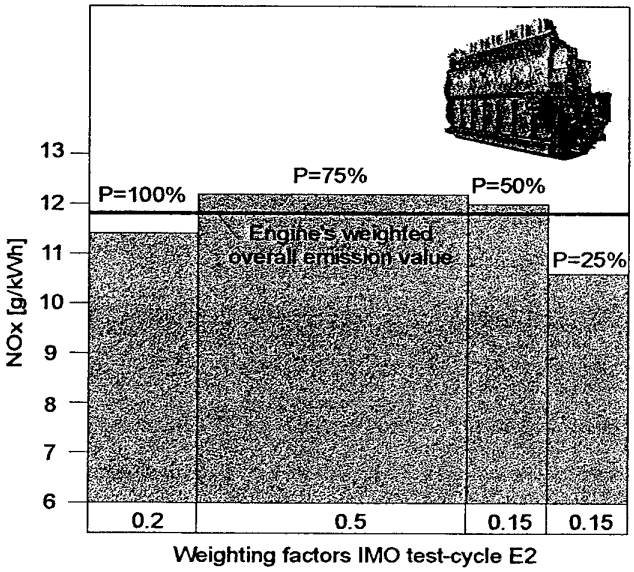
- The pre-certification survey for issuance of an Engine International Air Pollution Prevention (EIAPP) Certificate
- The initial certification survey as basis for issuance of the ship's initial International Air Pollution Prevention (IAPP) Certificate
- Periodical and intermediate surveys to ensure the engine continues to comply with the Code.

The EIAPP-Certificate will be issued either after

- testing of one single engine on a test bed or aboard, or after
- testing of a parent engine according to the engine group concept, or after
- testing of a parent engine according to the engine family concept.

The applicable limit value and the actual weighted value of the engine must be stated in the EIAPP Certificate.

As an example the graph below shows the results of the assessment of a medium-speed 4-stroke diesel engine on the test bed according to the $NO_x$ Technical Code. The engine is intended for use as main propulsion working on a controllable pitch propeller. Therefore test cycle E2 has to be applied. The picture shows the emissions at the relevant output and a graphical representation of the weighting factors. Due to the weighting, the overall emission value fulfils the IMO limit for this engine with a nominal speed of 600 rpm (12.5 g/kWh). Also, the maximum emission at 75 % output is below the IMO limit.



The certification of all diesel engines on board forms the basis for the IAPP Certificate as the ship's document.

Besides the formal scope, the Code also includes detailed specifications on measurement procedures. The basis for the measurement and calculation of exhaust gas emissions is ISO standard 8178, from which the applicable parts were taken over into the $NO_x$ -Technical Code. It regulates

- parameters to be measured,
- measurement equipment,
- permissible deviation of measured parameters,
- data evaluation, and the
- test report.

The exact date cannot be predicted with any certainty, when the MARPOL Protocol of 1997 will be set into force. This regulation will be internationally mandatory only afte the new Annex IV takes effect. However, irrespective of the actual date, according to Regulation 13 of this Annex the diesel engines aboard every ship built from January 1, 2000, must comply with the requirements of the $NO_x$ -Technical Code.

For the scheduling of manufacturers and operators, it is therefore now essential, to already implement the necessary measures for the national adoption of the MARPOL Protocol of 1997. Until the new Annex VI takes effect, as an interim solution the intention is to confirm the compliance of engines with the regulations of the $NO_x$ Technical Code by means of corresponding "Certificate of Compliance" issued by an organisation approved by the flag state.

Besides the measurements of the engine emissions on the test bed, an essential part of the IMO certification is the approval of the "Technical File" to be produced by the engine manufacturer. This technical documentation is the basis for a survey of the engine in operation to prove its conformity with the IMO Regulations according to the principle of a "check of the compliance of the engine, its equipment, and settings with the conditions as certified".

Regarding the certification procedures (Fig. 3) of the marine diesel engines, the "family" or "group" concept will most probably prevail. A group is characterized by engines with the same bore and turbocharging system of one manufacturer. When using this concept, the "parent" engine will be tested according to the appropriate test. If the total $NO_x$ emission values, calculated as the total emission level, meet the requirements of Regulation 13, the $NO_x$-relevant engine parameters have to be documented in the "approved technical file". This basic technical file of the parent engine has to be the same with all engines of the same group. If the conformity of production can be

also verified, the certified parent engine and all other engines of the group may be provided with an EIAPP Certificate.

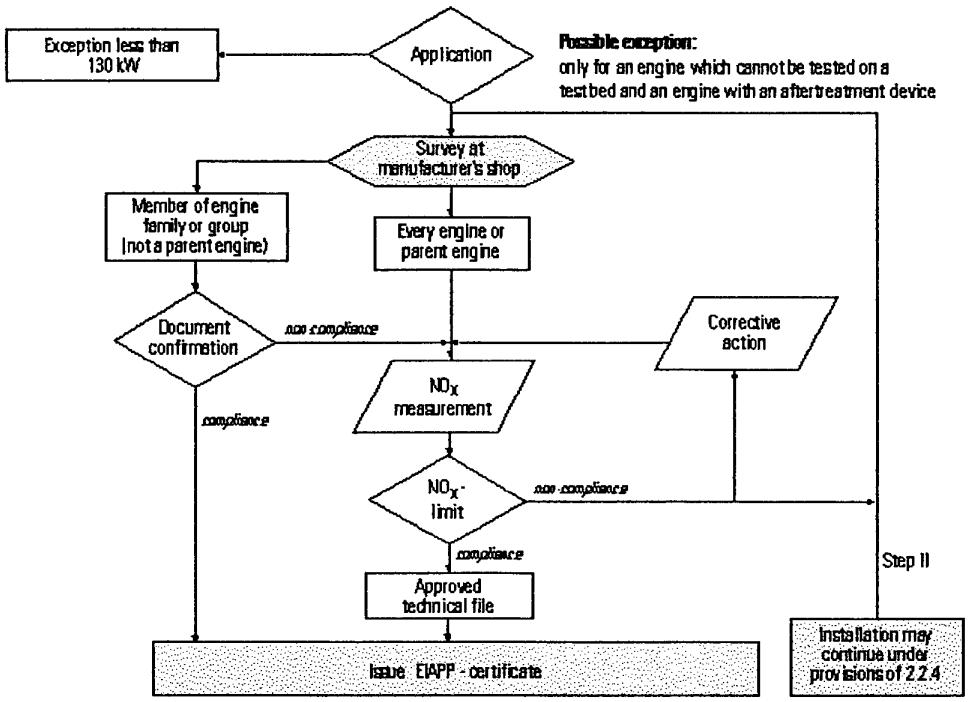



**Fig. 3 Pre-certification survey at the manufacturer's shop**

In the technical file, the components, settings and operating values of the engine which influence the $NO_x$ emissions are documented, i.e.:

- Injection timing
- Injection nozzle
- Injection pump
- Fuel cam
- Combustion chamber
- Compression ratio
- Turbocharger type and build, rotor and nozzle characteristics
- Charge air cooler, charge air pre-heater
- Water temperature at inlet charge air cooler (low-temperature stage)

Furthermore, the engine performance, the allowable adjustments, the test report and the identification number of the relevant components are also part of the technical file.

However, it is possible to carry out $NO_x$ measurements for each single engine in order to obtain the EIAPP Certificate.

If a single or a parent engine does not meet the requirement of the $NO_x$ Technical Code, the engine manufacturer can modify the engine parameters until satisfactory results are achieved. After certification the parameters must comply with those stated in the technical file. As an alternative, an external exhaust treatment plant can be provided; in such as case, the respective measurements will most probably be carried out on board the ships. Certification is also possible on the test bed for complete sets, if sufficient space is available.

## 3. Surveys on board ships

For issue of the IAPP Certificate, all diesel engines with 130 kW or above on board the respective vessel need an EIAPP Certificate (Fig. 4). During the initiative surveys, the surveyor checks, on the basis of the technical file, whether any $NO_x$-relevant modifications have been made. Provided there are no modifications to any of the engines (and shipboard incinerator, if applicable) in comparison with surveys conducted at the manufacturer's shop, the IAPP Certificate for the ship will be issued. If substantial modifications are detected, a complete $NO_x$ measurement has to be carried out. A new turbocharger type or a new fuel cam characteristic would be considered as a substantial modification. The influence of minor modifications can be evaluated by means of parameter surveys or simplified $NO_x$ measurements. Minor modifications as per specifications are all modifications where the limit values are not exceeded.

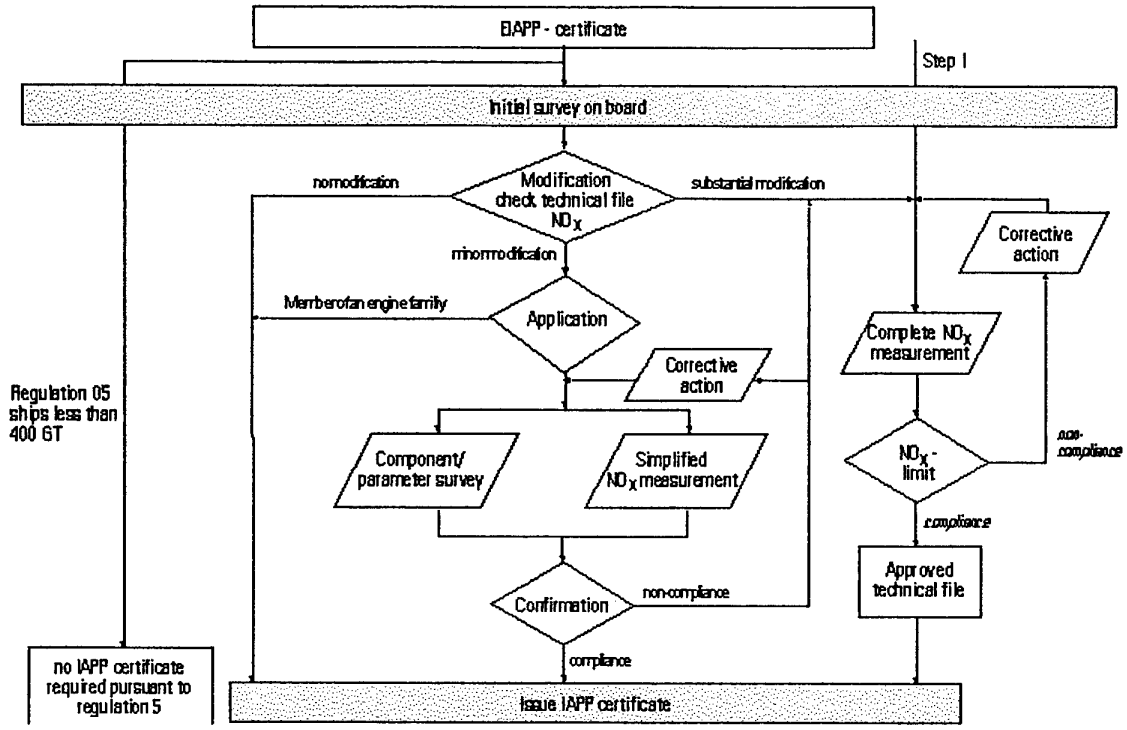



**Fig. 4 Initial survey on board a ship**

According to the IMO, this survey has to be repeated every five years (Fig. 5). For engines with external exhaust gas treatment plants, the $NO_X$ monitoring and the respective documentation will be reviewed.

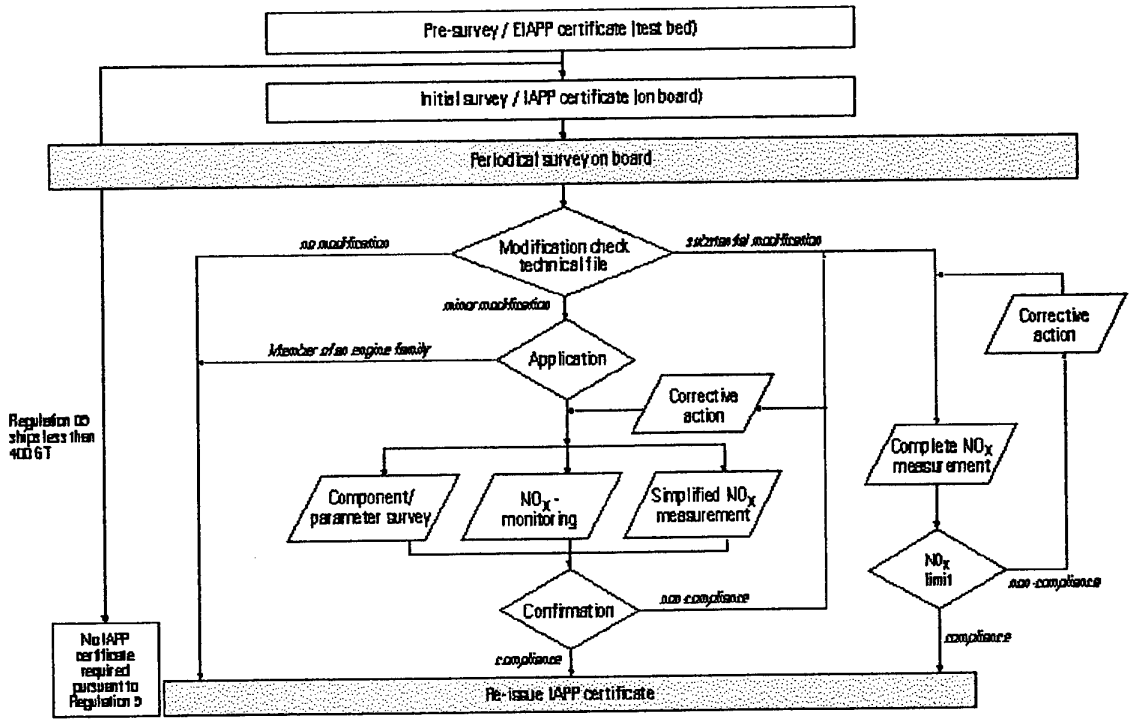



**Fig. 5 Periodical survey on board a ship**

## 4. Exhaust gas measurements at manufacturer's site or on board ship

The IMO Technical Code also includes detailed specifications on measurement procedures.

The basis for the measurement and calculation of exhaust gas emissions is ISO standard 8178, from which the applicable parts were taken over into the NOx Technical Code. It regulates

- parameters to be measured,
- measurement equipment,
- permissible deviation of measured parameters,
- data evaluation, and the
- test report.

The measurements should be carried out by organizations recognized by the IMO, preferably with laboratories accredited according to EN 45001 or similar regulations.

Germanischer Lloyd is currently performing measurements of the assessment of the exhaust gas emission behaviour of marine diesel engines on test beds and under service conditions. Besides the nitrogen oxides, some additional gaseous components have to be registered using special analysers:

- Nitrogen oxides - $NO_x$
- Carbon monoxide - CO
- Hydrocarbons - HC
- Oxygen - $O_2$
- Carbon dioxide - $CO_2$

In addition to the exhaust gas measurements, some essential operating data are measured to assess the respective engine operating conditions for all test cycles:

- Engine or shaft torque
- Engine or shaft revolutions
- Charge air pressure/temperature
- Ambient air conditions: temperature, pressure, humidity
- Fuel rack position
- Fuel consumption
- Exhaust gas temperatures

The analysers comply with the specifications given in the IMO's $NO_x$ Code with regard to measurement method, accuracy and performance sensitivity against other exhaust gas components. The exhaust gas is taken from the funnel via a common probe and then distributed to the various analysers (Fig. 6). It is very important to prevent especially the condensation of water, hydrocarbons and sulphuric acid. This is achieved by means of heated, temperature-controlled pipes. Numerous measurements performed by Germanischer Lloyd on test beds and especially on board ships have shown that special care has to be given to joints than can form heat sinks, for example at the probe connection or at the inlet of the pumping unit. Another source of errors can be leaks in the piping system, e.g. at hose connections. A measuring error is inevitable if the leakage occurs in the suction line of the pump. Therefore, it is highly recommendable to position the pump as close to the sampling point as possible, with the minimum length of the suction line. A very small leakage in the pressure line does not necessarily lead to measuring errors, but should be repaired immediately.

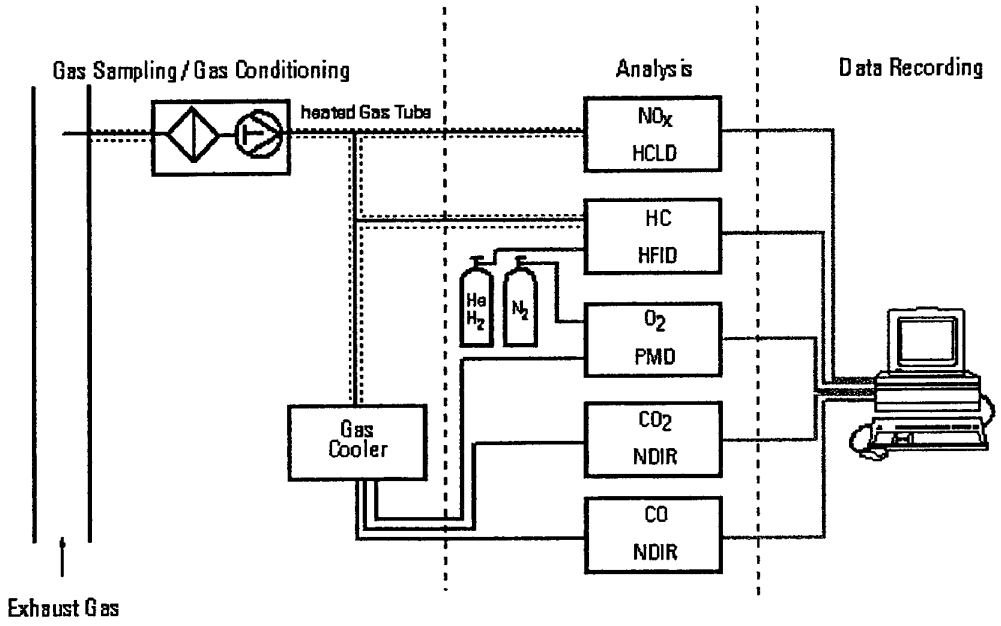



**Fig. 6 Schematic arrangement of analysers for the measurement of gaseous exhaust gas components**

Dependent on the type of analyser, the calibration uses either nitrogen or a special "zero gas" for zero point adjustment. The valid measuring range is set with a calibration gas (span gas) of suitable concentration corresponding to the exhaust gas component to be measured.

The gases measured in addition to nitrogen oxides, as well as the engine operational parameters recorded simultaneously, are needed to convert the measured concentrations from ppm or %-vol into the specific NOx value in g/kWh. Since errors in the measurement of the different values directly influence the accuracy of the NOx value, the gas analysers and the equipment for the measurement of the engine operational parameters, such as speed and torque, also have to meet the highest requirements.

## 5. Conclusion and outlook

The maritime industry is being forced to reduce the exhaust gas emissions of the merchant fleet. With the introduction of the "Technical Code on Emission of Nitrogen Oxides from Marine Diesel Engines", the IMO has presented the first requirements in this respect. With today's state of the art, marine diesel engines can achieve the NOx limits without external exhaust gas treatment. Ships with NOx reduction plants based on selected catalytic reaction are already in service. The certification procedures and the measurement methods are defined; the first certificates for engines have been issued.

Measures for a further reduction of sulphur oxides and particle emissions can be expected in the future. Particle and soot emissions represent only 0.02 % of the total mass emissions of a diesel engine. However, since they are visible and partly carcinogenic, measures for their reduction have to be developed.

## LITERATURE


1. International Maritime Organization, MP/CONF. 3/35, ANNEX "Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines", October 1997.
2. Krapp, R., Hadler, C., Götze, H.-J. "German Research into Diesel Engine Emission Controls Low Emission Ship Propulsion Plant", International Conference Propulsion '96, New Orleans.
3. Götze, H.-J., Krapp, R., Neddenien, S., Ulrich, E. "Diesel engine exhaust gas emissions - research, assessment and certification", MARPOWER 1999, Newcastle, UK

# The View of the International Harbour Master's Association on Atmospheric Pollution caused by Ships related to Port Operations

**Capt. Jaap Lems, Port of Rotterdam**

## Abstract

At the IMO/MFPC measures were/are being considered in the field of bunker fuel and ship's exhaust. In order to take a position as IHMA, a survey of the IH.MA-members was conducted by the IHMA's environmental working group, about atmospheric pollution by ships and the sulphur content used on board ships.

The aim of this survey was to provide information about actions taken or planned by the port authorities in order to decrease the atmospheric pollution (on a regional or local level). But also to produce an overview on the possible (operational or commercial ) consequences in the different seaports. The survey has resulted in a report with recommendations for possible measures to decrease atmospheric pollution by ships.

These recommendations will be highlighted during the presentation.

Session 1
Speaker Captain Jaap Lems

The last speaker of this session is Captain Jaap Lems.

Captain Lems graduated as Master Mariner and Master of Law.
He worked as Safety Inspector of Docklabour (Governmental Inspector), as Head of the Nautical Police Department in the Ministry of Transport and Public Works and as Project Manager Marpol Implementation at Rotterdam Municipal Port Management.

At present he is acting as Deputy Director of Shipping (Rotterdam Municipal Port Management), as Operational Harbourmaster of the port of Rotterdam and Operational State Harbourmaster (Region Rotterdam-Rijnmond).

Captain Lems is also the Chairman of the International Harbourmasters Association's (IHMA) "Evironmental Working Group" and in this role he will make his presentation on
"The View of the International Harbourmaster's Association on Atmospheric Pollution caused by Ships related to Port Operations"

Port of
Rotterdam

# The International Harbourmaster's Association (IHMA) Viewpoint on

# "Atmospheric pollution caused by ships, related to port operations"

Presentation during the international conference and exhibition

# "Treatment technologies for gaseous emissions from ships"

By Captain Jaap Lems,

on behalf of (and as such chairman of the environmental workinggroup) the IHMA

# Possible consequences of IMO's, resp. EU's measures

- A maximum sulphur content for all fuels used on board ships
- The potential establishment of special areas at sea
- The use of certified selective catalytic reactors on board, causing (possibly) a new type of waste product, and what should that mean on the port's reception facilities

# Questionnaire

1a Are there any national or local restrictions in common regarding the maximum allowed sulphur content in fuel oil used for domestic heating purposes ?

1b If such restrictions do not exist today, do you know if and when such will be decided ?

1c If these planned restrictions regard a max. percentage of sulphur, please give an indication what maximum it will become ?

1d Has the Port Authority made any move as to synchronise the max. sulphur content in the fuel burnt on board ships when alongside in the port with the maximum allowed percentage sulphur for domestic heating oil ?

2a Has the Port Authority any plans to decrease the impact on the atmosphere from ships' exhaust gases in port (other way than as indicated under 1d)

2b Has the Port Authority considered to promote the installation of selective catalytic reactors (SRCs) fitted to auxiliary engines used when ships in frequent traffic (ferries) are docked in the port ?

3a Does the Port Authority supply electric power sufficient to let the ferries berthed for more than 6 hours per call to shut off their auxiliary engines ?

# Questionnaire (2)

3b Has the Port Authority considered to invest in equipment to be able to serve the frequent sea traffic with sufficient electric power / connect the ships to the city's mains ?

4 Is your port situated in a possible special area regarding fuel oil to be used on board ships ?

5 IMO is considering the introduction of special areas at sea in relation to the maximum permitted sulphur content in fuel oil for use on board ships

5a Is your port situated in a possible special area ?

5b Will it bring your port in a less competitive position ?

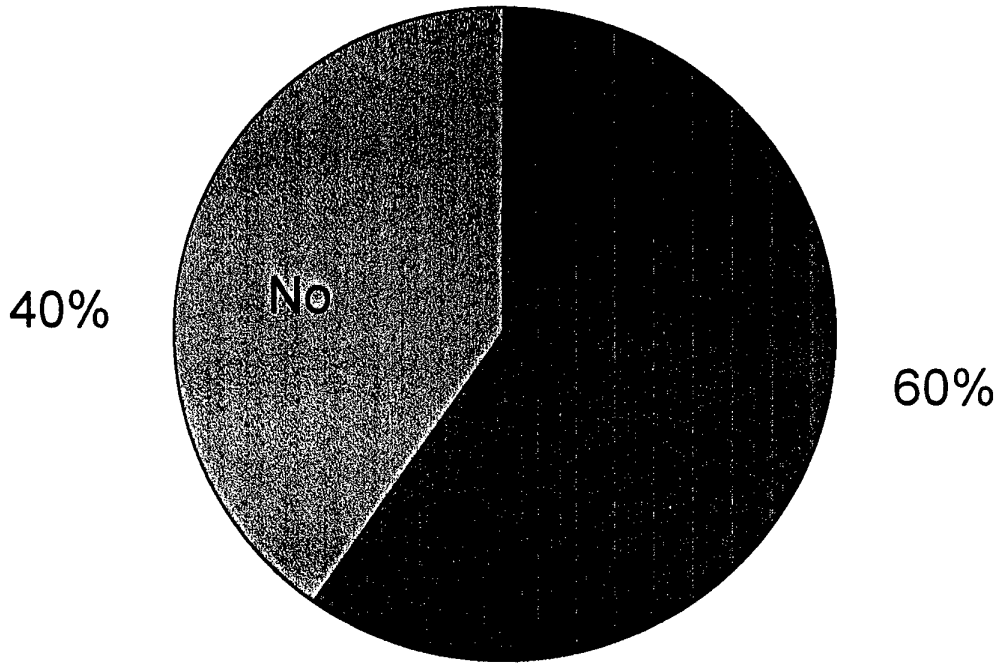
5c How can this be avoided ?

6 What should, as far as you have heard from influential decisionmaking bodies / authorities in your country, be the maximum content of sulphur in bunkerfuel ?

7 Please inform of other actions taken or planned by the Port Authority in order to decrease the atmospheric pollution caused by the ships and the port operation

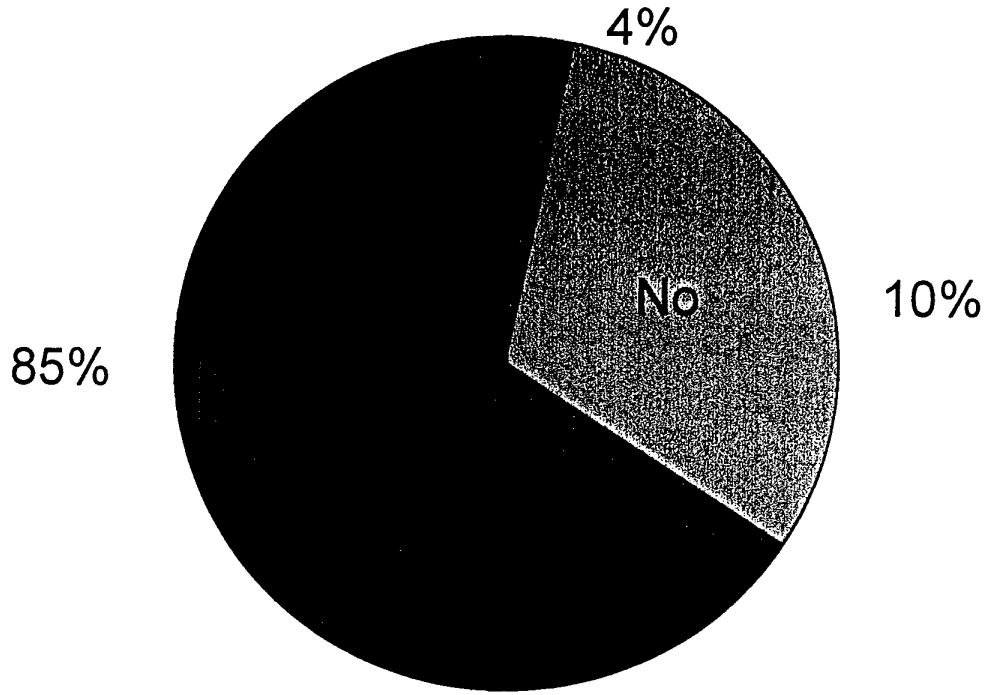
# Response question 1a

› Are there any national or local restrictions in common regarding the maximum allowed sulphur content in fuel oil for domestic heating purposes ?



# Response question 1d

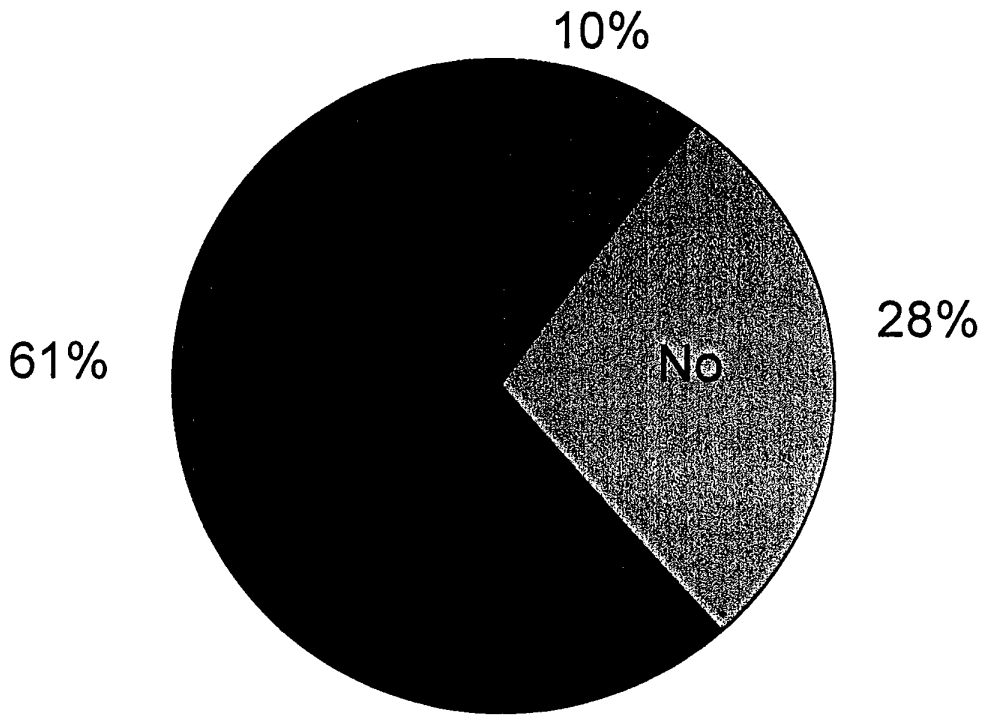
› Has the Port Authority made any move as to synchronise the max. sulphur content in the fuel burnt on board ships when alongside in the port with the maximum allowed percentage sulphur for domestic heating oil ?




9a

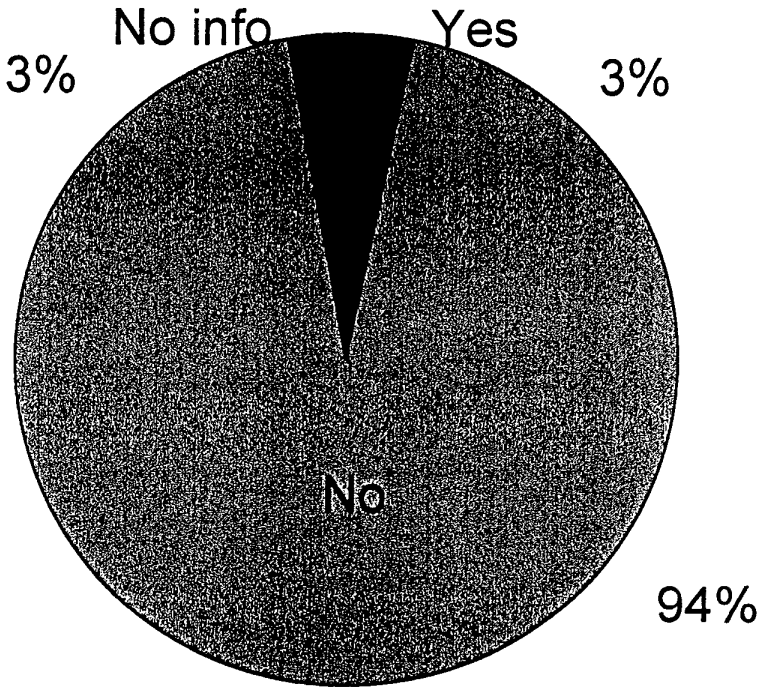
# Response question 2a

› Has the Port Authority any plans to decrease the impact on the atmosphere from ships' exhaust gases in port (other way than as indicated under 1d)



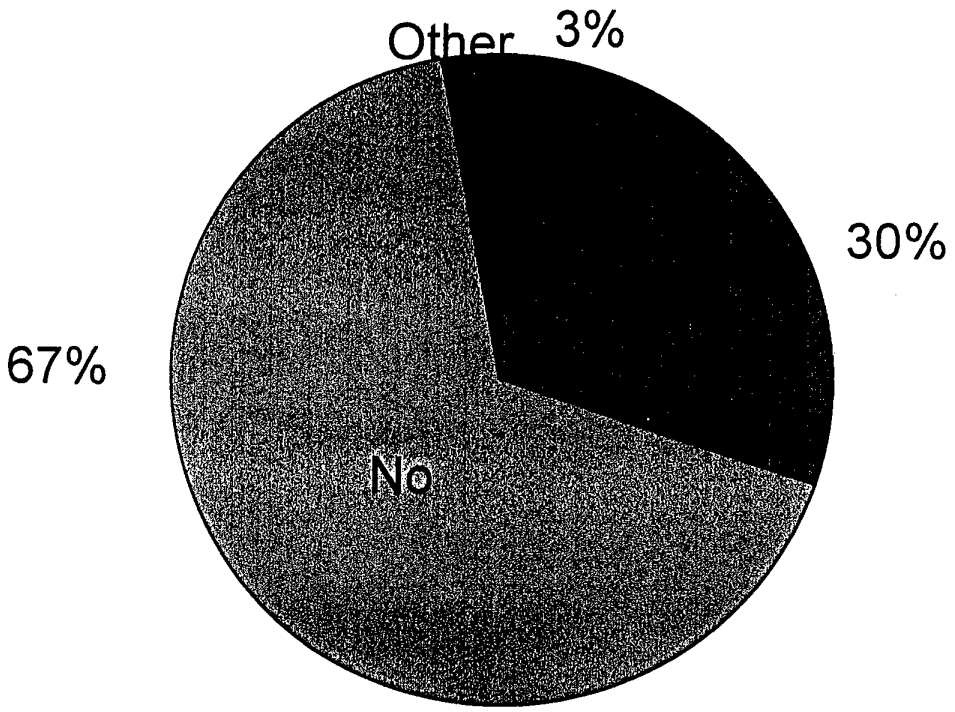
# Response question 2b

› Has the Port Authority considered to promote the installation of selective catalytic reactors (SRCs) fitted to auxiliary engines used when ships in frequent traffic (ferries) are docked in the port ?



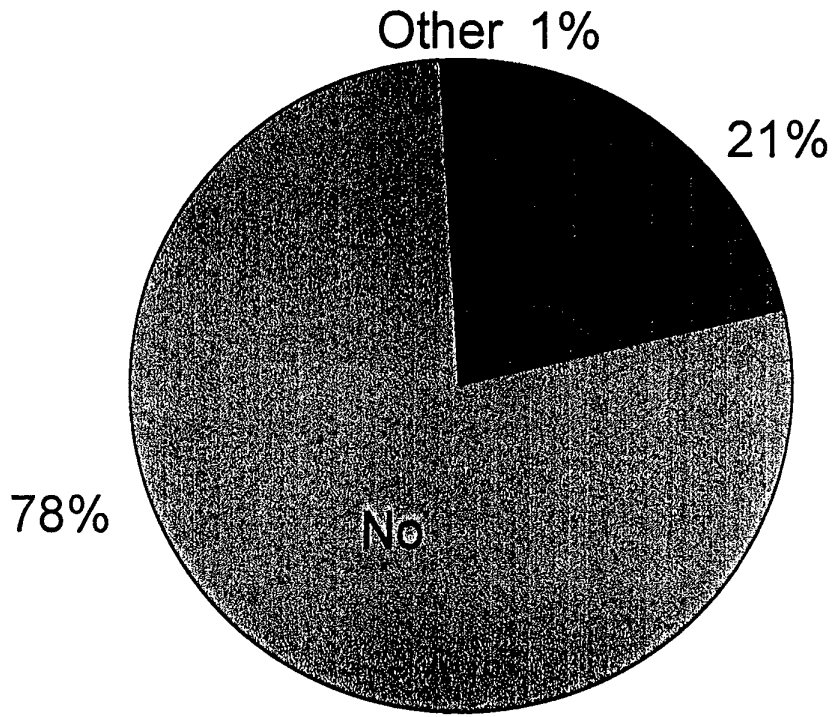
# Response question 3a

› Does the Port Authority supply electric power sufficient to let the ferries berthed for more than 6 hours per call to shut off their auxiliary engines ?



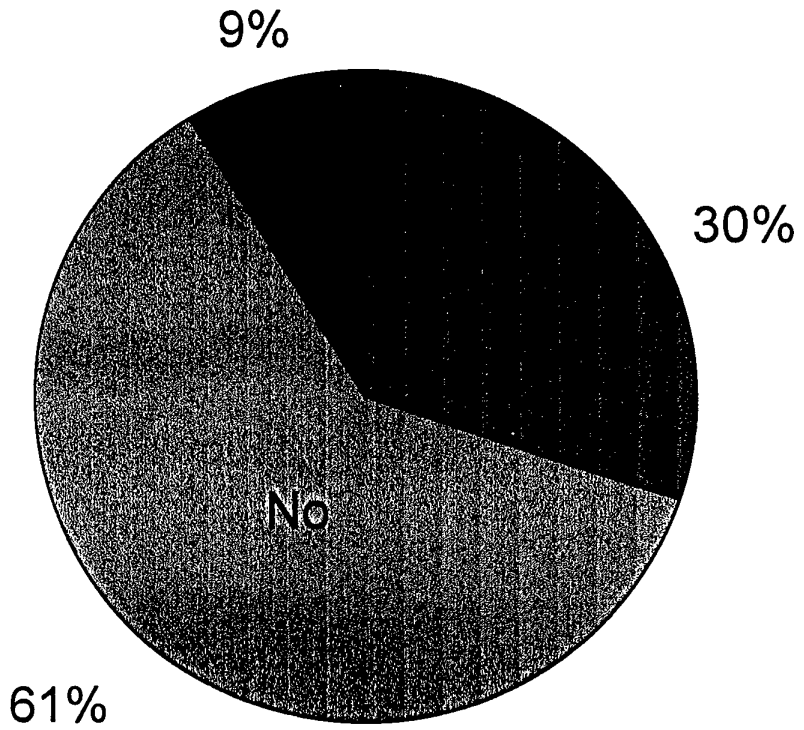
# Response question 3b

› Has the Port Authority considered to invest in equipment to be able to serve the frequent sea traffic with sufficient electric power / connect the ships to the city's mains ?



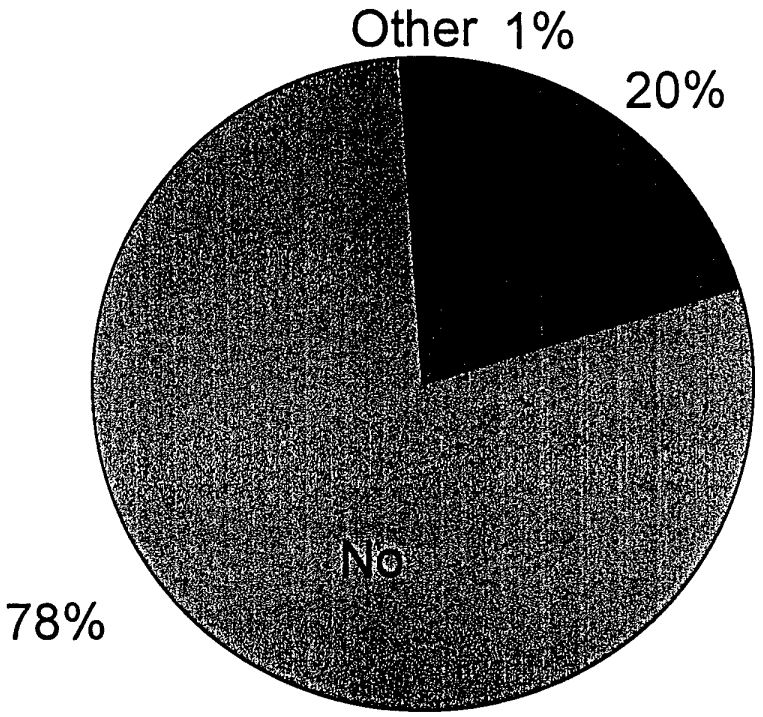
# Response question 4

› Is your port situated in a possible special area regarding fuel oil to be used on board ships ?



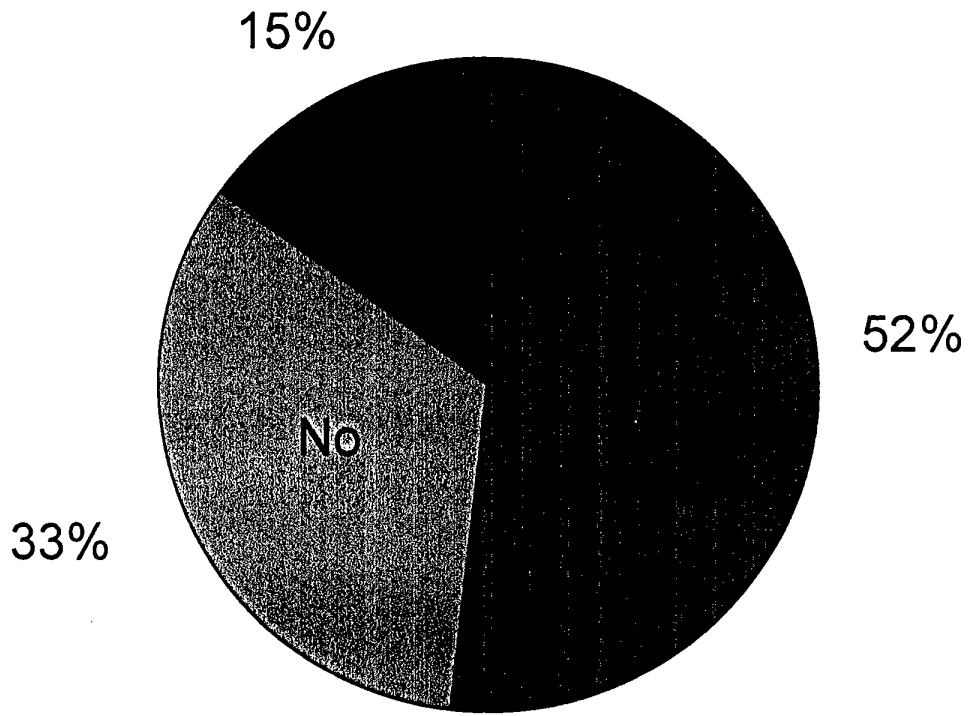
# Response question 5a

› Is your port situated in a possible special area ?



# Response question 5b

› Will it bring your port in a less competitive position ?




8b

# Conclusions (1)

- In many countries the quality of the atmosphere is provided for by national legislation. The effect of ships exhaust on the quality of the atmosphere is mostly not provided for by this legislation
- Atmospheric pollution by ships can be caused by ship management and / or cargo handling
- The PA have no interest in realising supplementary rules for management or ship handling themselves. They also lack the required instruments
- If individual PA impose measures on ships, this will affect their competitive position

# Conclusions (2)

- The majority of the ports is not yet sufficiently aware / involved of the topic of ships' exhaust gases
- The most expensive way of solving the problems is the possible obligatory introduction of selective catalytic reactors (SCR's)
- The Baltic area is (too) far ahead of the rest of the world; too far to be able to come to a compromise ?
- Regarding the provision of electrical power stations in behalf of the vessels. The community, so governments, have to consider these provisions (and the related problems) as being in the interest of all; so they also have to pay for it and not only the vessels
- It is necessary to find / develop clear criteria with regard to the definition of "special area"

# Conclusions (3)

- 40 PA (60%) state that restrictions exist for domestic fuel; 4 PA state that restrictions for domestic fuel are to be expected. Fuel is mostly supplied to ships in accordance with the ISO 8217 standard. The percentage of sulphur in gas oil, diesel oil and fuel oil is, in accordance with this standard, 1.5%, 2.0%, and 5.0% respectively
- Throughout the world ships bunker different sorts of fuel. It is impossible to check whether the right quality of fuel is used at a certain moment
- Considering the above a world-wide maximum percentage of sulphur in all sorts of fuel used on board ships should be provided for

Agreements

- In some ports where ferries regularly call in, agreements have been reached with ferry companies on the use of a SCR, in order to improve the quality of the atmosphere. The ships concerned have to pay less port dues

# Conclusions (4)

- 94% of the PA have not considered to recommend the use of SCR in the exhaust pipes of ships. Only 2 PA (Baltic and North Sea area) have considered to do so. Some PA wonder if it is advisable to use SCR in the exhaust pipes of existing engines. Setting standards for new engines in the field of fuel consumption and emission of harmful substances seems more realistic to them
- 20 ports (30%) with ferry traffic have connections to supply electric from shore, so that the auxiliary engines can be stopped. Sometimes, in places where this is put into practice, problems with the ship's regulating equipment occur. Another problem is the fact that no standards have been set up for such connections
- A world-wide use of connections to supply electricity to ferries from shore should be investigated for its technical feasibility

# Conclusions (5)

**Competitive position of ports**

- 52% of the PA which are situated in a potential special IMO area state (see question 5) that their competitive position can be affected. If this is to be prevented, so they say, there should be no special areas. Instead, there should be an international harmonisation of rules or a harmonisation of rules in separate areas

Ship handling

- **Loading, unloading and cleaning**
- For some PA it is possible to locally prescribe supplementary rules to ships and for certain cargo handling operations in order to improve the quality of the atmosphere
- Technical standards should be set for ships in order to collect emission by ships which are being loaded, unloaded or cleaned. The necessary technical facilities for this should be available at landside companies where ships are loaded, unloaded or cleaned
- Technical regulations for ships with regard to this facilities should be provided for on a global scale. Regulations for connections on shore for these facilities should be included in the local or national rules and should come into force simultaneously

# Recommendations

- The maximum percentage of sulphur in all fuels used on board ships should be regulated on a global scale, considering the practicability
- Avoid measures which can affect the competitive position of ports
- A world - wide use of connections to supply electricity to ferries from shore should first be investigated for its technical feasibility

Port of
Rotterdam

# • The Maritime Environment •

## "Treatment Technologies for Gaseous Emissions from Ships"

## Session 2

### Emissions from Thermal Waste Treatment Processes – Treatment Technologies and Alternatives –

**Session Chairwoman:** ***Dr. Fiona Winterbottom*****, AEA Technology, UK**

# Non-Thermal Plasma for MARINE Diesels

**Fiona Winterbottom, AEA Technology,UK**

## Abstract

Increasing attention is being paid to the potential of non-thermal plasma technologies for the batement of gaseous pollutants from a wide range of processes. AEA Technology has been developing one such technology based on pulsed corona discharge for the treatment of incinerator flue-gas emissions. The thrust of the programme has been to demonstrate the efficiency of the process whilst obtaining an understanding of the mechanisms involved and their scaling. This has been achieved by carrying out trials at increasing flow rates using the flue gas from municipal waste incinerators. The results of these trials on the abatement of NOx, VOCs, dioxins, furans and SOx will be reported.

Chairwoman Session 2
Dr. Fiona Winterbottom

Ladies and Gentlemen,

It is my pleasure to welcome and introduce the Chairwoman of Session 2,
Dr. Fiona Winterbottom

Dr Fiona Winterbottom is presently the Plasma Processing Manager at AEA Technology, UK. She has responsibility for AEA Technology's plasma based flue gas clean-up, waste solvent treatment, air filtration, UV waste water treatment and marine diesel exhaust after-treatment programmes. She received her Ph.D in Chemical Physics from the University of Manchester in 1990 and has been with AEA Technology since 1994.

We are very happy to have you here!

Dr. Fiona Winterbottom will now present her paper on
"Pulsed Corona Plasma Treatment of Gaseous Pollutants in the Flue-Gas from Waste Incinerators"

# Non-Thermal Plasma for MARINE Diesels

**Lt Cdr G. E. Walters (CF -Canadian Forces)**
**Diesel Development Officer**

## Abstract

### INTRODUCTION

The British Royal Navy operates a wide range of diesel engines in various environments and under varied operating conditions. In anticipation of increasingly stringent future environmental legislation, MOD(Navy) continue to evaluate the feasibility of exhaust control technologies suitable for the reduction of NOx and particulate emissions from diesel engines. To this end, in 1995 a full scale Selective Catalytic Reduction (SCR) system was extensively trialed. An AEA Technology proprietary and patented Non-Thermal Plasma system is now being developed for the naval environment. When scaled up to full size, this technology has the potential to offer significantly improved low load and shock performance over the conventional SCR without the inconvenience of using an ammonia based reductant.

### OBJECTIVES

The primary objective of the paper is to discuss the technical, engineering and economic feasibility of fitting the AEA system to a broad range of operational Naval diesels.
The secondary objective is to compare recorded intermediate scale Non-Thermal Plasma system results with the achieved results from the previous MOD(N) SCR trial (summarised in tabular format).

### CONTENT

Information enabling conclusions to be drawn on the viability of a Non-Thermal Plasma treatment device through a combination of experiment and theory will be presented. The latter is in the form of the predictive design model that facilitates extrapolation from the small-scale technology demonstrator produced as part of the study to the full-scale marine diesel aftertreatment demonstrator. Recent results from an intermediate scale exhaust control device treating from a full-scale naval engine exhaust slipstream will be discussed. A direct comparison between the Non-Thermal Plasma and SCR systems will also be conducted.

Session 2
Speaker Lt Cdr Glenn E. Walters

I should like to introduce Lieutenant Commander Glenn Walters as the next speaker.

Lt Cdr Glenn Walters is presently the Canadian exchange officer serving as the Diesel Development Officer within the propulsion section of the Ship Support Agency, MOD London.

Prior to joining the section, he received his MSc in Marine engineering from University College London.

Lt Cdr Walters previously served as the Marine Systems Engineering Officer of the submarine HMCS ONONDAGA.

He will now present his paper on
"Non-Thermal Plasma for Marine Diesels"
(⇒ Presentation Dr. F. Winterbottom)

# Plasma Treatment of Gaseous Pollutants

Treatment Technologies for Gaseous Emissions from Ships

Brussels 18-19 October 1999

**Lt Cdr Glenn Walters**

SSA
Ships Support Agency

**Dr Fiona Winterbottom**

AEA TECHNOLOGY
PRODUCTS & SYSTEMS

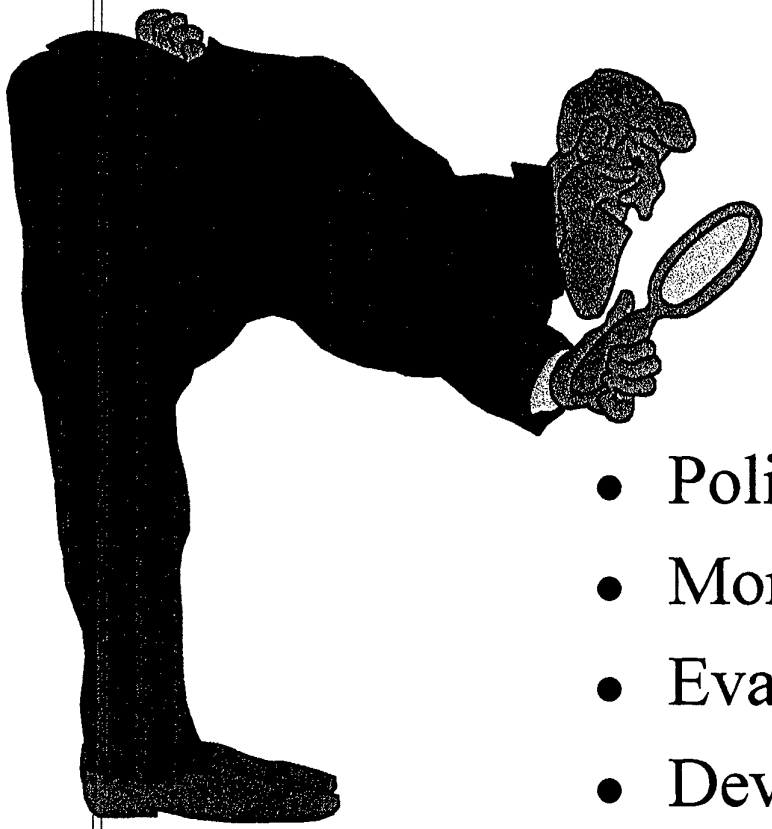
# Plasma Engineering for Pollution Control

## *Overview of presentation*

- Background
- Three case studies
  - Incinerator flue gas treatment
  - Air filtration
  - Diesel exhaust after treatment
- Summary


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# Environmental Strategy



- Policy
- Monitor
- Evaluate
- Develop
- Advise



Slide serial no 3

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# Non-Thermal Plasma

## *Principle of process*

- Input power converted into electron energy
- Electrons create free radicals
  - reactively hot
  - thermally cool
  - waste heat minimised
- Destruction of many species
  - NOx, SOx, dioxins, organics, particulates


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# Benefits of Plasma Treatment

***Simplicity and flexibility***

- ☑ Low cost manufacture
- ☑ Compact and robust
- ☑ New installation or retrofit
- ☑ Flexible
- ☑ Rapid response
- ☑ Ease of operation
- ☑ Simplicity for treatment of many pollutants


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# Application Areas

***Production viable development of technology***

- Industrial waste solvent treatment
- Air filtration
- Odour abatement
- Diesel exhaust after-treatment
- Incinerator flue gas clean-up


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# Case Study 1 - Incinerator Flue-Gas Treatment

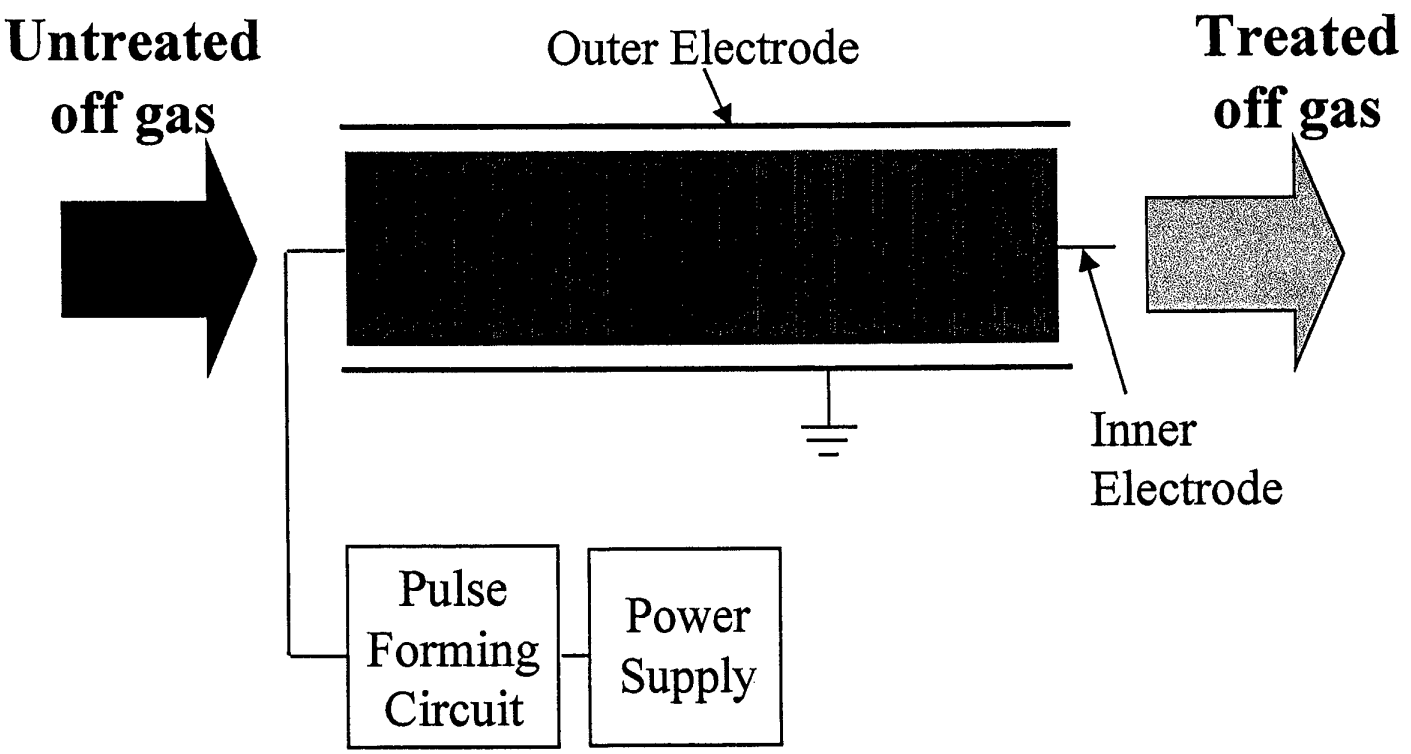
## *Product specification*

- Integrated after-treatment technology
- Modular construction
- Intermittent operational capability
- Reduce raw dioxin and furan concentrations
- NOx, SOx and VOC removal capability
- Power requirement < 15Whrs/$Nm^3$
- Operation between incinerator maintenance shutdowns


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# Case Study 1 - Incinerator Flue-Gas Treatment

## *Principle of operation*

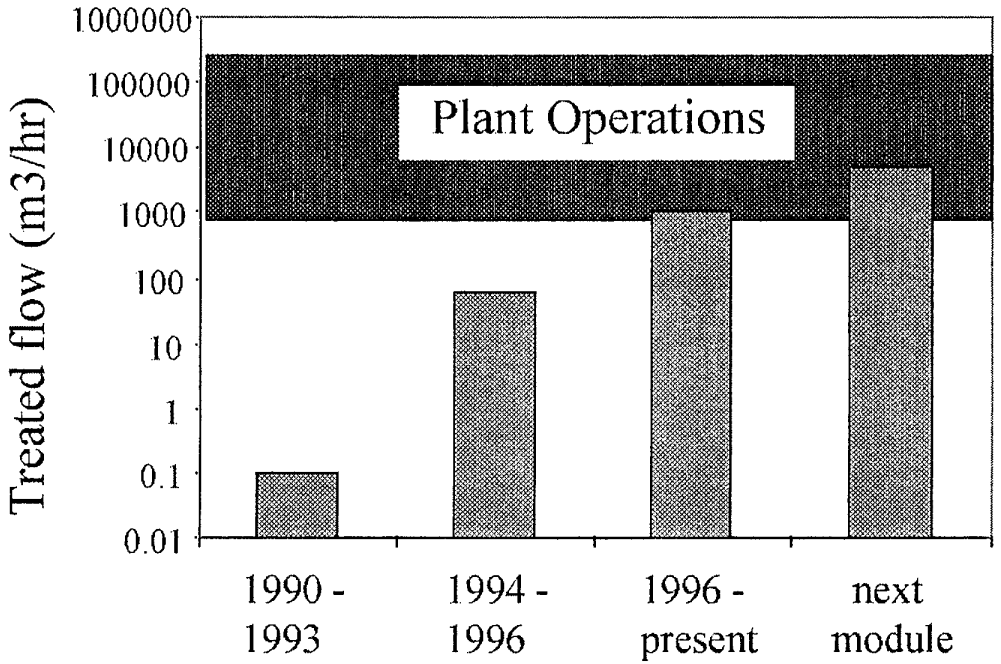



Slide serial no 8

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# AEA Technology Programme

## *Targeted pulsed corona development*





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# Confirmation of Operation

- Treatment capability:
  - 95% NOx
  - >90% SOx
  - 84% THC
  - >85% dioxin and furans
- Rapid response to application of power
- Deal with changing input concentrations


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# Operational Performance

- > 600 operational hours
- No degradation performance with time
- Reactors and materials > 3 years operation


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# Full-Scale Design

- Concept
  - single system to treat NOx, SOx, dioxins, furans, VOC and fine particulate
- Detail design
  - full-scale system capable of treating between 10,000 and 25,000 $m^3/h$


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# Case Study 2 - Air Filtration

## *Product specification*

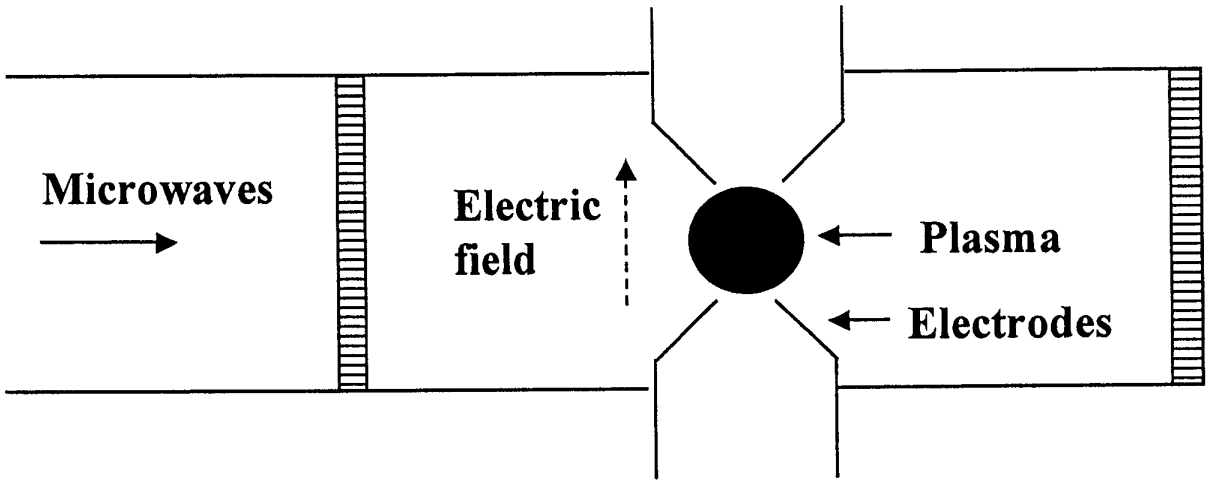
- Low cost compact treatment
- Integration into treatment solution
- Modular construction
- Halogenated species removal capability
- Intermittent operation capability
- Capability to handle spikes
- Potential for in-built sensor with feedback control




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# Case Study 2 - Air Filtration

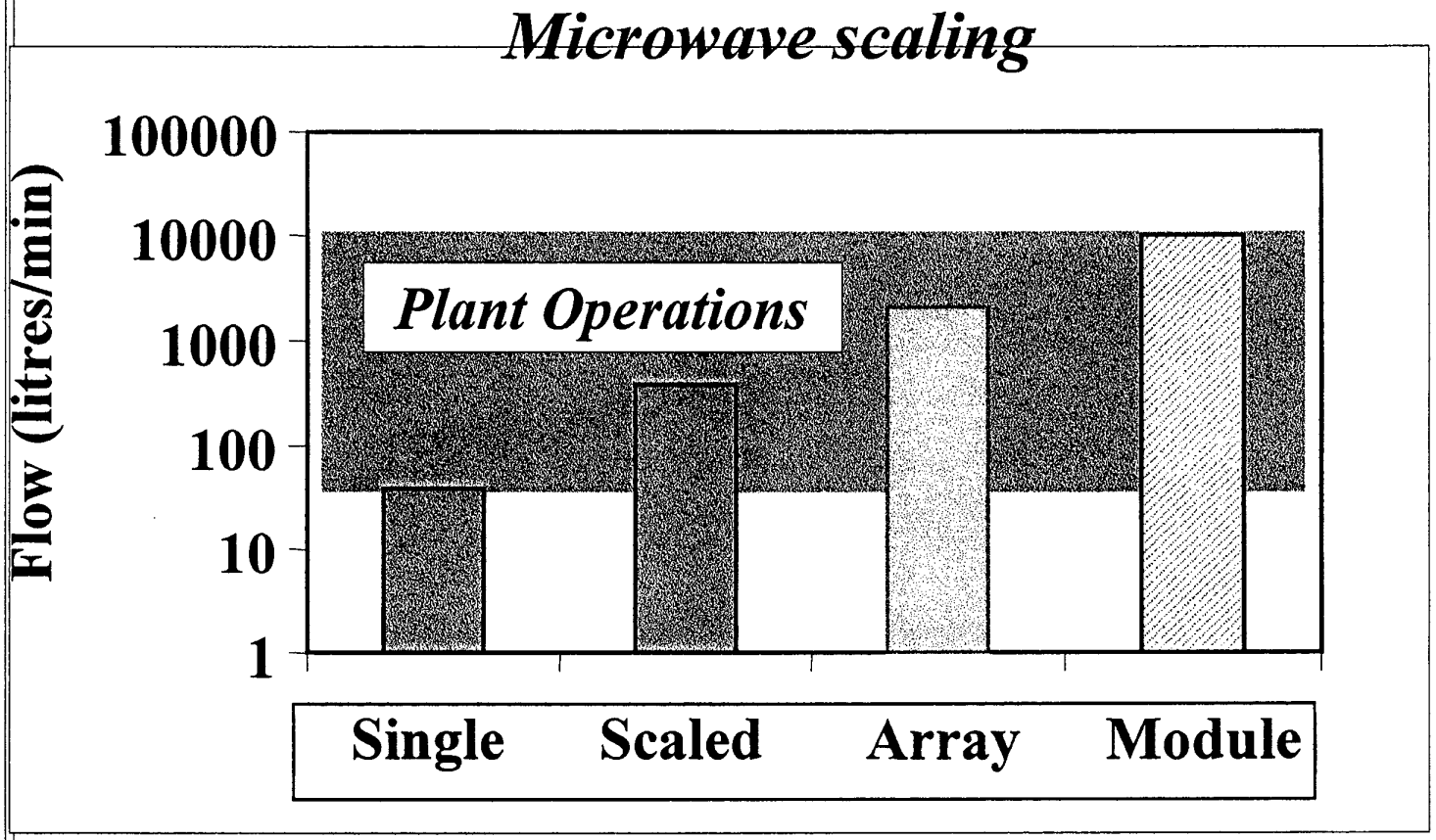
## *Principle of Operation*




Slide serial no 14

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# AEA Technology Programme

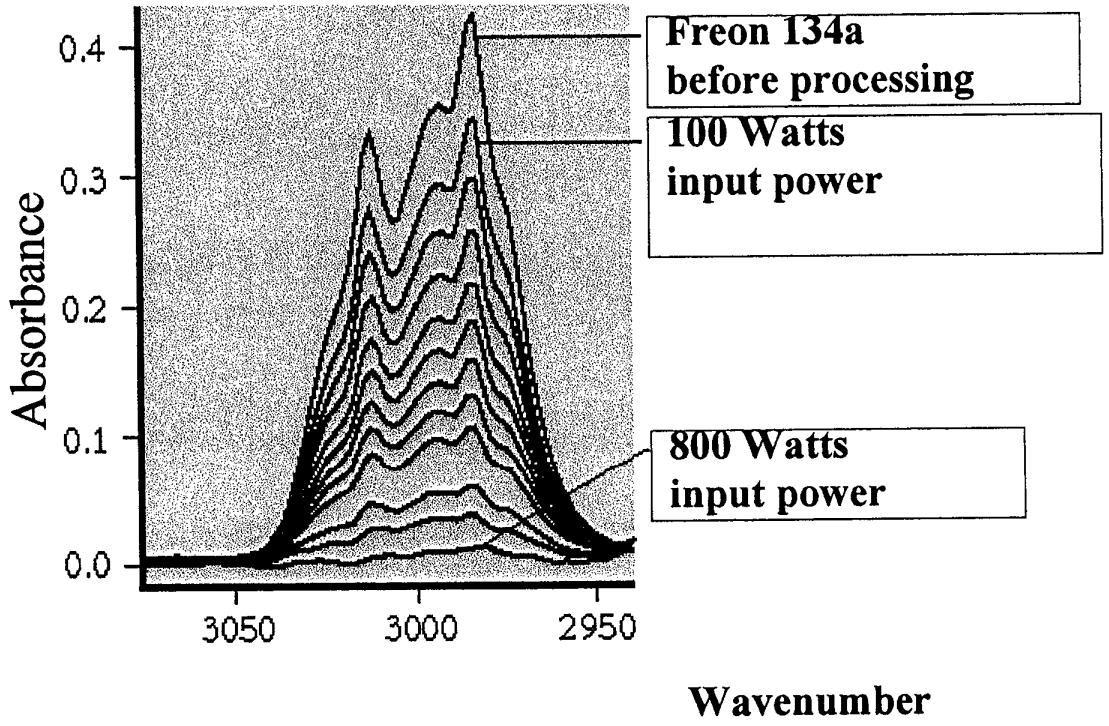




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# Confirmation of Operation

## *Freon 134a removal as a function of plasma power*





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# Case 3 - Diesel Exhaust After-Treatment

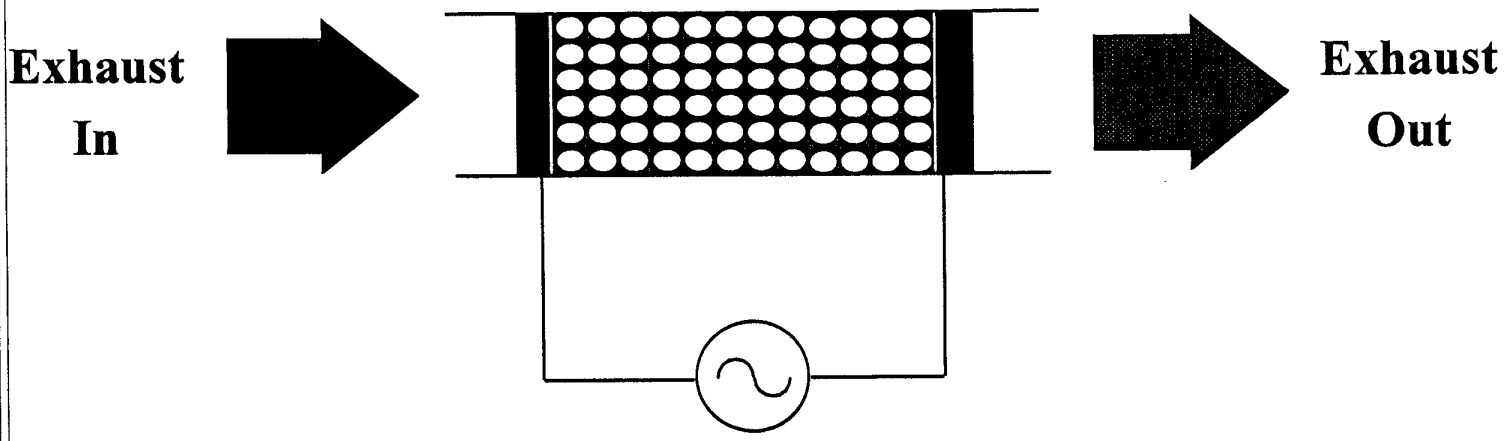
## *Product Specification*

- NOx reduction >90%
- Particulate reduction >70%
- Hydrocarbon reduction >80%
- Noise attenuation >25 dB(A)
- Weight 20-50% additional to silencer
- Space requirement equivalent to silencer
- Power increase <5%
- Lifetime of mean engine overhaul


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# Principle of Operation

- Surface discharge
- Electrically augmented catalyst
- Alternating high voltage
- Packed bed reactor



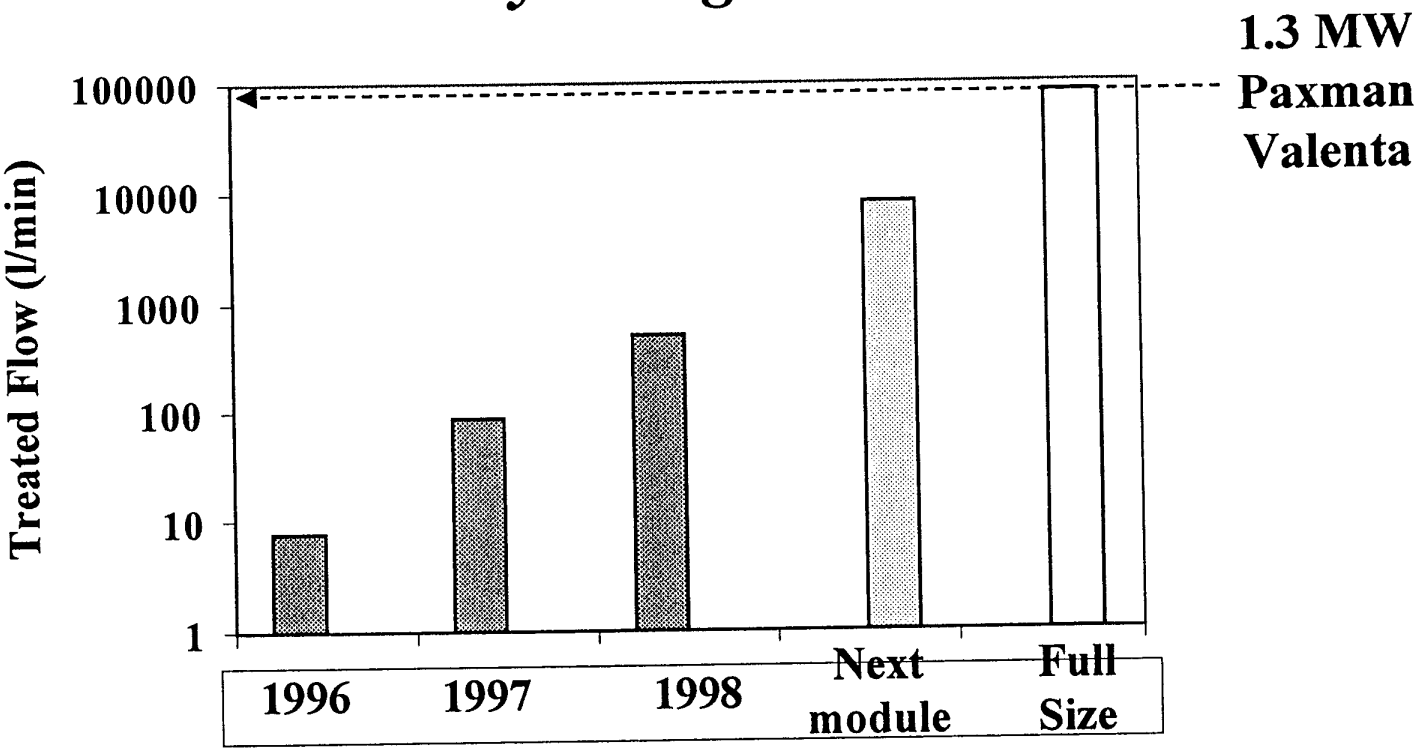



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# Evaluation

## *Laboratory to engine test bed*





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# Operational Performance

## *Small scale*

- Up to 97% NOx removal
- Flexible rapid control of NOx levels through control of applied power
- NOx performance not effected by fuel sulphur composition
- Particulate removal capability
- Removal of PAHs and aromatics


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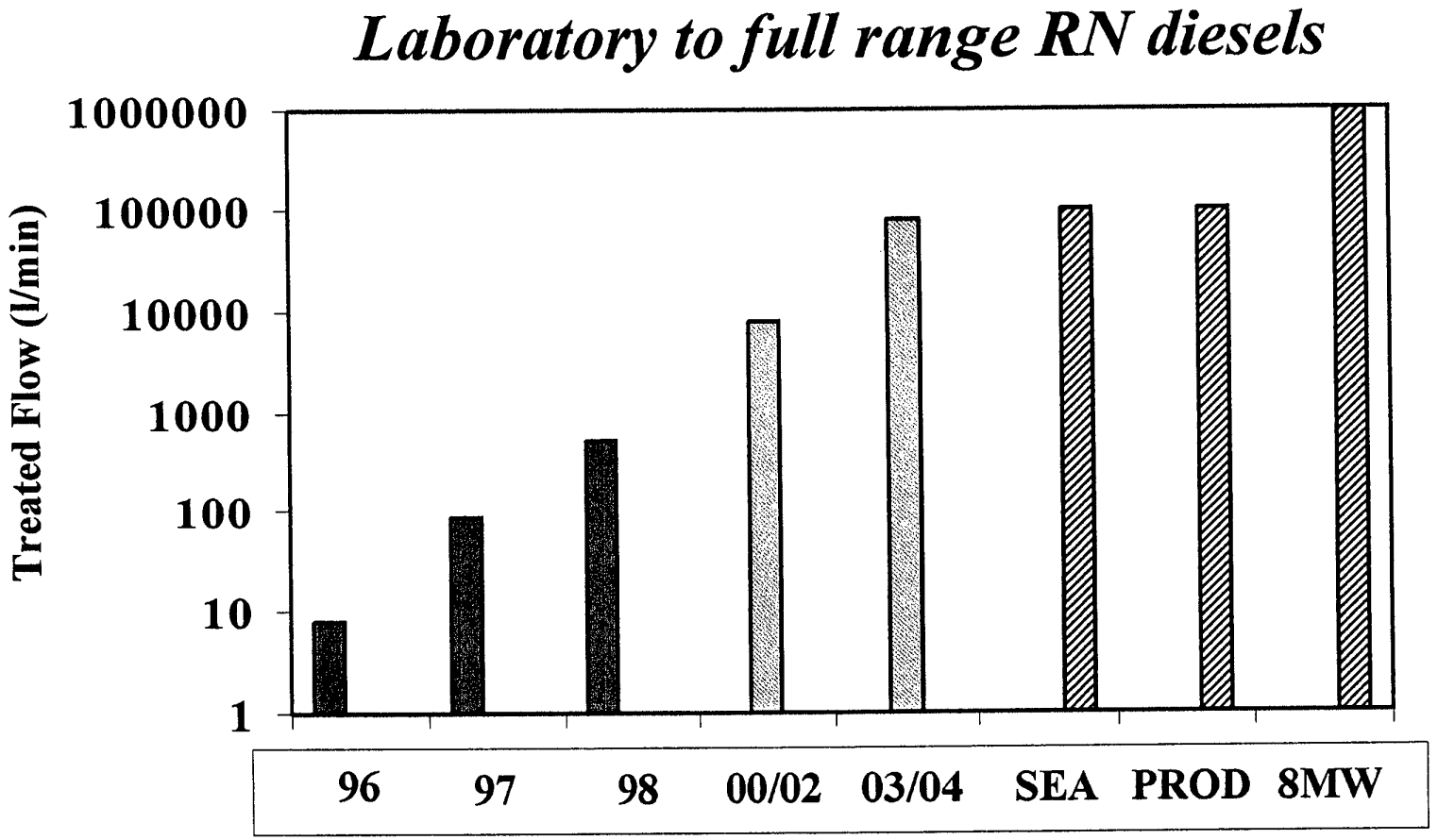
# Full-Scale System Design

***Combined NOx and particulate removal***

- Indicative conceptual design
- Ship Integration
  - Type 23 Frigate
  - ILS / ARM
- Safety Case
  - DEFSTAN 00-56, JSP 430, JSP 375 & JSP 418


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# The Way Forward




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# Development Potential

## *Environmental strategy*

- After-treatment as good as SCR
- Improved performance
  - ☑ low load
  - ☑ shock
  - ☑ transient response
  - ☑ fullest range of engine sizes
  - ☑ all environments (including submarines)
  - ☑ all MGO fuels

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# Summary - Plasma Technology

## *Marine applications*

☑*Cost effective*

☑***Simplicity*** **from simultaneous treatment of many pollutants**

☑***Flexibility*** **in meeting current and future emission legislation**


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# Treatment of off-Gas VOC and Odor Emissions from Ships and Other Point Sources Using Biotreatment Systems

**William J. Guarini, Todd S. Webster, A. Paul Togna, Brian Hooker and Hien Tran**

## Abstract

The passage of the Clean Air Act Amendments (CAAA) has justified the need for increased investigation into the treatment of air streams containing volatile organic compounds (V0Cs) and hazardous air pollutants (HAPs). In cooperation with the Office of Naval Research, North Island Naval Air Station (San Diego, CA) and ENVIROGEN have recently completed bench and field demonstrations and begun operation on a full-scale biotrickling filter reactor to treat V0Cs, HAPs, and odorous emissions from the North Island's industrial wastewater and oil recovery holding and load equalization tanks.

Bench-scale studies involved developing microbial cultures that could effectively treat gaseous emissions shipboard and four representative spray paint booth V0Cs; toluene, xylenes, methyl ethyl ketone (MEK), and n-butyl acetate. Using the characterized microbial cultures as inoculum, bench-scale testing demonstrated that target compounds could be simultaneously removed with greater than 95 percent efficiency in biotickling filters. In addition, over a three-year period, a 12 inch diameter column was tested using three different sizes of a proprietary random packing material under full-scale flow regime conditions. Operated under varying air velocities and liquid recirculation rates, pressure drops were demonstrated to be below 0.2" WC/ft for full-scale system flow regimes.

From the bench-scale study results, an optimal biotrickling filter support was selected and tested in a pilot-scale biotrickling filter reactor treating spray paint booth emissions generated at the North Island Naval Facility (San Diego, CA). The microbial cultures developed during the bench-scale experiments were used as inoculum. Four different vapor contact times (39, 28, 16, and 11 seconds) were tested and conditions were optimized to achieve maximutn VOC removal. The intermittent operation of the spray paint booth created unsteady organic loads to the biotrickling filter. Total VOC and HAP removal efficiencies ranged from 70 to 100 percent. These experiments, including the results and methods used to maintain steady performance for treatment of intermittent loads are discussed.

Session 2
Speaker Mr. William J. Guarini

The last speaker of session 2 is Mr. William Guarini.

Mr. Guarini is the Vice President of ENVIROGEN, INC., Laurenceville, New Jersey. He is also Project Manager for ENVIROGEN's government projects including the Navy's biotrickling projects and the Air Force's bioaugmentation project for chlorinated solvents and a biofilter project for gaseous emissions.

His previous assignments were
- Manager, Commercial Development/Process Design Engineer for Halcon/Scientific Design Company
- Senior Development Engineer, EXXON Chemical Co.
- Marketing Manager, American Nukem

Mr. Guarini will now present his paper on
"Treatment of Off-Gas, VOC and Odor Emissions from Ships and other Point Sources Using Biotreatment Systems"

# PRESENTATION TO

# MARITIME CONFERENCE

# ON

# TREATMENT TECHNOLOGIES FOR

# GASEOUS EMISSIONS FROM SHIPS

134




ENVIROGEN

# Treatment of Gaseous Emissions Using Biological Treatment Technologies

**William J. Guarini, Todd S. Webster, A. Paul Togna**

**Envirogen, Inc.**
**and**
**the U.S. Navy Office of Naval Research**






# *ACKNOWLEDGMENTS*


- U.S. Navy
  - Small Business Innovation Research Program
    - Doug Harry
- Office of Naval Research
  - Linda Chrisey
- Naval Air Station North Island
  - Ed Bonnes
  - Mike Magee
  - Christina Graulau
  - Hector Padilla
  - Steve Sanford
  - James Sanfedele
  - Joe Olson





ENVIROGEN

# Presentation Outline

- Brief "Who is Envirogen?"
- Advantages of Biotechnology
- Project Objectives Phase I and II
- Project Results Phase I and II
- Conclusions




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# *Envirogen's Mission*

**Environmental Biotechnology Company**

**Providing Innovative Solutions for Treating**

**and Degrading Hazardous Wastes**




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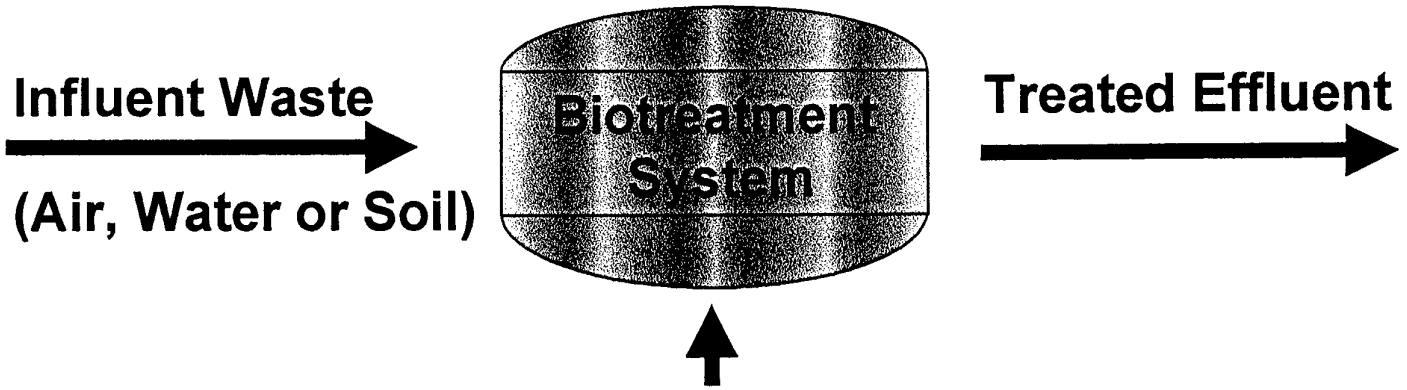
# *Envirogen's Offices*

- **Lawrenceville, NJ (Corporate Headquarters)**
- **Milwaukee, WI**
- **Lansing, MI**
- **Boston, MA**
- **Houston, TX**
- **Geneva, IL**




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# Systems Approach to Biodegradation




**1 MICROORGANISM SELECTION**

- Based on Targeted Chemicals in Waste Stream

**2 SYSTEM SELECTION**

- Suspended Growth
- Biotrickling Filter
- Biofilter
- Bubble Column
- Membrane
- Fluidized Bed
- Soil Slurry
- Composting
- Biopile
- Bioventing
- Biosparging

**3 APPLICATIONS KNOW-HOW**

- D.O., Nutrients
- Temperature, Moisture, pH
- Bioavailability
- Geotech
- Co-substrates
- Substrate Loading
- Monitoring

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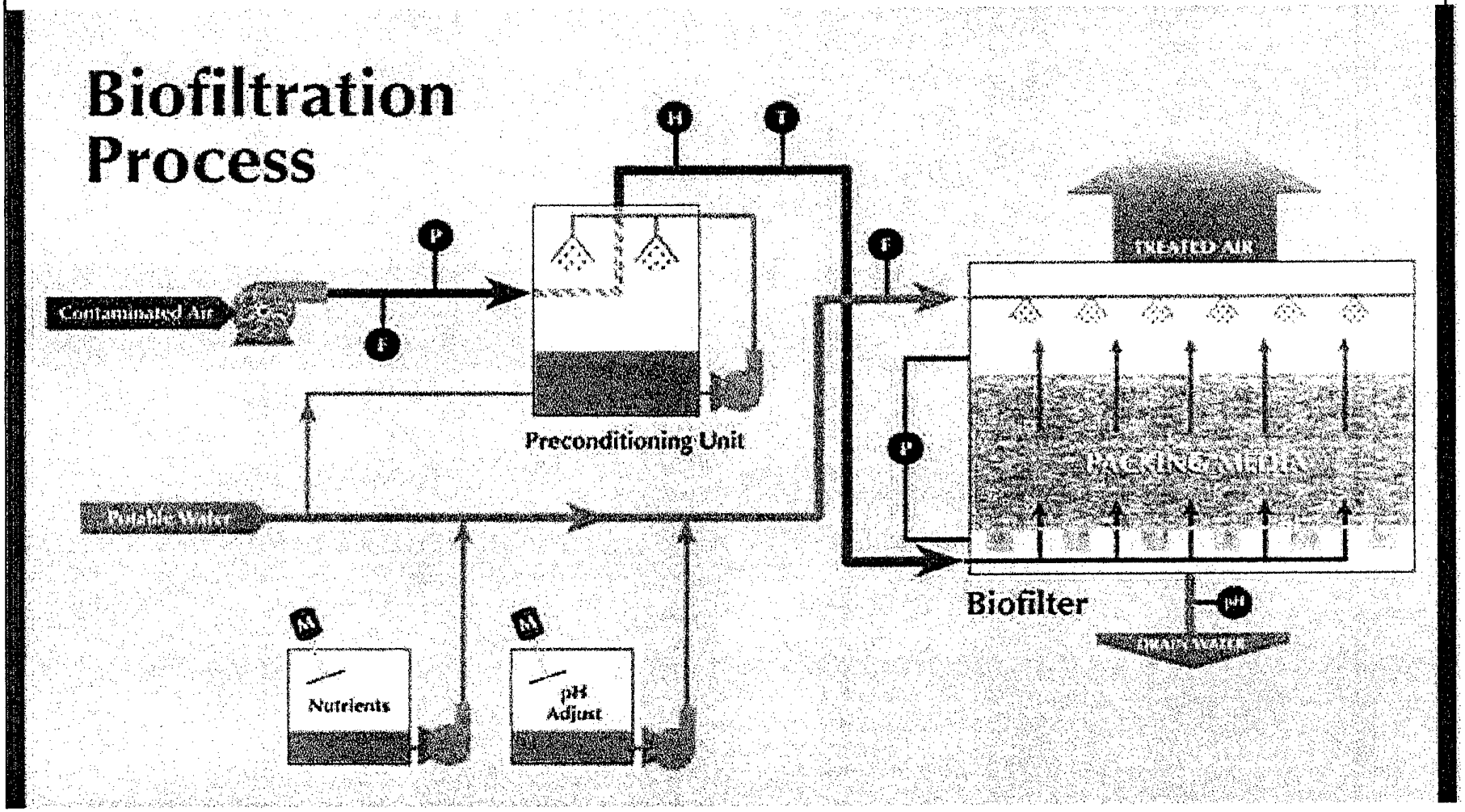
# *The Advantages of Biotechnology in Environmental Restoration and Protection*

- **Lower Costs**
- **Destruction of Toxics**
- **On Site Treatment**
- **Natural Solution**



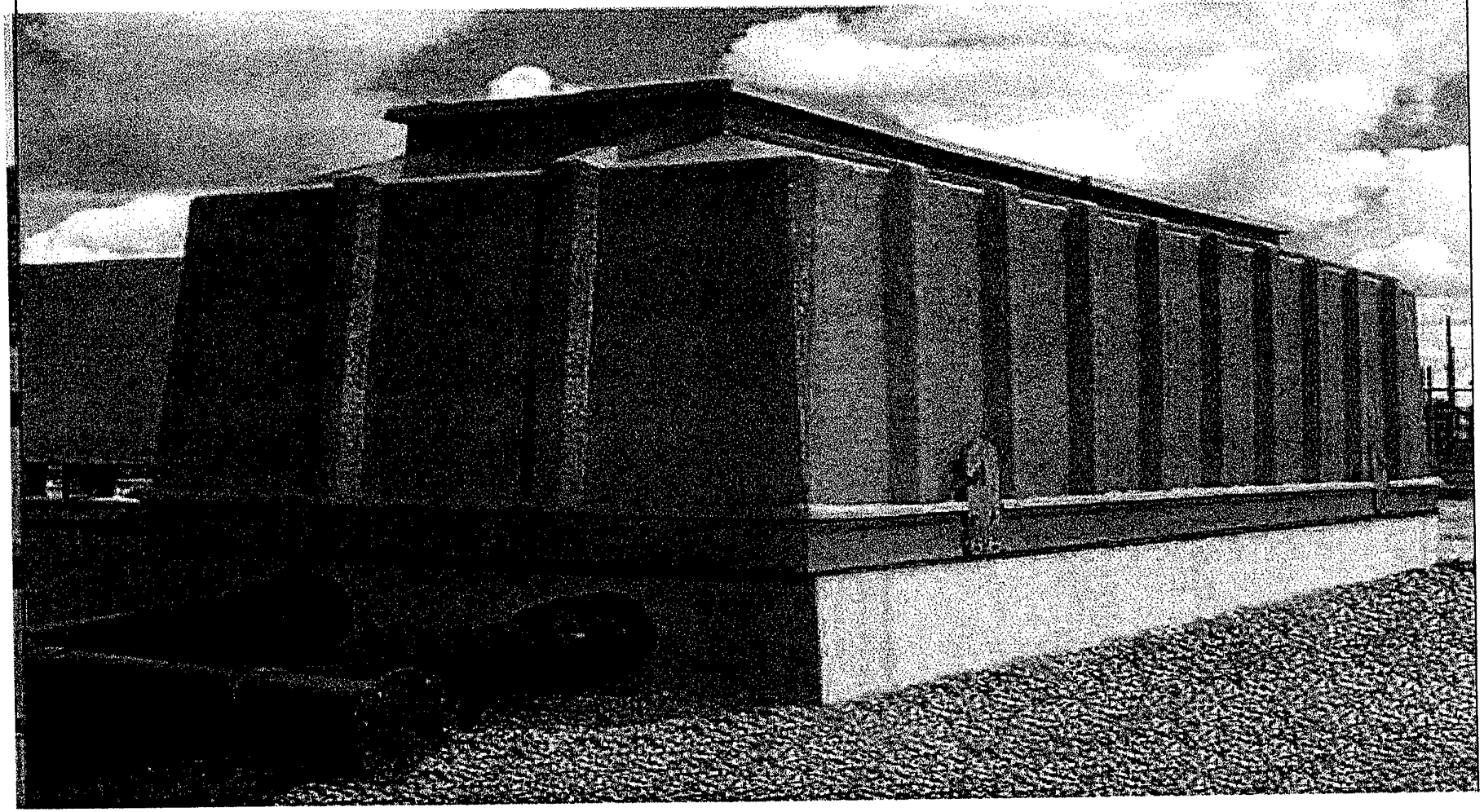

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# Biofiltration Process




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# Envirogen's P600 Modular Biofilter



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# *What Compounds Are Treatable?*

- Alcohols
- Aldehydes and Ketones
- Non-Chlorinated Solvents
- Aromatic Hydrocarbons
- Aliphatic Hydrocarbons
- Selected Chlorinated Solvents
- Hydrogen Sulfide
- Carbon Disulfide
- Mercaptans
- Odor-Causing Compounds

# *Under What Conditions?*

- Readily biodegradable compounds
- Concentrations typically less than 1,000 to 2,000 ppmv
- Appropriate temperature and moisture
- Typical gas contact times of 10 to 30 seconds for odors
- Typical gas contact times of 20 to 45 seconds for VOCs




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# *Traditional Biofiltration Applications*

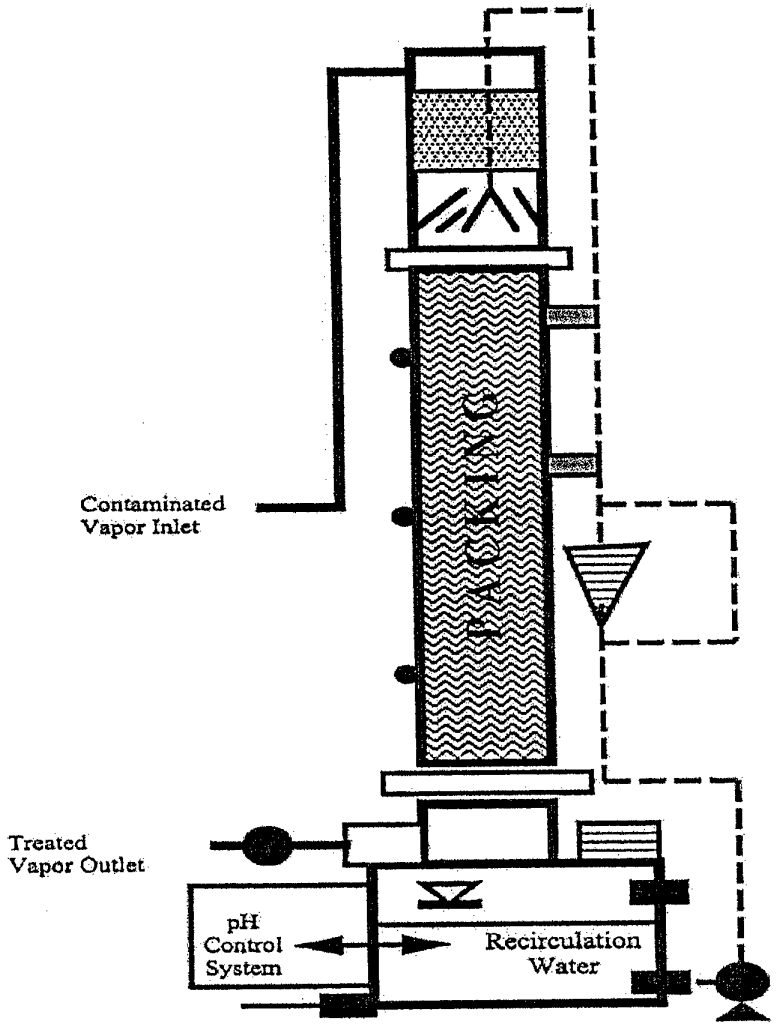
- **Sewage treatment plants**
- **Compost facilities**
- **Rendering plants**
- **Slaughter houses**
- **Agriculture Industry**
- **Food Industry**
- **Fragrance Industry**






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# Biotrickling Filter






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# *Project Objectives*

- **Bench-Scale**
  - **Determine the feasibility of using biological systems to control odorous vapor emissions from sewage, garbage and oily bilge tanks on Navy vessels**
  - **Screen microbial cultures**
  - **Demonstrate target compounds can be degraded in biotrickling filters**
  - **Screen three different packings**
  - **Develop flow regime characteristics for full-scale biotrickling filters**








# *ONR Phase 1 SBIR Project*
# *Target Compounds*

- **Hydrogen sulfide**
- **Methyl mercaptan**
- **Butyric acid**
- **Propionic acid**
- **Toluene**
- **Xylenes**
- **Methyl ethyl ketone**
- **n-butyl acetate**



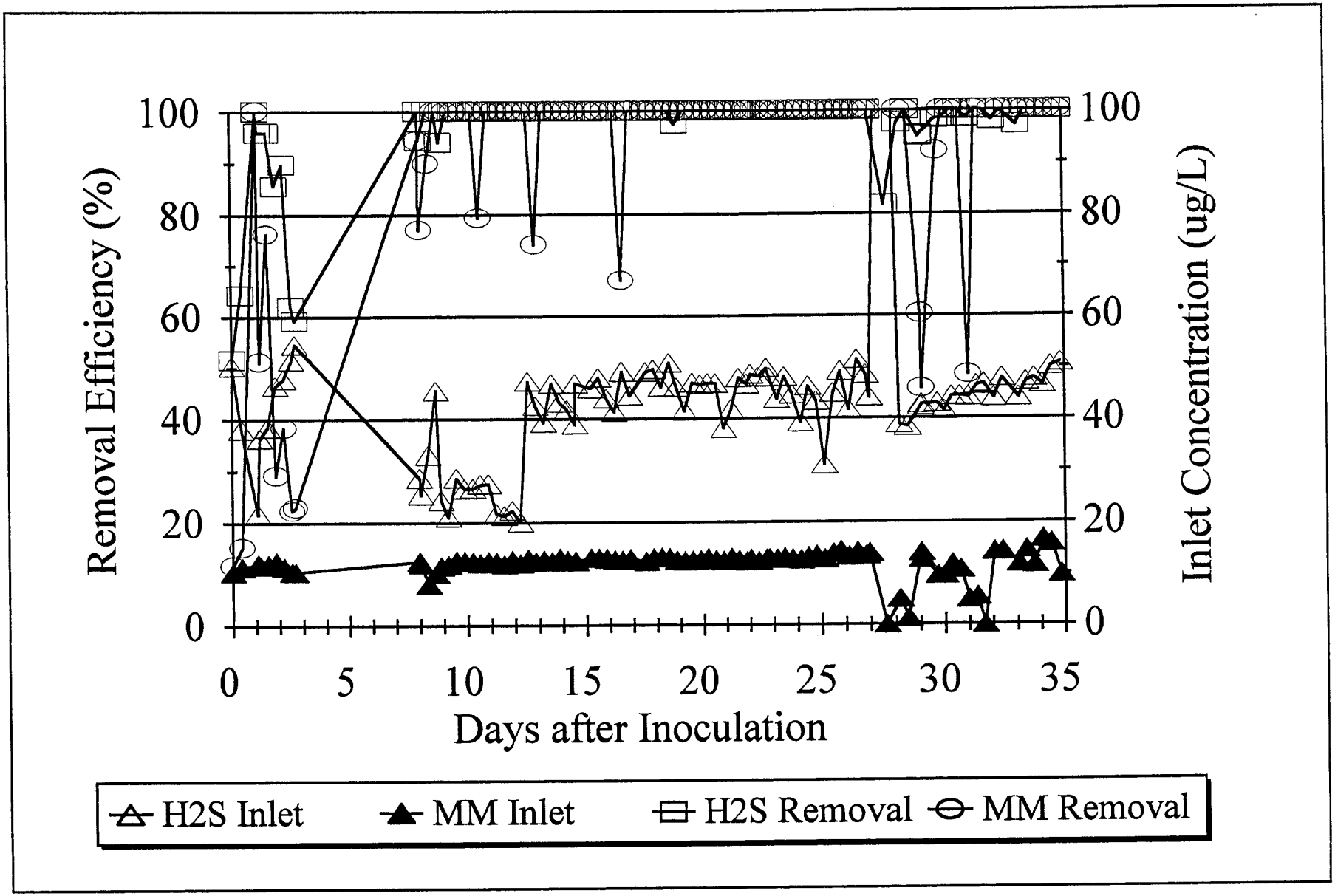

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# ONR - Phase 1 -- SBIR Project Results

- 3 mixed and 2 pure cultures capable of growing on propionic acid (garbage odor)
- 2 mixed and 1 pure culture capable of growing on butyric acid (garbage odor)
- 1 mixed and 2 pure cultures capable of growing on toluene (paint emission)
- 2 mixed and 3 pure cultures capable of growing on xylenes (paint emission)
- 2 mixed and 1 pure culture capable of growing on MEK (paint emission)
- 3 mixed and 5 pure cultures capable of growing on n-butyl acetate (paint emission)
- 1 mixed culture capable of degrading $H_2S$ and methyl mercaptan (sewage and oily bilge)
- 1 mixed culture capable of degrading toluene, xylene, MEK, and n-butyl acetate (paint)

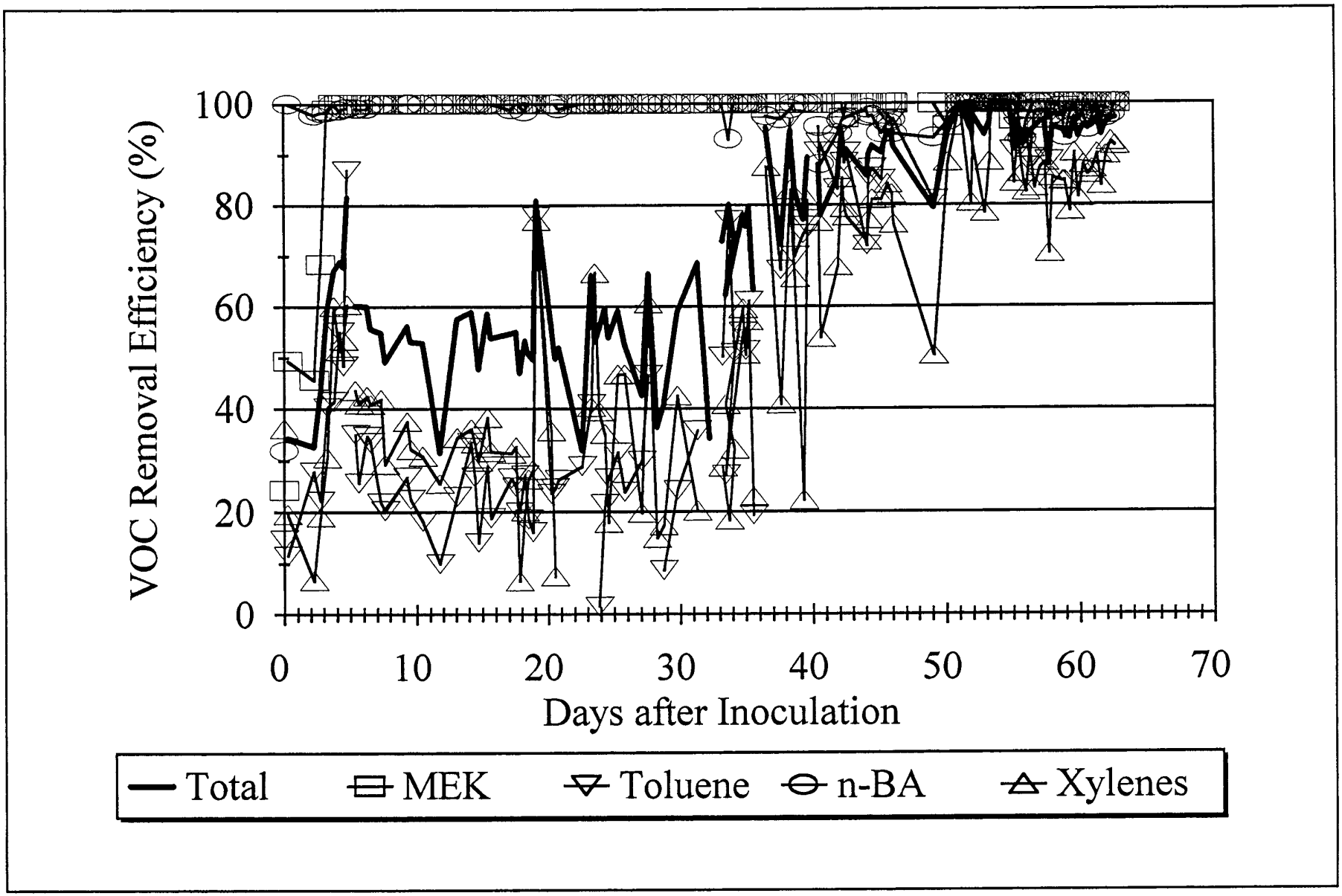


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Removal Efficiency (%)
Inlet Concentration (ug/L)
100
80
60
40
20
0
0
5
10
15
20
25
30
35
Days after Inoculation
H2S Inlet
MM Inlet
H2S Removal
MM Removal


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VOC Removal Efficiency (%)
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Days after Inoculation
Total
MEK
Toluene
n-BA
Xylenes


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# *Project Objectives*

- **Pilot-Scale**
  - **Demonstrate performance for transient loads**
  - **Operate under various loading conditions**




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# *Pilot-Scale Set-Up*

- North Island Naval Station (San Diego CA)
- Spray Paint Booth Operation
  - 4 to 5 days a week, 6 to 8 hours a day
  - Primary VOCs: toluene, MEK, MIBK, xylene, and n-butyl acetate
- Pilot Reactor
  - 0.47 $m^3$ of packing, stainless steel, concurrent operation, computer controlled
  - Vapor contact times: 11, 16, 28, and 39 seconds

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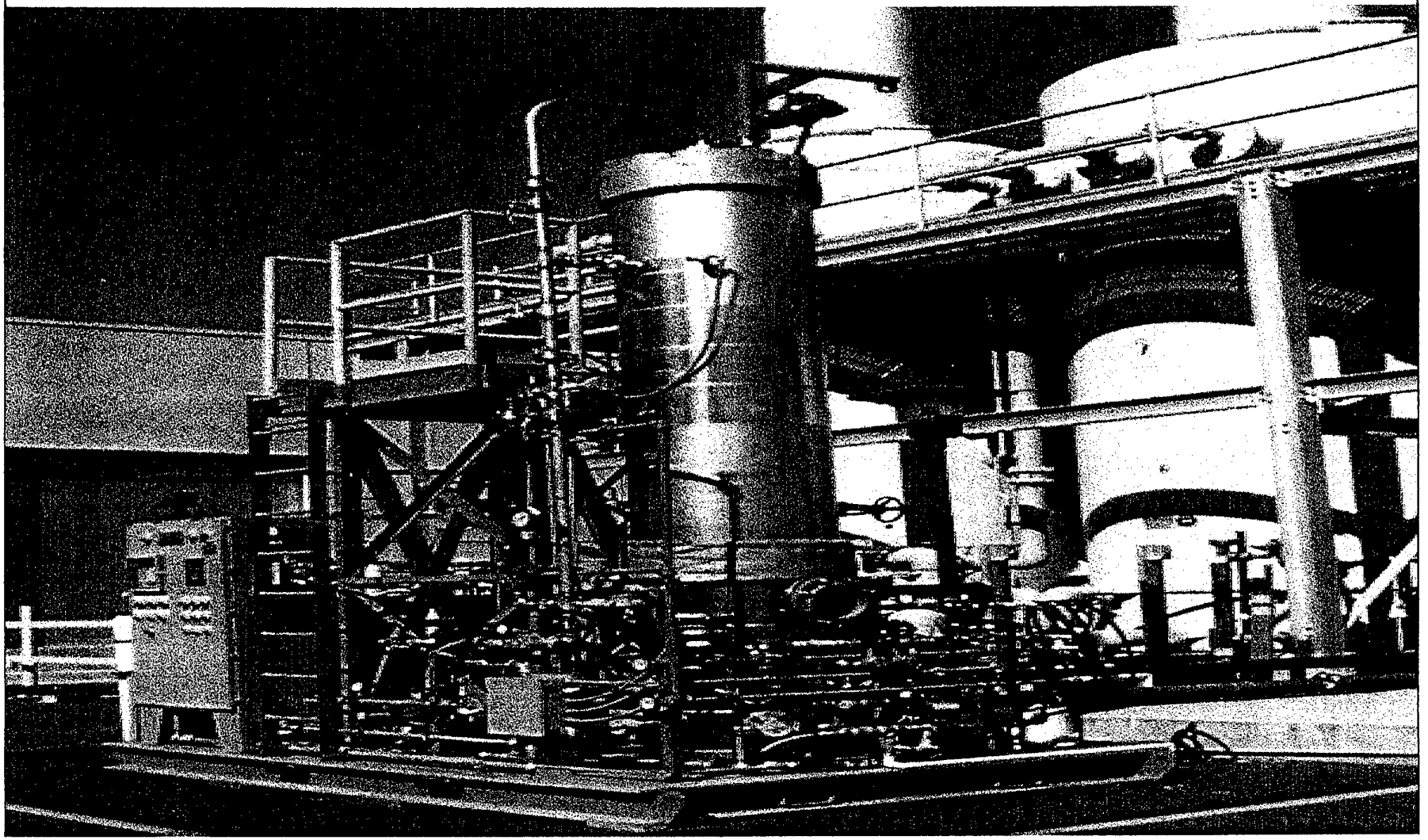
# *Pilot-Scale Findings*

- Intermittent loading conditions did not hamper reactor performance
  - Upon morning start-up, absorption dominated
  - As the day progressed, biological activity increased
- Long periods of no loading to the system did not affect performance once loading was restarted
- Nitrification was a concern during no loading conditions but was controlled

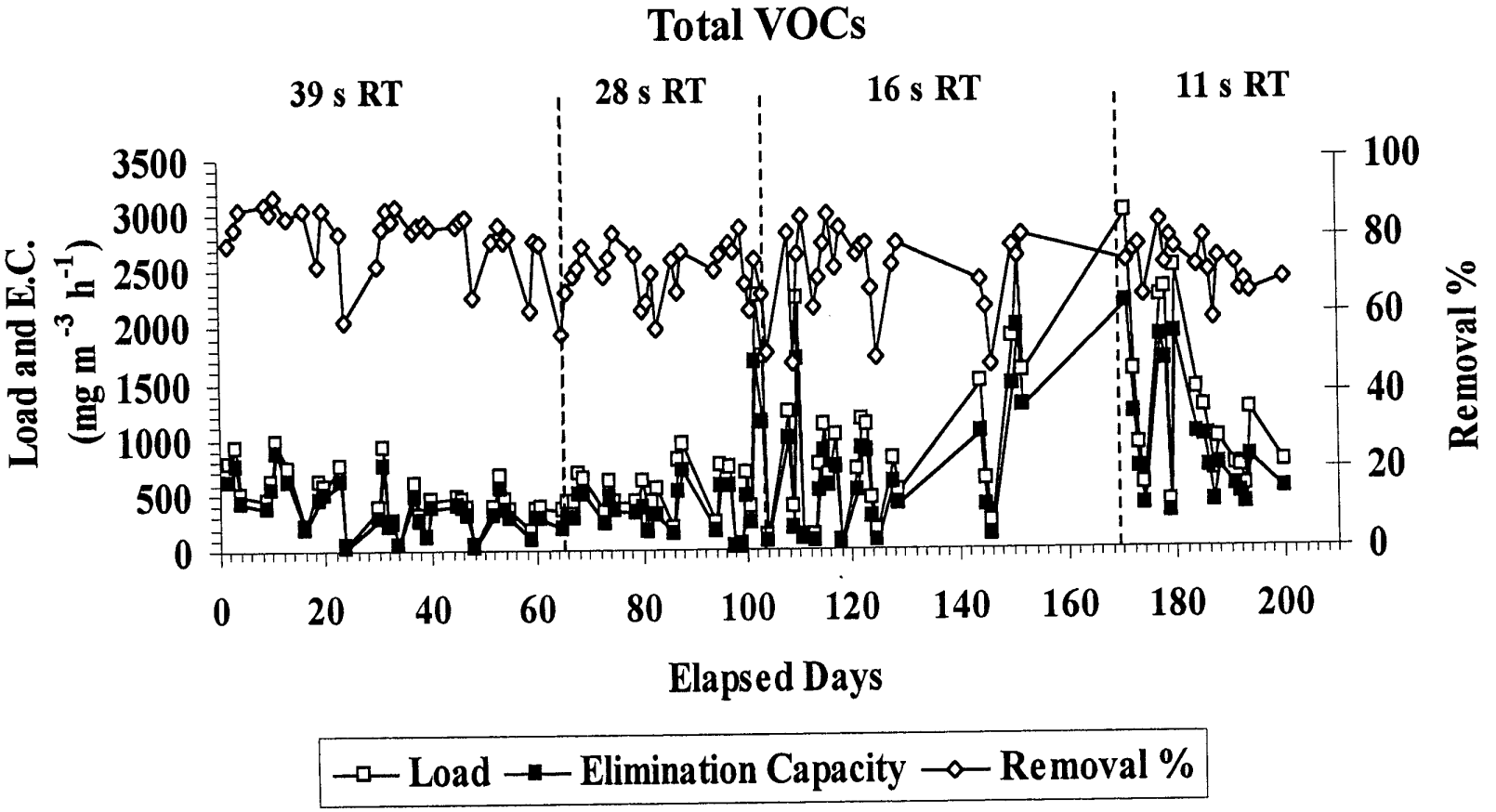


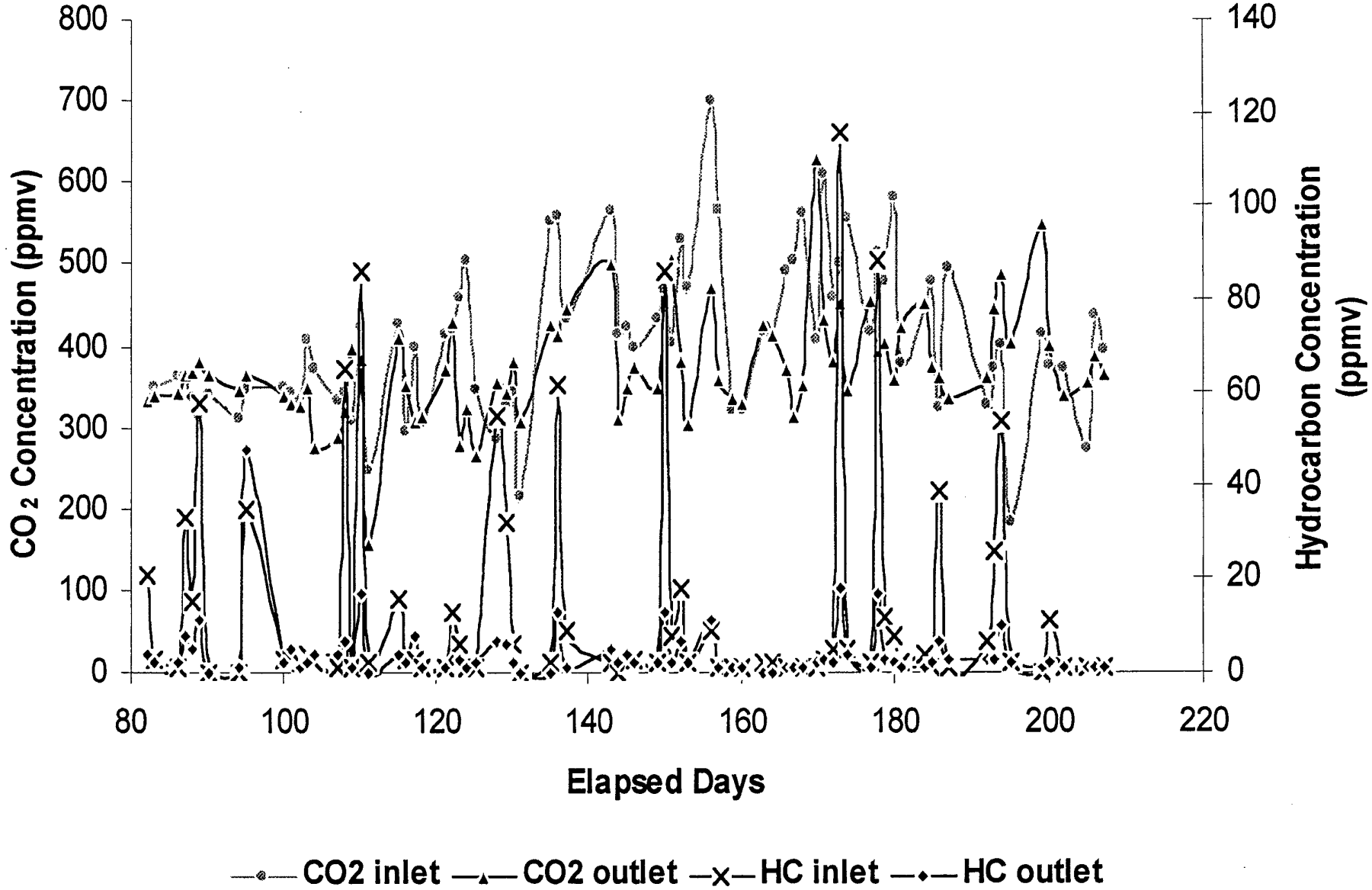

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# Envirogen's Biotrickling Filter

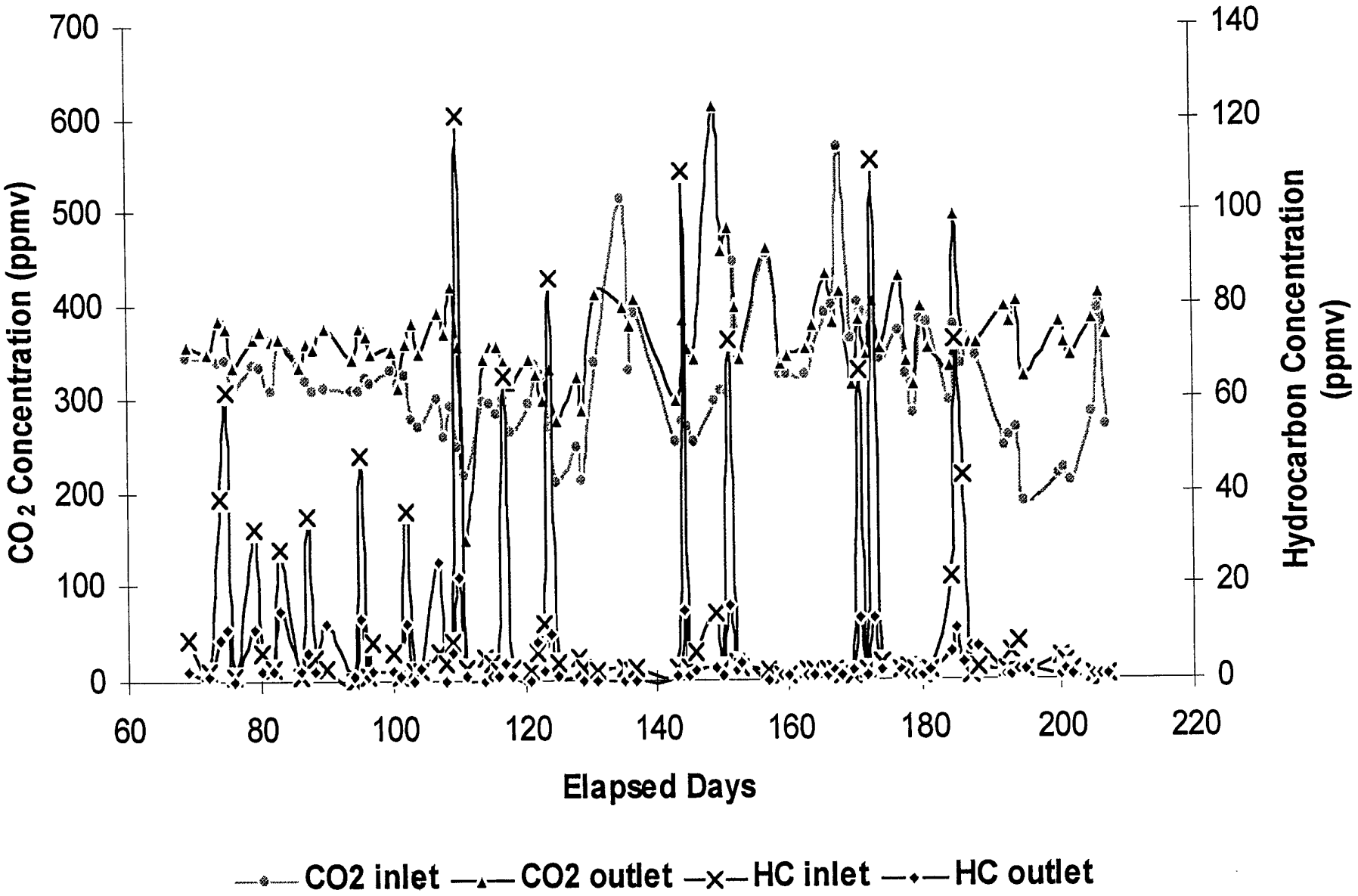


# Total Targeted HAPs Removal Efficiency Results

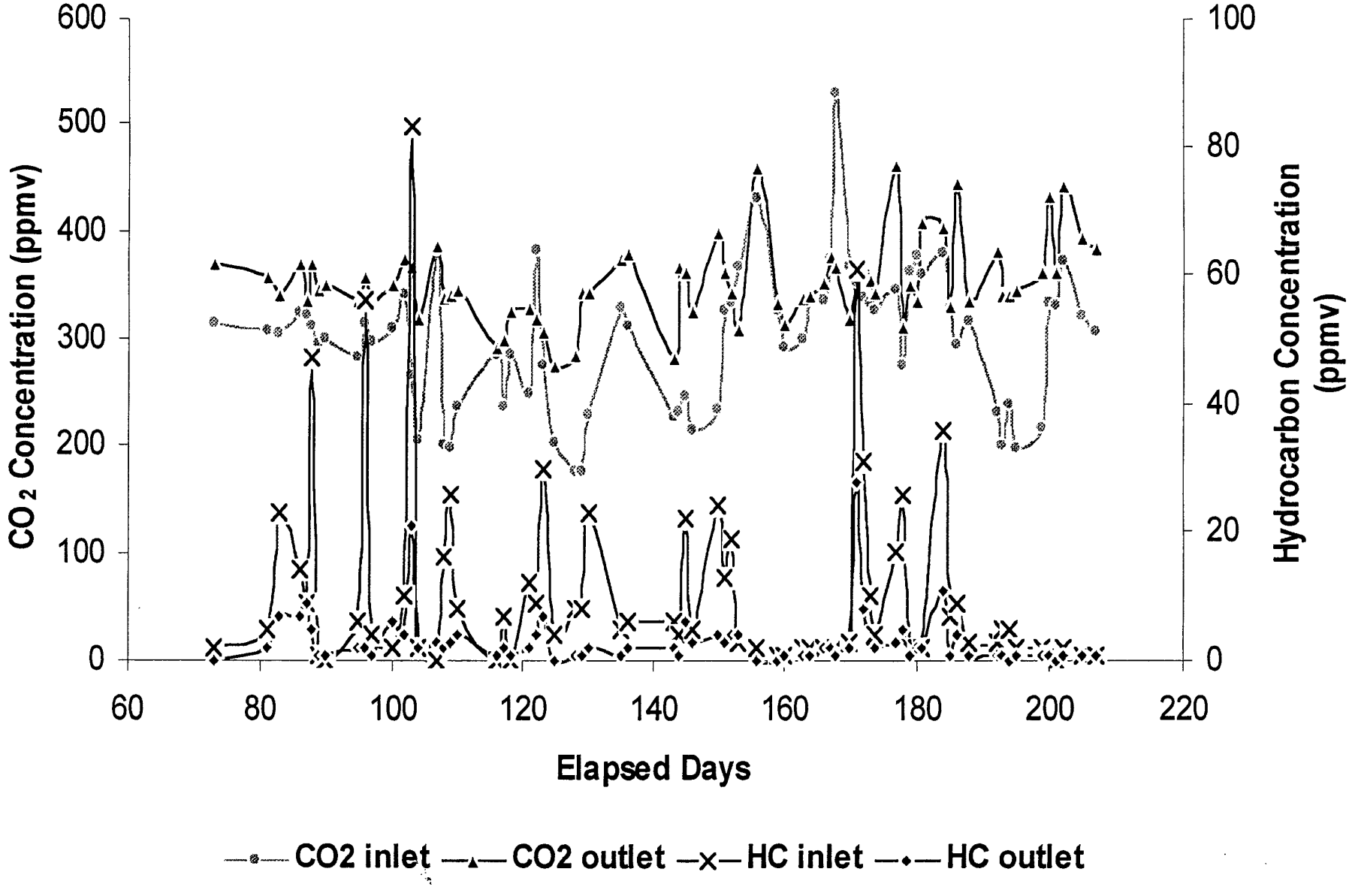



$CO_2$ and Hydrocarbon Inlet and Outlet Data (10:00 AM)
$CO_2$ Concentration (ppmv)
Hydrocarbon Concentration (ppmv)
800
700
600
500
400
300
200
100
0
140
120
100
80
60
40
20
0
80
100
120
140
160
180
200
220
Elapsed Days
CO2 inlet
CO2 outlet
HC inlet
HC outlet

# $CO_2$ and Hydrocarbon Inlet and Outlet Data (12:00 PM)



# $CO_2$ and Hydrocarbon Inlet and Outlet Data (3:00 PM)



# *Conclusions*

- **Removal efficiencies were greater than 95% for MEK, MIBK, and n-butyl acetate under various loading conditions**
- **Total target HAPs removal exceeded 88%at and above a 16 second vapor contact time**
- **Intermittent operation did not affect system performance**








# • The Maritime Environment •

## "Treatment Technologies for Gaseous Emissions from Ships"

## Session 3

### Reducing Ozone Depleting Substances and other Greenhouse Gases – Impact of the Implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry –

**Session Chairman:** ***Dipl.–Ing. Volker Behrens*****, NOSKE–KAESER GmbH, GE**

# Development of Refrigeration Agents from R12 to Halogen Free Substances

**Dipl.–Ing. Volker Behrens, NOSKE–KAESER GmbH, GE**

## Abstract

The presentation is divided into three main parts.

After a short introduction of the enterprise NOSKE-KAESER I will start with the first part, which is about the physical basics of the ozone destruction by chlorine contained carbon-hydro-oxide as also an explanation of some basic expressions.

The second part shows the up to date level of refrigeration agents in cooling plants as also their influences for the environment. The main topics are on the one hand the destruction of the ozone shield and on the other hand the global-warming-up caused by carbon dioxide emission.

The last part affords an insight into possible development of new potentialities for the use of refrigeration agents.

This part ends with a short resume.

Chairman Session 3
Dipl.-Ing Volker Behrens

Ladies and Gentlemen,

I am very pleased to introduce Mr. Volker Behrens who will act as the Chairman; Session 3.

Mr. Behrens joined the German Navy in 1984 where he studied Mechanical Engineering and Economy Management. He worked as ships engineer on mine sweepers and destroyers and as teacher at the Naval Technical School in Kiel. He left the Navy as Lt Cdr and started a new career at Noske-Kaeser, a major producer of refrigeration and air-condition equipment.
He is now sales division manager for merchant ship systems.

Mr. Behrens will now present his paper on
"Development of Refrigeration Agents from R12 to Halogen Free Substances"

Mast- und Schotbruch, Herr Behrens!

NOSKE-KAESER

# DEVELOPMENT OF REFRIGERANTS FROM R12 TO HALOGEN-FREE SUBSTANCES

**Presented by:** **Volker Behrens, MSC**
Noske-Kaeser GmbH
Schnackenburgallee 47-51
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Tel.: 0049/40/8544-2391
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NOSKE-KAESER

# Development of Refrigerants

# from R12 to Halogen-free substances

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# 1 Introduction

In the 80s and the 90s, the discovery and research of the effects of substances containing HCFC on the ozone layer of the earth resulted in fundamental new insights and developments. In addition to the propellants in spray cans, the halon gas used in stationary fire extinguishing systems as well as the refrigerants containing HCFC – highly esteemed due to the high safety standards – became the target of criticism. By consequence and as a result of various international agreements, alternative environmentally compatible products had to be developed or rediscovered. In the area of refrigerants, this development process has made great progress. Today, all relevant technical refrigeration processes are possible with environmentally compatible agents which are free of HCFC.
This contribution will briefly outline the physical and chemical basics as well as the legal situation before describing the state of the art of refrigeration systems for ships. The agents substituting the substances containing HCFC will be summarized and the pertinent problems concerning the technical implementation of the corresponding systems outlined.
This contribution is not intended to give a final and all-comprehensive presentation – particularly so in view of the fact that developments can be expected in the future which will account for the second environmental problem, the greenhouse effect.

# 2 Physical-chemical basics and the legal situation

## *2.1 Effects of HCFC in the stratosphere*

The ozone ($O_3$) in the stratosphere (15 to 40 km altitude) protects the earth's surface from ultraviolet radiation (UV) by means of absorption. There is a balance reaction concerning the ozone depletion and regeneration. Chlorine atoms from refrigerants, foams and cleaning agents disturb this equilibrium. When an HCFC molecule is broken up, molecular oxygen ($O_2$) and atomic chlorine result. Within the framework of reciprocal reactions, this chlorine atom can react with up to an additional 100,000 ozone molecules before it becomes inactive.

The rise of the HCFC to the stratosphere and the time it remains in the atmosphere are considered to be several decades.

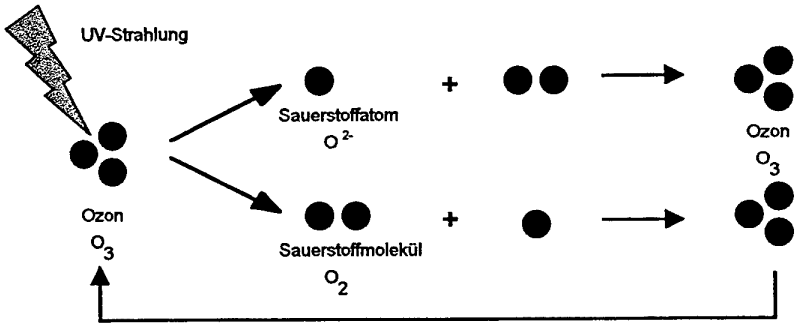



**Fig. 1.1a: Absorption of the UV radiation through ozone ($O_3$) and the corresponding balance reactions[ 2.1 ]**

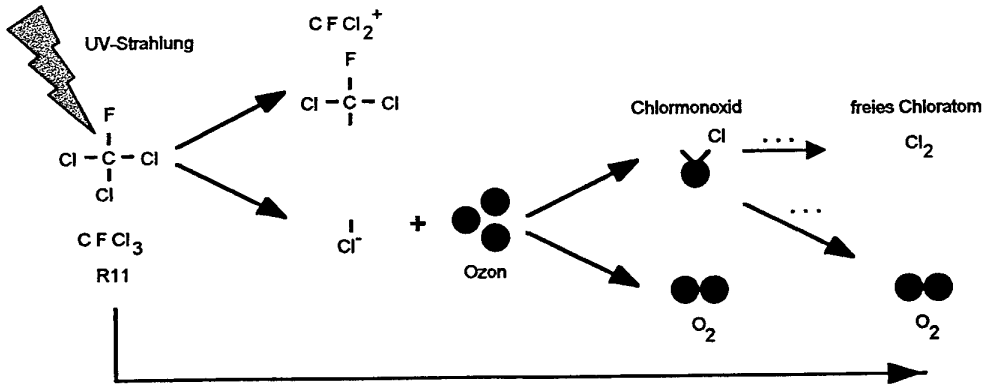



**Fig. 1.1b: Depletion of the ozone layer, example of R11 ($CFCl_3$) [2.1]**

Three factors are used to determine the environmental compatibility of refrigerants:

## 1. Ozone Depletion Potential ODP [R12 equivalent]

The degree of harmfulness depends on the amount of chlorine in the molecule of the refrigerant. Due to its high chlorine concentration, R12 is used as a reference to determine the ozone depletion potential. Therefore, by definition, the ODP value of R12 is 1.0. For example, the ODP value of R22 is 0.05, i.e. it is 20 times smaller.

## 2. Global Warming Potential GWP [$CO_2$ equivalent]

If the atmosphere did not contain climate-relevant trace gases ($H_2O$, $CO_2$, $O_3$, $N_2O$, $CH_4$), the temperature at the earth's surface would be -18°C. Due to these so-called greenhouse gases, a part of the heat radiation (infrared radiation) is absorbed in the atmosphere, resulting in a mean ground level temperature of + 15°C [2.5].
In the upper air layers, refrigerants contribute to the warming up of the atmosphere. The so-called GWP (Global Warming Potential) is used to rate the corresponding effect. Carbon dioxide ($CO_2$) serves as the reference value. The GWP value thus describes the greenhouse potential with reference to carbon dioxide ($CO_2$). In the atmosphere, one kilogram of R22 (GWP = 1650) has the same greenhouse potential as 1650 kilograms of $CO_2$. As compared to R12 (GWP = 7100) or R502 (GWP = 4300) this is a relatively low greenhouse potential. With a GWP of 1300, R134a offers a more favorable result.

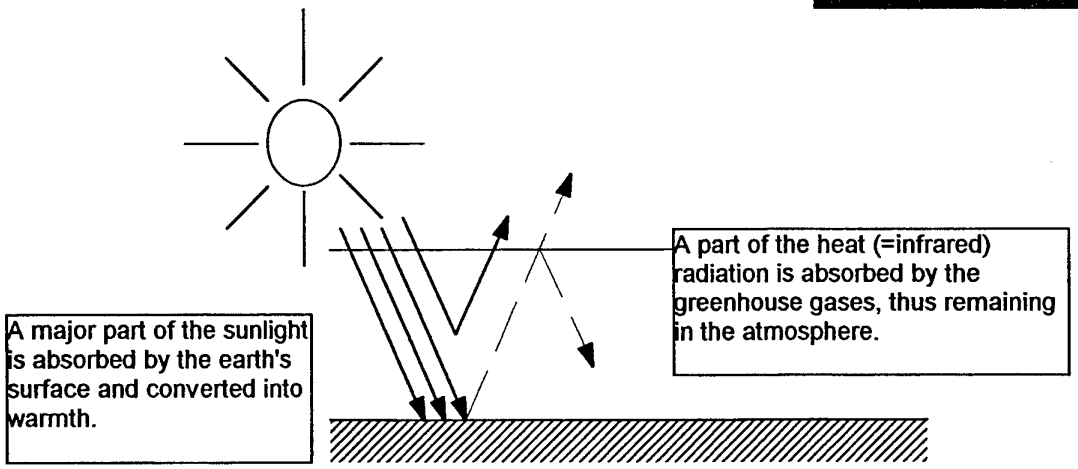
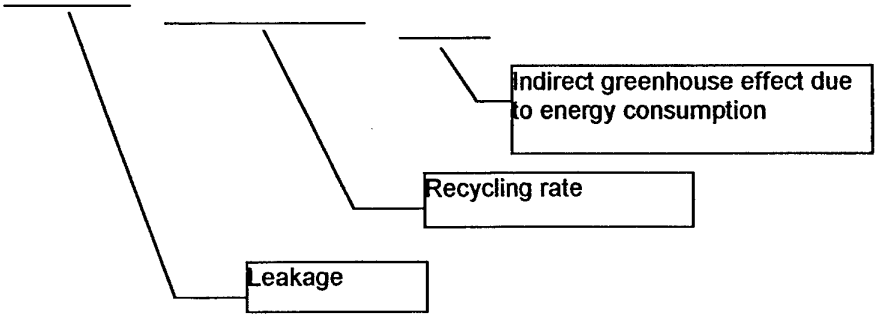



**Fig. 1.2: Summary of greenhouse effect**

## 3. Total Equivalent Warming Impact (TEWI)

Among other things, the TEWI value takes into account the $CO_2$ emissions which result from the operation of the refrigeration system due to the energy it requires (compressor drive) [2.1/2.3]:

$$TEWI = (GWP \cdot L \cdot t) + [GWP \cdot m \cdot (1-\alpha)] + (n \cdot W \cdot \beta) \qquad (2.1)$$




where:

| | | |
|---|---|---|
| GWP | Global warming potential | ($CO_2$ equivalent) |
| L | Leak rate per year | (kg) |
| t | Service life of system | (years) |
| m | Filling weight of system | (kg) |
| $\alpha$ | Recycling factor | |
| W | Energy consumption per year | (kWh) |
| $\beta$ | $CO_2$ emissions per kWh | (energy mix) |

This shows that the TEWI value indirectly considers the coefficient of performance $\varepsilon$, i.e. the ratio refrigeration capacity $Q_o$/driving power P of the refrigeration process.

### *2.2 Refrigerants: designation, composition and selected properties:*

The American designation, consisting of the letter F (Frigene) or the letter R plus a three-digit number, is used for HCFC:

| | | | |
|---|---|---|---|
| 1st digit: | number of carbon atoms | (C) in molecule | -1 |
| 2nd digit: | number of hydrogen atoms | (H) in molecule | +1 |
| 3rd digit: | number of fluorine atoms | (F) in molecule | |

All further carbon valences not used carry chlorine (Cl).
DIN 8962 stipulates the designations of all other refrigerants and blends of such agents [table 1].

When selecting a suitable refrigerant for application on a ship, the following properties have to be considered and weighted:

- Thermodynamic data of the wet steam area (great enthalpy of vaporization? high coefficient of performance ε or good ratio refrigeration capacity/driving power? good heat transmission characteristics? condensation temp./condensation pressure and vaporization temp./vaporization pressure suitable for this application?)
- Environmental compatibility?
- Poisonous?
- Combustibility / danger of explosion?
- Compatible with system (corrosion)?
- Availability on world-wide basis?
- Maintenance characteristics (how do leaks affect the operation? leak detection?)

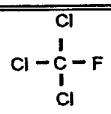
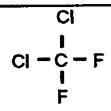
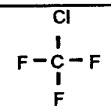
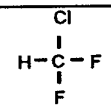
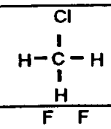
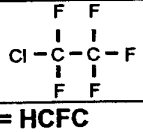
| *Refrigerant* | *Composition* | | *Remarks: Ozone Depletion Potential (ODP) Global Warming Potential (GWP)* |
|---|---|---|---|
| R11 | Trichlorofluoro-methane<br>$CCl_3F$ |  | ***ODP = 1,0 (by definition)***<br>not combustible<br>***Substitute: R123 and R134a*** |
| R12 | Dichlorodifluoro-methane<br>$CCl_2F_2$ |  | ODP = 1<br>GWP = 7100<br>not combustible<br>***Substitute: R134a*** |
| R13 | Chlorotrifluoro-methane<br>$CClF_3$ |  | not combustible<br>***Substitute: R410 and R23*** |
| R22 | Chlorodifluoro-methane<br>$CHClF_2$ |  | ODP = 0,05 → Phase-out periods [2.1]<br>GWP = 1650<br>not combustible<br>***Substitute: R407C and R410*** |
| R40 | Chloromethane<br>$CH_3Cl$ |  | not combustible |
| R115 | Chlorotrifluoro-ethane<br>$CClF_2$-$CF_3$ |  | |

**Table 1 a: Halogenated refrigerants = HCFC**

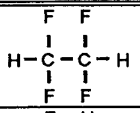
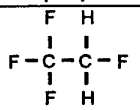
| *Refrigerant* | *Composition* | *Remarks:*<br>*Ozone Depletion Potential (ODP)*<br>*Global Warming Potential (GWP)* |
|---|---|---|
| R134 | 1,1,2,2-<br>Trifluoroethane<br>$CHF_2$-$CHF_2$  | |
| R134 a | 1,1,1,2-<br>Trifluoreethane<br>$CF_3$-$CH_2F$  | High availability due to massive use in automobile industry<br>ODP = 0<br>GWP = 1300 [2.7] |

**Table 1 b: Chlorine-free hydrocarbons (HC)**

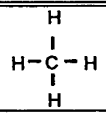
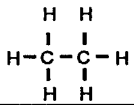
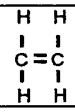
| *Refrigerant* | *Composition* | *Remarks:*<br>*Ozone Depletion Potential (ODP)*<br>*Global Warming Potential (GWP)* |
|---|---|---|
| R50 | Methane $CH_4$  | ODP = 0<br>combustible |
| R170 | Ethane $C_2H_6$<br>$CH_3$-$CH_3$  | combustible |
| R290 | Propane $C_3H_8$ | ODP = 0<br>GWP = 3<br>combustible |
| R600 | Butane $C_4H_{10}$ | ODP = 0<br>GWP = 3<br>combustible → safety measures |
| R1150 | Ethylene $C_2H_4$  | ODP = 0<br>combustible |
| R1270 | Propylene $C_3H_6$ | ODP = 0<br>GWP = 3<br>combustible |

**Table 1 c: Halogen-free hydrocarbons**

| *Refrigerant* | *Composition* | *Remarks:*<br>*Ozone Depletion Potential (ODP)*<br>*Global Warming Potential (GWP)* |
|---|---|---|
| R404a | Blend<br>44 % R143a<br>52 % R125<br>4% R134a | ODP = 0<br>GWP = 3750<br>Temperature drift 0.7°C at 1 bar |
| R 407a | Blend<br>20 % R 32<br>40 % R125<br>40 % R134a | ODP = 0<br>GWP = 1920<br>Temperature drift 6.6°C at 1 bar |
| R 407b | Blend<br>10 % R 32<br>70 % R125<br>20 % R134a | ODP = 0<br>GWP = 2560<br>Temperature drift 4.4°C at 1 bar |

| | | |
|---|---|---|
| R 407c | Blend<br>23 % R 32<br>25 % R125<br>52 % R134a | ODP = 0<br>GWP = 1610<br>Temperature drift 7.4°C at 1 bar |
| R410(a) | Blend<br>50 % R 32<br>50 % R125 | ODP = 0<br>GWP = 1890<br>Temperature drift 0.2°C at 1 bar |
| R502 | Blend<br>***R22*** / R 155 | ODP = 0.23<br>GWP = 4300<br>***Substitute: R507 and R404A*** |
| R507 | Blend<br>50 % R143a<br>50 % R125 | ODP = 0<br>GWP = 3800<br>Temperature drift 0°C at 1 bar |

**Table 1 d: Non-azeotropic blends**

| *Refrigerant* | *Composition* | *Remarks:*<br>*Ozone Depletion Potential (ODP)*<br>*Global Warming Potential (GWP)* |
|---|---|---|
| R717 | Ammonia<br>$NH_3$ | ODP = 0<br>GWP = 0 → suitable for new systems<br>combustible (forms explosive mixture with air)<br>poisonous,<br>caustic, pungent odor → the natural warning threshold is 0.0005 % by volume, harmful at concentration > 0.1 % by volume (factor 200!),<br>→ safety equipment:<br>• Ammonia scrubber (sprinkler systems)<br>• separate brine circuit with calcium chloride brine [1] [2.1 / 2.4]. |
| R718 | Water<br>$H_2O$ | ODP = 0<br>GWP = 0<br>not combustible |
| R744 | Carbon dioxide<br>$CO_2$ | ODP = 0<br>***GWP = 1.0 (by definition)***<br>not combustible |
| R729 | Air | ODP = 0<br>GWP = 0<br>not combustible |

**Table 1 e: Halogen-free refrigerants**

## *2.3 Legal situation*

As a consequence of the depletion of the ozone layer, an international agreement, the Montreal Protocol of 1987, which went into effect on 01/01/89, stipulated the following measures:

- Freezing of the HCFC production at the production level of 1986
- Prohibition of import via countries who did not ratify the agreement
- Prohibition of new agreements which grant the non-ratifying countries financial aid used for the production of HCFC

Germany turned the stipulations of the Montreal Protocol into much more stringent national legislation, the HCFC Halon Prohibition Act which became effective in 1991. The essential national regulations comprise:

- Prohibition of refrigerants containing HCFC and of indexed refrigerants in the construction of new systems (R12, R115, R502), starting on 01/01/95
- Prohibition of the production or introduction of HCFC systems, starting on 01/01/95
- Phase-out solutions for the protection of existing systems by means of conversion to environmentally compatible refrigeration agents by 06/30/98

Due to its considerably lower ODP, R22 is a special case. Up to 01/01/2000 its application is permitted in new systems. In compliance with EU regulations, the usage of R22 for service purposes is to be reduced to zero by 2015. General prolongations are possible, but not foreseeable at the moment.

## 3 Comparison of the new refrigerants

After the problematic aspects of the conventional refrigerants had become obvious, substitutes had to be found. The primary focus was placed on the search for chlorine-free refrigerants. Later on, further research also showed the influence on the global temperature behavior, so that the **TEWI** value has become an important refrigerant evaluation criterion in addition to the **ODP**.
At first, it was of prime importance to find a substitute for the refrigerant that had the greatest ODP and that was most widely used in refrigeration systems.

The refrigerants described below turned out to be alternatives. With the exception of R134a and R123, these refrigerants are blends which consist of up to four components.
While initially it was feared that leaks in the system would cause changes in the composition of the refrigerants, the practical experiences showed that the blends do not separate out in general. If at all, such effects only occur during vaporization or condensation.
Most leaks do not occur in the apparatuses, but in the screwed connections, valves and solder points at the piping outside of the heat exchangers.
The composition ratio of the refrigerants does not change when leaks occur at such points. The systems can be refilled as usual.

### *3.1 R12 - R134a*

R12 is used in systems with high condensation pressures such as systems with air-cooled condensers.
As compared to the other refrigerants mentioned, a disadvantage of R12 is the great compressor volume flow required (approx. 130-140% with reference to R22 at the same refrigerating capacity).
This requires large and, by implication, expensive compressors.
Due to the same K value the heat exchangers can have a size similar to that of R22 or R502 systems.
As one of the first refrigerants, R12 was substituted by R134a.
R134a is a pure substance without chlorine. The ODP is 0.
Therefore, it not harmful to the ozone layer. The GWP is 1200, a relatively high value.
From a thermodynamic perspective, there are no essential differences to R12 up to -10°C.
The refrigerating capacity, temperature behavior and the dimensions of the components are similar.
However, R134a should not be used at temperatures below –20°C because of the massive decrease in capacity.

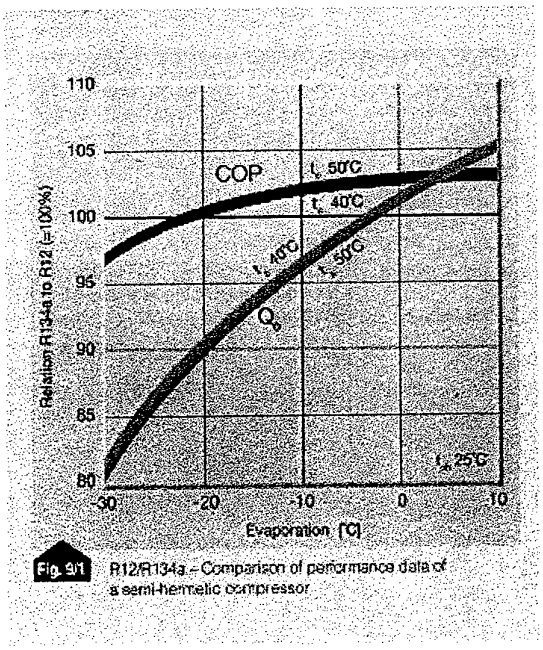


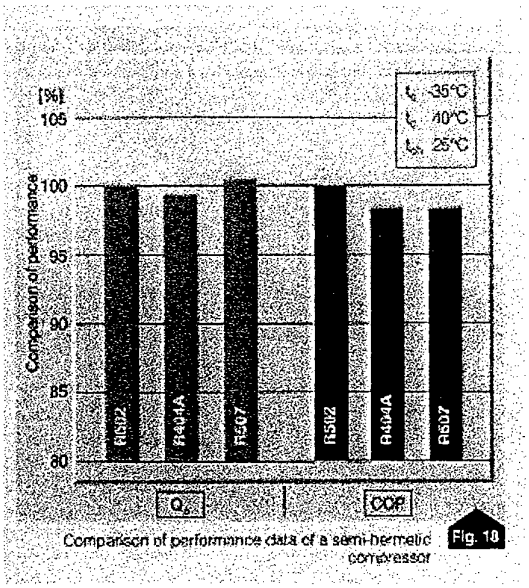

Fig. 9/1 R12/R134a – Comparison of performance data of a semi-hermetic compressor

**R134a/R12- Comparison of the performance data of a semi-hermetic compressor**

### *3.2 R502 - R404A -R507*

R 502 was developed as a refrigerant for low vaporization and high condensation pressures.

After R134A turned out to be a good substitute for R12, the development efforts were focused on a substitute for R502.
R404A and R507 are proven products, well introduced on the market.
Just like R134a, R404A/R507 have an ODP of 0. As compared to R134a, the GWP is even higher (3750/3800). All important parameters are essentially identical to those of R502.




**Comparison of the performance data of a semi-hermetic compressor**

As opposed to R134a, R404A is not a pure substance. Rather, it is a blend of three different, chlorine-free refrigerants (44% R125 - 4% R134a - 52% 143a). However, from a thermodynamic perspective and within the temperature range for which it was developed (-30°C to -45°C), it can be considered as one substance.

R507 is a blend consisting of two components (50% R125 and 50% 143a). its properties are comparable to those of R404A. Due to the missing R134a portion, it has a slightly higher condensation pressure.

While R404A is massively used in Europe, R507 is primarily employed in the USA. Both refrigerants are available on a world-wide basis.

Time will show which of the refrigerants will be more successful.

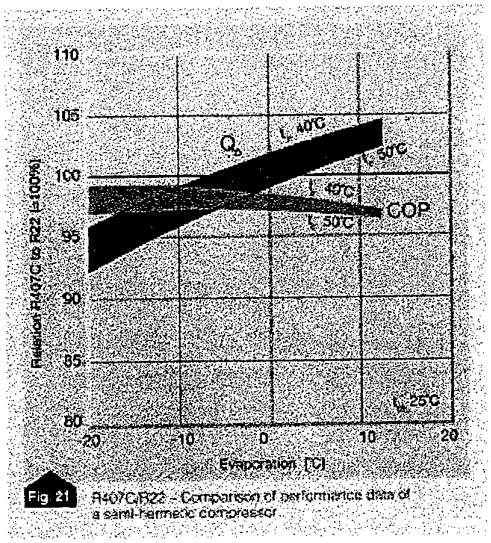
### *3.3 R22 - R407C*

Since, as mentioned above, the substitution of R22 was not the top priority due to its low ODP, a replacement was not developed until alternatives for R12 and R502 had been found.

In the meantime, excellent experiences have been made with R407C which is available on a world-wide basis.
R407C is a blend consisting of three components (23%R32 - 25%R125 - 52%R134a) and it has a favorable GWP of 1610. It was adapted to the thermodynamic properties of R22.
R407C is primarily an R22 substitute for air conditioning and normal cooling.

Due to the high percentage of R134a, the refrigerating capacity rapidly decreases at lower temperature, just like in the case of pure R134a.

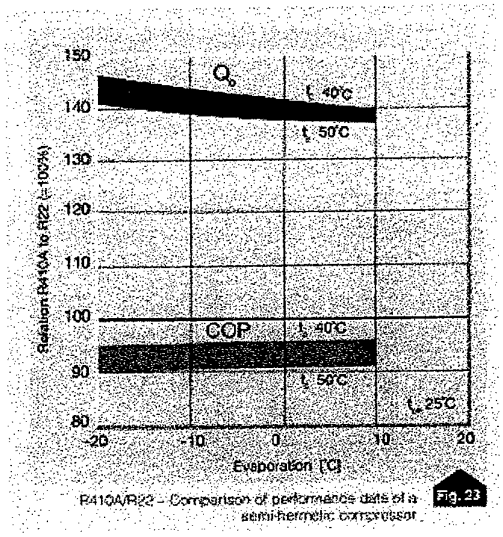
The considerable temperature drift requires a special design of the system components (refrigeratory, condenser, expansion valves).
The usage of flooded refrigeratories is not recommended due to the layers in the refrigeratory.




**R407C/R22- Comparison of the performance data of a semi-hermetic compressor**

### *3.4 R22 - R410A*

In addition to R407C, R410A is also being subjected to comprehensive experiments. It is already used in a number of small series systems.



**R410A/R22- Comparison of the performance data of a semi-hermetic compressor**

R410A is an almost azeotropic blend (50% R32 and 50% R125) with a temperature drift of less than 0.2 K. A GWP of 1890 promises a favorable TEWI value.

A main feature is a refrigerating capacity which is 50% greater than that of R22, however at a considerably higher pressure situation (26 bar at 43°C as opposed to 16 bar for R22).
Most fittings in the refrigeration industry are available for a pressure of 25 bar.
We are currently seeing a trend on the market towards 28/32 bar.

Currently, R407C and R134a are available as substitutes for R22. It is to be expected that the further development of R410A will yield positive results.

### *3.5 R22- R134a*

In the area of air conditioning, R134a can be used to substitute R22.
It must be noted that the refrigerating capacity is inferior and decreases even more at lower temperatures.

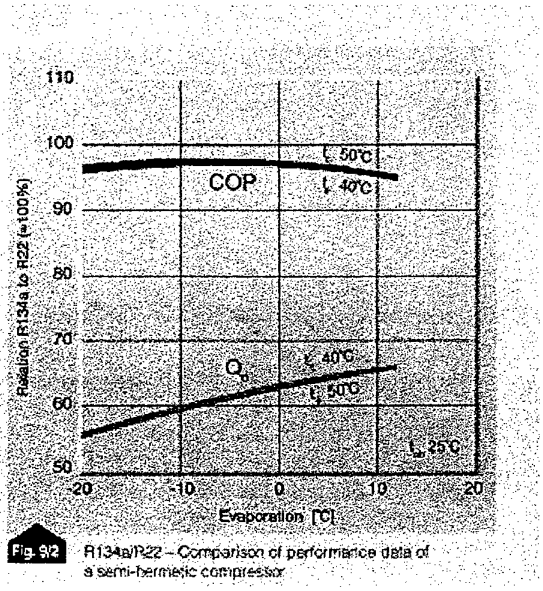


Fig. 9/2 R134a/R22 – Comparison of performance data of a semi-hermetic compressor

**R134a/R22- Comparison of the performance data of a semi-hermetic compressor**

In addition, it must be noted that $t_o$-26°C=0 bar. Systems which work with low pressures continuously operate in the vacuum range which poses the danger of air/humidity entering the system.

### *3.6 R11 - R123*

R11 is only used in liquid coolers with turbocharged compressors for high-capacity air conditioning systems. A substitute is R123, which, is not unproblematic in view of the toxic characteristics (the maximum concentration at the workplace MAK is 30 ppm as opposed to 1,000 ppm for the other refrigerants). The GWP is 85, the ODP 0.02.

Systems with R123 require increased technological effort such as greater air exchange rates of the engine room ventilation and alarm systems. The low greenhouse potential is an advantage of this agent so that it is used on a transitory basis.

### *3.7 New "old" refrigerants*

As shown, the substitution of the refrigerants has almost been fully completed. The new agents do not pose any technical problems. However, all new refrigerants have a relatively great greenhouse potential.

This is one of the reasons why the substitute refrigerants are also becoming the target of criticism. The impact this fact is going to have on the future of the refrigeration technology is not foreseeable at the moment. This poses the question for alternatives.

#### *3.7.1 $NH_3$*

One of the oldest refrigerants that was specially used on ships until HCFC took its place is ammonia ($NH_3$). Today, $NH_3$ is still used in industrial large-scale refrigeration applications, and it is becoming increasingly attractive, since it has neither an ODP nor a GWP. Additional advantages are its low production cost as well as its availability on a world-wide basis.

The thermodynamic properties of $NH_3$ are very favorable. The high volumetric refrigerating capacity results in low volume flows and small compressors. To a certain extent, it can also be considered as a substitute for R22.

The GL guidelines require indirect cooling of $NH_3$ systems on ships.

This means that brine/water cooling units must be installed in separate engine rooms.

The consumers in air conditioning units, supply and cargo cooling holds are supplied via coldness carriers. The minimum $NH_3$ filling that is technically possible is required.

The engine rooms must be gas-tight, have an air exchange rate of at least 40 and be provided with alarm and sprinkler systems.

The German SeeBG (Naval Employer's Liability Insurance Association) permits $NH_3$ systems only in cargo hold cooling. The pertinent national regulations of other countries must be observed.

The requirement for the minimum refrigerant volume can be accounted for by means of dry expansion.

In connection with water, $NH_3$, is highly aggressive to copper and alloys such as red bronze and brass. This means that all pipes and valves must be of materials that are free of copper. In the past, steel and cast steel as well as stainless steel was used.

Several research experiments with aluminum as a material for the use with ammonia systems have yielded very good results. If aluminum pipes and semi-hermetic compressors with aluminum units which are now available are selected, even $NH_3$ systems can be cost-efficient in terms of piping and compressors. The usage of stainless steel or aluminum also efficiently counteracts the problem of corrosion at the outside of the pipes in the temperature change areas.

A disadvantage is the high compression temperature at great pressures which limits the single-stage application with piston compressors to approx. -10°C. Due to oil cooling and the special technology of screw-type compressors, this refrigerant can be used with these machines up to the deep-freezing range (-35°C).

Many supplies refrigeration systems require only a small cooling capacity. The screw-type and dual-stage piston compressors available are often too big for this type of application. Therefore, the feasibility of $NH_3$ for supplies refrigeration systems needs to be determined for each individual case.

The chemical structure of ammonia is simple. It is inexpensive and available on a world-wide basis. In addition, it does not have an ozone depletion and greenhouse potential. Due to the good thermodynamic properties, its application is energy-saving, so that the TEWI value of most systems can be considered to be low. Therefore, $NH_3$ is a refrigerant that will also be used in the future without posing problems.

### *3.7.2 Hydrocarbons (propane)*

In land-based applications, hydrocarbons are increasingly being used as replacement refrigerants. The thermodynamic properties of pure propane are very similar to those of R22. Propane has no ODP and only a very small GWP. From a technical standpoint, it does not pose significant problems. Propane and isobutane blends are highly suitable as R12 substitutes. In addition, these agents are neutral to copper materials so that semi-hermetic compressors can be used.
A major reason for the fact that these agents are only used occasionally is the combustibility of the hydrocarbons. Therefore, naval applications are very unlikely.
While guidelines have been implemented for non-naval applications with these refrigerants, its usage on ships is prohibited by the GL.

### *3.7.3 Carbon dioxide ($CO_2$, R744)*

$CO_2$ is a refrigerant with a long tradition. When substances containing HCFC started to be used, the importance of $CO_2$ decreased rapidly. The advantages of this medium comprise:

- no ODP
- negligible GWP
- chemical inactivity
- not combustible
- inexpensive production
- high volumetric refrigerating capacity

This is opposed by a lower degree of efficiency as compared to the standard cold steam process. Therefore, $CO_2$ is no longer used, particularly in systems on ships.

## 4 Impact of the new refrigerants on system engineering

### *4.1 Refrigerator oil*

An important factor in the operation of refrigeration systems is the recirculation of the oil ejected by the compressor. Even good oil separators cannot fully prevent oil from getting into the system.
Conventional refrigerants can be mixed with mineral and synthetic oils so that the oil recirculation does not pose any problems

Chlorine-free refrigerants **cannot** be mixed with these oils.

Synthetic diester oils of a highly polar structure can be used for such systems.
They are proven, and more and more manufacturers offer them on a world-wide basis.

Diester oils are soluble with mineral oils (important for the conversion of existing systems to refrigerant substitutes).

The PAG oils initially tested for HFHC refrigerants (whose base substance is ethylene), are – in most cases – only used for $NH_3$ systems.

### *4.2 Water absorption capacity of refrigerator oils*

Both oil types have similar lubrication characteristics as mineral oils. However, in terms of water absorption (*hygroscopicity*), they are much more critical.

While mineral oil absorbs almost no humidity during the entire test duration, the curve for diester oil is slightly more critical. On the other hand, the liquid absorption values of PAG oils greatly exceed the values of the other two oil types.

In the past, it was important not to leave refrigerator oils open. Today, the hygroscopicity of the oils forces the user to be even more careful in handling these media.

Humidity has always been the enemy of refrigeration systems since the decomposition products can be acids which are dangerous to the system.

Even with conventional refrigerants, copper deposits at the axial face seals and bearings caused damages which could have been prevented with careful drying.
Considering this fact, the problem is not new as far as the new refrigerants are concerned.
However, due to the **hygroscopicity** of the diester refrigerator oils, the requirement for the **drying** of the system has become even more important.
The installation of a system therefore necessitates tightness and drying which also meets the requirements for a low TEWI value.

Modern components have been designed with this aspect in view.
For example, systems with the new refrigerants primarily use **soldered valves, fittings** and **pressure gauges**. For safety reasons, we also install additional **suction gas dryers**.

## 5 Summary

- The Montreal Protocol marked the beginning of the end of the HCFC technology. It forced the development of alternative refrigerants.
- Substitutes for R12 and R502 are available.
- R407C and R134a are used to replace R22.
- For the R22 substitute R 410A the components are pressure-increased.
- R11 which is primarily used in turbocharged cold water systems, can be replaced by R134a and R123. R123 is still under development and not yet approved.
- The temperature drift necessitates a careful selection of the components.
- All new refrigerants require synthetic diester oils.
- The new systems must be hermetic to the maximum degree possible. Both from a technical and from an environmental perspective this implies that semi-hermetic compressors and soldered components must be used.
- Special attention must be paid to the problem of the hygroscopicity of the diester oils.
- The conversion of existing systems to the new refrigerants does not pose problems.
- The new refrigerants are available on a world-wide basis. Alternatives with natural substances are also available.
- Ammonia used to be employed almost exclusively in systems on ships.
- German classification associations permit the usage of $NH_3$ only for cargo refrigeration systems.

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[2.3] Rodermund, Siegmund: Schiffskälteanlagen nach der FCKW-Verordnung, STG-Sprechtag "Seetransport von Kühlcontainern", Bremerhaven, 25.02.97.

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[2.5] Dreyhaupt, F. J.: VDI-Lexikon Umwelttechnik, VDI-Verlag, Düsseldorf (1994).

Illustration source: *Refridgerant Report 6,* Bitzer

We would like to express our gratitude to the "Institut für Schiffsbetrieb, Seeverkehr und Simulation", Prof. Dr. Watter, for the support in preparing this paper.

# United States Navy Ozone Depleting Substances (ODS) Policy

**Mr. Joel Krinsky**
**Director, Environmental Programs Division,**
**Naval Sea Systems Command (SEA 03L1)**

## Abstract

In 1974 the research scientists Dr. Mario Molina and Dr. Sherwood Rowland published a paper that suggested that industrial chlorofluorocarbons (CFC's) and Halons could react in the stratosphere and destroy stratospheric ozone. Between the years 1974 and 1985 the scientific community made remarkable advances in understanding atmospheric processes affecting stratospheric ozone and discovered the Antarctic Ozone Hole. In response to the growing threat that CFCs and Halons presented, the international community responded and negotiated the Montreal Protocol on Substances that Deplete the Ozone Layer. Originally the Protocol called for a 50% reduction in production and consumption of CFCs and Halons. However, subsequent amendments in London in 1990 and Copenhagen in 1992 called for the complete elimination of the production and consumption of CFCs and Halons, collectively known as Ozone Depleting Substances (ODS's). These ODS's are used as refrigerants, fire extinguishing agents and solvents and are vital to the mission of the United States Department of Defense. This paper will trace the evolution of the United States Department of Defense (DoD) and United States Navy policies developed in response to the original Montreal Protocol and subsequent amendments. These policies and programs developed in response to these policies have enabled DoD and the Navy to transition away from ODS's without adverse impact to the National Security mission, while minimizing total cost.

Session 3
Speaker Mr. Joel Krinsky

I am very happy to announce one of the best known speakers in this forum,
Mr. Joel Krinsky from NAVSEA,USNavy.

Mr. Joel Krinsky graduated from US Merchant Marine Academy in 1960 as BS Marine Engineer and 1966 from American University as MBA Production Management.

He worked in computer industry for IBM and other companies and has been associated with the US Navy for 30 years as Project engineer, program manager, deputy director for Auxiliary Systems, division director for HVAC and Submarine Life Support Systems.
His present posting is division director Environmental Protection Systems.

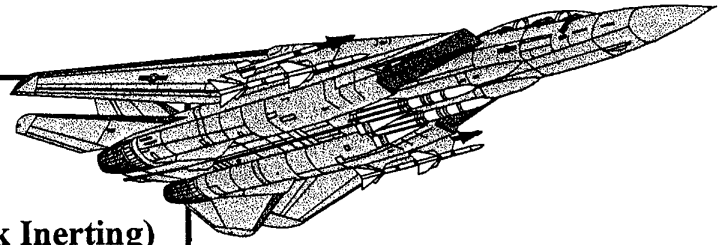
Mr. Krinsky will present his paper on
"Navy Ozone Depleting Substances (ODS) Policy"

# U.S. Navy Ozone Depleting Substances (ODS) Policy

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# Typical Navy ODS Uses

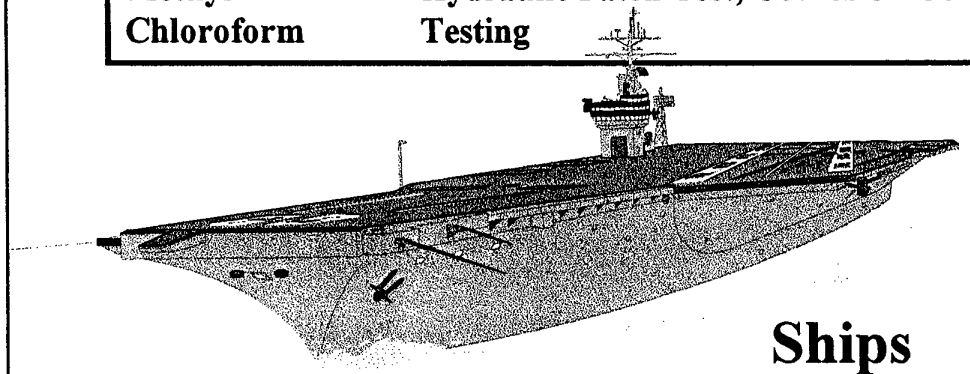
## Aircraft



| | |
|---|---|
| CFC-12, -114 | Aircraft Cooling |
| R-500 | (Avionics Cooling, Cabin Climate Control) |
| Halon 1211 | Aircraft Crash, Fire, Rescue; Flightline |
| Halon 1301 | Fire Protection (Engine Nacelles, Fuel Tank Inerting) |
| CFC-113 | Electronics/Avionics, Oxygen Systems, Bearings, |
| Methyl Chloroform | Hydraulic Patch Test, Corrosion Control, Leak Testing |

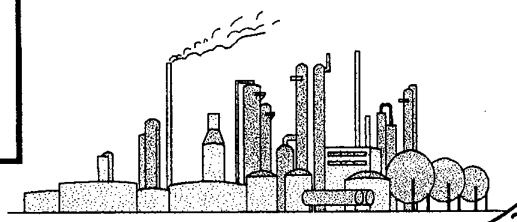
## Shore Facilities

| | |
|---|---|
| CFC-11, -12 | Facilities AC&R |
| CFC-113 | Electronics |
| Methyl Chloroform | Solvent Cleaning |
| Halon 1301 | $C^3$ Fire Protection |
| Halon 1211 | Portable Fire Extinguishers |



## Ships

| | |
|---|---|
| CFC-11, -12, -114 | AC&R (Electronics and Weapon Systems Cooling) |
| Halon 1301 | Shipboard Fire Protection (Main Machinery Spaces) |
| CFC-113 | Electronics , $O_2/N_2$ Cleaning |
| Methyl Chloroform | |





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# Early Navy Planning

- Initial Response To Montreal Protocol of 1987 - 50% Reduction
  - Conservation & "Outbid" Other Users For Limited Supply
- Concern For Total Phaseout
  - December 1987 Meeting Between DOD, EPA & State Department
    - ODSs Are Mission Critical
      - CFC Refrigerants Required To Keep Combat Systems Operating
      - Halons Required For Peacetime Safety & Wartime Survivability
    - Navy Ships & Aircraft Have Unique Problems
      - Space Limited, Carefully Integrated, High Cost, Major Redesign, Long Procurement Lead Time, Fire Risks, Submarine Atmosphere, Acoustics

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# DOD Issues Policy

- CFC & Halon Directive Issued February 1989 (DODD 6050.9) In Response To Montreal Protocol
- Established Policy For Services
  - Conservation
  - Identify Uses & Prioritize
    - Ensure Adequate Chemical Supplies Are Available For Mission-Critical Uses
  - Modify MILSPECs To Allow Use Of Alternatives
  - Conduct R&D To Find Alternatives
  - Establish a Central Point Of Contact To Oversee Implementation

# Navy Develops Program Plan

- In 1989 Total Phaseout Was Apparent
- NAVSEA Assigned Navy Lead In April 1989
  - First Navy Program Plan Developed October 1989
- Strategy
  - Conserve, Recover, Recycle
  - Adopt Suitable Substitutes for Existing Equipment
    - CFC-12 Chilled Water & Refrigeration Systems
    - CFC-114 Chilled Water Systems
    - Halon 1211 & 1301 Fire Protection Systems
    - Solvents
  - Develop New Non-ODS Equipment
  - Strategic Reserves / "Vintaging"

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# Navy Develops Policy

- Navy Policies Issued To Support Program Plan
- SECNAVINST 5090.5 (November 1989) & OPNAVINST 5090.2 (January 1990)
  - Eliminate Use of ODS As Soon As Possible Consistent With Mission Requirements
  - Request Funding For R&D, Conservation, and MILSPEC Modifications In Program Planning Process (POM)
  - Begin Work On A Strategic Reserve (Use Surveys/Reports, Inventory Management, Etc.)
  - Prohibit Direct Emissions As Of 1 January 1993
  - All Echelon II Commands Submit Annual Reports to NAVSEA On Efforts To Eliminate ODS
- London Amendments of 1990 - Total CFC/Halon Production Phaseout In 2000



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# Actions Taken

- Obtained Funding- Limited Funds 1990-1991, Full Funding 1992
- Began RDT&E For Existing Equipment/Applications
  - CFC-12 Chilled Water & Refrigeration Systems
    - Tested Blends, Focused On HFC-134a (Industry Alternative)
  - CFC-114 Chilled Water Systems
    - Little Industry Help, Evaluated Several New Alternatives
    - Extensive Toxicity & Submarine Atmosphere Testing
  - Halon 1301 - Test & Qualify Industry Alternatives
  - Solvents - Test & Qualify Industry Alternatives
- Review & Revise MILSPECs
  - Electronics (Joint Testing With EPA & Industry)
  - Identified & Reviewed More Than 8000 Affected Specs - Began Modifications & Tracked Changes
- Began RDT&E For New Equipment
- Developed Specifications, Tested & Procured Recovery/Recycling Equipment
- Began Usage Surveys & Modeling To Develop A Strategic Reserve

# Key Events

- Feb. 1992 - President Bush Announces 1995 Phaseout In U.S.
- Fiscal Year 1993 DoD Authorization Act (Public Law 102-484)
  - No Contracts Can Contain A Requirement For A Class I ODS Unless Approved By A Flag/General Officer or SES
- Nov. 1992 - Copenhagen Amendments
  - 31 Dec. 1993 - Halon Phaseout; 31 Dec. 1995 - CFC Phaseout
- May 1993 USEPA Issues Regulations On Refrigerant Recycling

# Responding to Events: Policy Revisions

- Aug. 1992 - DOD Assigns Defense Logistics Agency Task Of Establishing & Managing a Reserve of ODSs For Mission-Critical Applications
- ASN Interim Policy (August 1993) & OPNAVINST 5090.2A (July 1994)
  - Refrigerant Technicians Must Be EPA Certified
  - Recover/Recycle & Repair Leaks
  - Comply With Civilian Regulations Except Where Not Practical
  - Prohibits Procurement Of CFC- or Halon-Containing Equipment For Non-Mission Critical Uses
  - All New Equipment Must Use USEPA SNAP-Approved Alternatives With An ODP Of 0.05 Or Less, ODP Of Zero Where Possible
  - Remove Non-Mission Critical Halon Fire Extinguishers & Redistribute To Mission Critical Uses By 1 January 1996
  - Convert Or Replace Non-Mission Critical Class I ODS Equipment By 31 December 2000
  - No Sale Or Transfer Of A Class I ODS Outside The Navy - Send To ODS Reserve
- Navy Wins USEPA Award For ODS Policy

# Responding To Declining Budgets

- End Of Cold War & Shift Of Military Mission Toward Regional Conflicts Results In Decline Of Navy Budget
- Ship/Submarine Platform Sponsors Report That ODS Conversions Are Becoming Unaffordable
- ODS Reserve Model Shows Submarines Can Be "Vintaged" With An Additional 4000 kg Of CFC-114
  - Aug 94 - CNO Issues Policy To "Vintage" Submarines
- No Drop-In For Halon Identified
  - "Vintage" Halon 1301 Uses & Use ODS Reserve
- Allow Interim Use Of Reserve For Shipboard Ancillary Equipment (Galley, Dehydrators, Etc.) - October 1996
- Late 1996, CNO Expresses Concern Over Continued Acquisition of Class I ODS Equipment
  - CNO Will Not Add Additional Users To ODS Reserve
  - ASN (RD&A) Issues Guidance On Unplanned Uses Of Class I ODS (November 1997)
    - Technical Review, ODS Reserve Impact Analysis & Trade-Off Analysis Required

# Evolving Policy

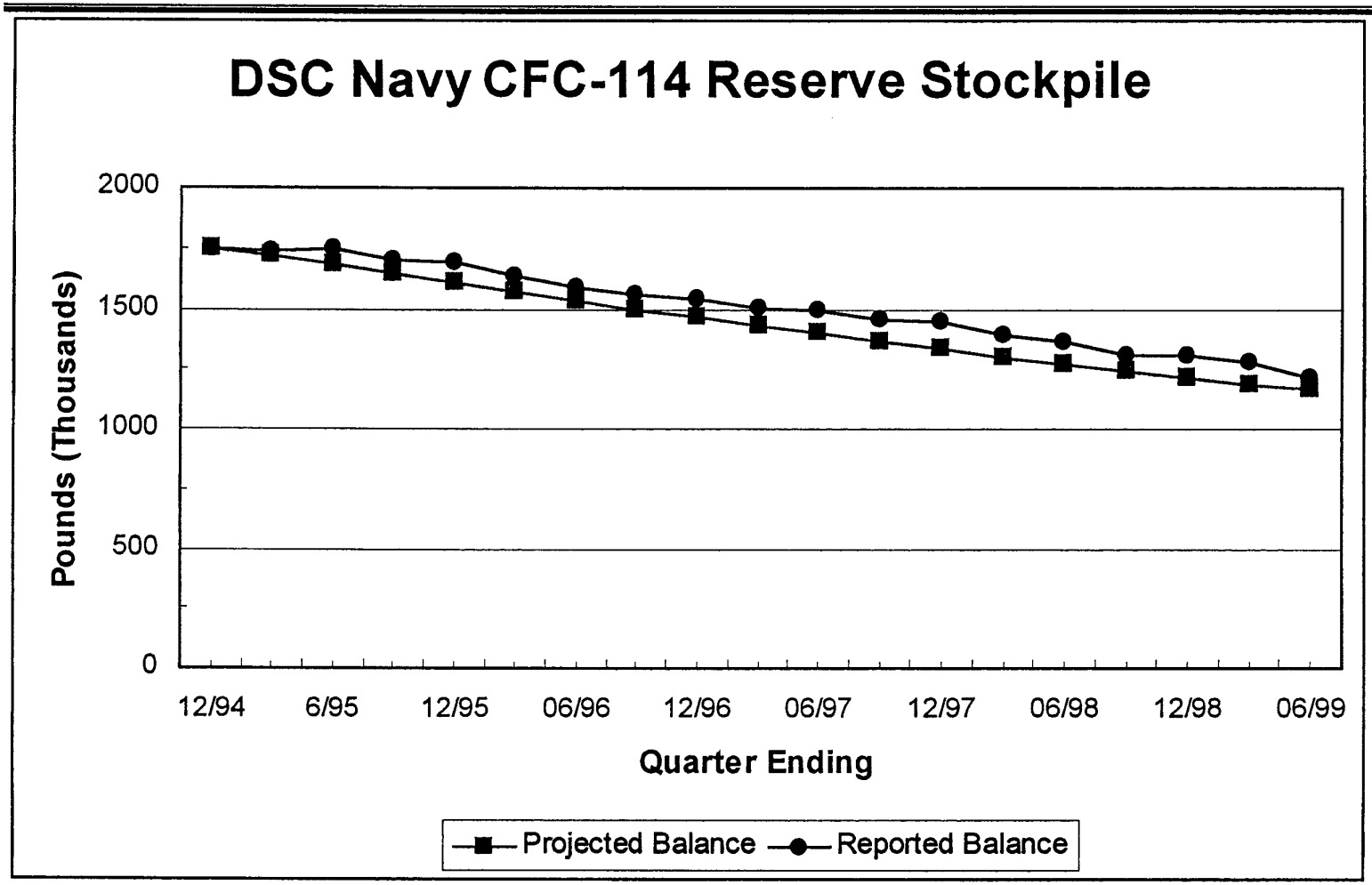
- Navy ODS Policy Is Not Stagnant
  - Continues To Evolve To Meet Requirements
- Policy Incorporated Into Navy Environmental & Natural Resources Program Manual (OPNAVINST 5090.1B) Issued November 1994
  - Revision 1 (February 1998)
  - Revision 2 (September 1999)
    - Lifecycle Of New Equipment With HCFCs Cannot Extend More Than 5 Years Beyond HCFC Production Phaseout
- Future Policy Likely To Further Address HCFC Usage

# Navy ODS Program Status

- CFC-12 Conversion Program Underway
  - 580+ AC&R Plants Converted to Date
  - 147+ CFC-12-Free Ships
- HFC-236fa is the Selected Substitute For CFC-114
  - Fleet Conversion Program Underway
  - Many Conversion Advantages
    - Quieter, More Reliable, Enhanced Troubleshooting / Diagnostics, Expanded Operational Envelope (95 F +), Improved Efficiency, etc
- ODS Reserve Established And Being Monitored
  - 99.9% Chance Of Success
- Halon 1301 Alternatives Selected For New Construction Ships
  - HFC-227ea
  - Fine Water Mist

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# ODS Reserve Monitoring



# Summary

- Effective ODS Elimination Program Requires Clear Policy
  - Balance Environmental Issues With Technical, Financial,and National Security Considerations
- Policy & Program Have Enabled The Navy To Transition Away From ODS Without Adverse Impact To National Security, While Minimizing Total Cost To The Navy
- Program Is Recognized As A World Leader
  - USEPA Stratospheric Ozone Protection Award For ODS Policy
    - 30+ EPA Stratospheric Ozone Protection Awards For ODS Programs, Organizations, & Navy Individuals

**"The Navy program is known for its global leadership, smart technology, and sensible pace."**--Ms. Drusilla Hufford, Director, USEPA Stratospheric Ozone Protection Division

# • The Maritime Environment •

## "Treatment Technologies for Gaseous Emissions from Ships"

## Session 4

### Exhaust Gases from Engines and Power Generators – Treatment Technologies and Alternatives –

**Session Chairman: Dr. *Peter Sunn Pedersen*, MAN B&W Diesels A/S, SE**

# Environmentally Friendly Propulsion Systems

**Peter Sunn Pedersen, Vice-President R&D, MAN B&W Diesel A/S, Denmark**
**Ola Ruch, VOC-Fuel part-project leader, Statoil, Norway**

## Abstract

The paper opens with a brief outline of the methods used by MAN B&W Diesel to ensure compliance with the IMO $NO_x$ Regulation for its two-stroke marine diesel engines and methods available for ensuring compliance with stricter regulations. The main methods used are combustion system modification for the IMO Regulation, the use of water emulsified fuel for somewhat stricter regulations and SCR exhaust gas after-treatment for very strict regulations.

The second part of the paper deals with an innovative system for simultaneous reduction of emissions of Volatile Organic Compounds (VOC) from crude oil carriers and the exhaust gas emissions from the vessels' main engines. For shuttle tankers in particular, the VOC emission primarily takes place during loading of the crude oil. On the basis of measurements recorded by Statoil, the composition, amount and energy content of the VOC are evaluated. The measurements show that the magnitude of the energy lost by the release of VOC to the atmosphere was comparable to the total HFO consumption of the vessel, which led to the idea of using the VOC as the main fuel for the engines.

The technical solution, the "VOC Fuel" system, reduces the VOC emission problem by collecting and storing the VOC and utilising it as fuel for the main engine(s). This makes the engine's exhaust gas significantly cleaner, and substantially reduces the expenses for heavy fuel oil. A 50-90% reduction of $SO_x$ emissions (directly proportional to the HFO substitution percentage), a similar reduction in particulate emissions (due to the clean and volatile fuel), and a 20-30% reduction in $NO_x$ emissions can be expected.

The results of combustion tests with VOC are presented. These tests serve to identify the demands made on engine and fuel injection system control when using various VOC compositions. As the next step, a full-scale demonstration of the technology and concept for shuttle tankers is being carried out on one of Statoil's shuttle tankers, serving the Norwegian Statfjord oilfield. The design concepts for this vessel will be outlined.

Chairman Session 4
Dr. Peter Sunn Pedersen

Ladies and Gentlemen,

Session 4 will be dealing with treatment technologies and alternatives.

I am very pleased that Dr. Peter Pedersen agreed to chair this session.

Dr. Pedersen studied Mechanical Engineering at the Technical University of Denmark and received his Master of Science degree in 1967and Ph D in 1975.
13 years he was employed at the Technical University of Denmark with research and teaching activities in the areas of diesel combustion, emissions and alternative fuels.
In 1980 he joined the Research and Development Department of MAN B&W Diesel in Copenhagen where he worked as Section Manager for Basic Research, Manager of Technical Staff Engineering and Senior Manager for Research and Development.
In 1996 he took over his present position as Vice-President Research Development.

Dr. Pedersen will now present his paper on
"Environmentally Friendly Propulsion Systems"

# Environmentally Friendly Propulsion Systems

by

Peter Sunn Pedersen, Vice-President R&D, MAN B&W Diesel A/S, Denmark
Ola Ruch, VOC-Fuel part-project leader, Statoil, Norway

## EMISSION CONTROL OF LARGE-BORE TWO-STROKE MARINE ENGINES

The methods used by MAN B&W Diesel to ensure compliance with the present IMO $NO_x$ Regulation for its two-stroke marine diesel engines are relatively simple combustion system modifications. For future, stricter regulations by IMO and for applications where lower limits apply (such as stationary applications), the use of water emulsified fuel is an effective and well proven solution, while SCR exhaust gas after-treatment allows compliance with even very strict regulations.

### Primary methods for $NO_x$ emission reduction

For the moderate emission reductions necessary to ensure compliance with the IMO Regulation, primary methods are used for our low speed two-stroke engines. The methods comprise modifications to the fuel injection system and, in some cases, the use of a new fuel valve design. The fuel nozzle designs exert a strong influence on the formation of $NO_x$ because of the influence via mixture formation and combustion on the local temperature level and oxygen concentration in the fuel spray area.

The main method, used on all engine types, involves the application of the so-called Low-$NO_x$ layout of the fuel nozzles. 10-25% reductions have been achieved in certain engines by using this method, which is normally associated with a modest fuel penalty (1-2%). Furthermore, this method is generally attractive because of the easy implementation. Fig. 1 shows a comparison between the $NO_x$ emissions (according to the standard measuring method for IMO) of the previously used fuel-optimised nozzles and the Low-$NO_x$ nozzles for a number of MC engines. These Low-$NO_x$ nozzles will be standard for all new orders since the engines in question will have to comply with the IMO limits - even though the Regulation has not yet been ratified.

Table 1 shows results from tests carried out on a 12K90MC engine with two new types of fuel valve. As can be seen, the mini-sac fuel valve shows very low smoke values and also low CO and HC values. The new (patented) slide fuel valve design gave a significant reduction of CO, HC and smoke values as well as a reduction of the $NO_x$ emission so as to comply with the IMO limits. The fuel oil consumption with the slide valve is marginally higher at 100% load, but lower at part load.

| Fuel valve type: | Mini-sac fuel valve | | Slide-type fuel valve | | Average reduction |
|---|---|---|---|---|---|
| Engine load: | 75% | 100% | 75% | 100% | |
| $NO_x$ [ppm/15%$O_2$] | 1580 | 1315 | 1415 | 1070 | 14% |
| CO [ppm/15%$O_2$] | 78 | 89 | 42 | 54 | 42% |
| HC [ppm] | 184 | 123 | 114 | 93 | 33% |
| Smoke [$BSN_{10}$] | 0.16 | 0.16 | 0.08 | 0.11 | 40% |

*Table 1. Effects of fuel valve design on emissions from a 12K90MC engine at 75 and 100% load. $BSN_{10}$ is the direct reading of the Bosch Smoke Number after 10 pump strokes*

As can be seen from Fig. 2, the new types of fuel valve incorporate a conventional conical spindle seat as well as a slide inside the fuel nozzle. The mini-sac valve has a slide which divides the sac-volume into two part-volumes and reduces the effective sac-volume to about one-third. The mini-sac valve is standard on some engine types and has shown reduced smoke and combustion chamber deposits in service. The goal is, however, to completely eliminate the sac-volume - which has been achieved with the slide-type fuel valve.

The clearance between the slide and the nozzle in the slide-type valve is of the order of 10-15μm, corresponding to normal fuel injection pump clearances, and measurements of the pressure inside the nozzle between two consecutive injections have confirmed that the leakage past the slide is negligible. Consequently, the slide-type fuel valve behaves as if it had no sac-volume from which fuel could seep out during the late part of the cycle. This type of fuel valve has just entered long term service testing on 12K90MC engines and is expected to become standard in the near future.

Injection rate shaping, too, has a potential for reducing the $NO_x$ formation, by direct influence on the burning rate. This is difficult to obtain in a conventional fuel injection system but the computer controlled mechatronic fuel injection system developed as part of the 'Intelligent Engine' concept is able to adapt the fuel injection pattern to such demands. The system has been used since 1993 on the 4T50MX research engine in Copenhagen (for further details, see [1]). Fig. 3 shows that a $NO_x$ reduction of some 20% was obtained by this method, utilising pre-injection. This resulted in a reduced peak-value of the rate of heat release and thus reduced peak combustion temperatures. The fuel consumption penalty was a modest 0.6%.

For larger reductions of the $NO_x$ emission, the addition of fresh water to the fuel and emulsification of the mixture before supplying it to the engine is a very efficient tool, and substantial reductions can be obtained. This proven method for reducing $NO_x$ emissions is effective in all engine types. The reduction is typically some 10% for each 10% water addition, see Fig. 4, and the associated fuel consumption penalty ranges from zero to some 1% increase for each 10% water addition.

Water-emulsified heavy fuel oil (in combination with slightly reduced firing pressure) was first utilised commercially by MAN B&W Diesel in a 20 MW 7L90GSCA engine for a co-generation plant in Puerto Rico, which has been in operation since 1984. This engine operates with 30% water addition to HFO to achieve the required approx. 30% reduction of $NO_x$ in order to comply with the US-EPA emission limits. The service experience with this engine is excellent, with low cylinder liner wear and a total absence of problems in the fuel injection system (which was specially adapted to the use of emulsified fuel).

Against this background, MAN B&W Diesel favours the use of emulsified fuels (in combination with Low-$NO_x$ fuel nozzle layout) to ensure that engines comply with future stages of the IMO Regulation and with more stringent reguirements for land-based applications. An example of the latter is a recent installation on Guam of two 12K80MC-S engines for an 80 MW power station. The engines were designed to use emulsified fuel with up to 50% water addition in combination with mini-sac fuel valves, and had to comply with emission limits on CO, HC, $NO_x$ and particulate matter. The engine emissions are well below the contract values, and the $NO_x$ values obtained correspond to around 50% of the present IMO limit value for this engine type.

**Emission reduction by combining primary methods**

In general, it is difficult to evaluate a combination of emission reduction methods when more than one of the methods can have the same effect. In order to see the potential for combining some of the more promising methods, experiments were carried out on a 5S70MC engine with slide-type fuel valves, reduced firing pressure, water-emulsified fuel and exhaust gas recirculation (EGR). The results are illustrated in Fig. 5, which outlines the emission reductions obtained and the corresponding effects on specific fuel oil consumption.

As can be seen, the slide valve gave a reduction of some 20% in $NO_x$ and a slight reduction in SFOC. A significant further reduction was obtained by combining this with emulsified fuel (50% water addition) and reduced firing pressure, but at a rather high fuel penalty of around 6 g/kWh. By further adding 20% EGR, a total $NO_x$ reduction of around 80% was obtained at a fuel penalty of some 7 g/kWh. However, when the firing pressure was re-adjusted to its normal value, almost the same $NO_x$ reduction was obtained at a fuel penalty of around 1.5 g/kWh.

**Secondary methods for $NO_x$ reduction**

Very large $NO_x$ reductions can be obtained by means of exhaust gas after-treatment using a Selective Catalytic Reactor (SCR), and this method has been used commercially on an MAN B&W two-stroke marine diesel engine since 1989. The method, the system design and the main results (more than 93% reduction) are described in detail in [2] and [3].

It should be mentioned, however, that an engine with high pressure direct gas injection (12K80MC-GI-S) and a very large SCR is in operation in a power plant in Japan, probably being the large bore engine with the lowest $NO_x$ emission worldwide. The very strict local regulations in the Tokyo area require a $NO_x$ emission of less than 10 ppm, so it was necessary to provide more than 99% $NO_x$ reduction. This requires a very large SCR that must be placed between the engine and the turbocharger turbines in order to have the right temperature level for the catalyst (300-400 °C). Thus, the thermal inertia of the catalyst has a strong influence on the engine performance during the warming up of the plant.

This was known from the marine plants (see [3]) to be a source of turbocharger instability, which could be controlled by suitable operation of the auxiliary blowers on the engine. For the (much larger) catalyst on the 12K80MC-GI-S engine, dynamic simulations of the engine operation at the design stage had indicated that more was needed to obtain a satisfactory load-up capability after a cold start. As a consequence of the calculation results, the engine was equipped with a 6 MW gas burner, situated between the engine and the SCR, and operated to heat up the catalyst, resulting in a very satisfactory load-up capability [4].

## TOTAL EMISSION CONTROL OF SHUTTLE TANKERS

As described in [5], shuttle tankers are widely used to serve offshore oilfields from which pipeline connections to the shore are not feasible. The shuttle tankers load their crude oil cargo either from storage facilities at the oilfield or directly from the production platforms and loading buoys at the oilfield. The crude oil cargo is then transported to oil refineries or terminals ashore close to the oilfield.

During the handling of the oil, and in particular during loading, large quantities of the light components of the oil evaporate. These oil vapours are normally called VOC, short for Volatile Organic Compounds. The VOC emission during the voyage is not normally significant because of the short sailing distance.

Measurements taken by Statoil [5] showed that the magnitude of the energy lost by the release of VOC to the atmosphere was comparable to the total HFO consumption of the vessel. This led Statoil to the idea of using the VOC as the main fuel for the engines provided, however, that the engines' capability to operate on HFO could be maintained in the event that VOC should be unavailable. This would substantially reduce the environmental effects of VOC release, provide significant savings on HFO costs and a considerable reduction in toxic gas emissions from the engines.

Since the majority of main engines in Statoil's shuttle tanker fleet are of MAN B&W design, the two companies entered into a joint project to develop and demonstrate the relevant technology for utilising the concept in shuttle tankers. MAN B&W Diesel is responsible for the engine development and Statoil for the VOC collection and storage systems. As described in more detail in [5], the propane and heavier hydrocarbons in the VOC are liquefied, while methane and ethane are vented to the atmosphere together with inert gas, as usual. The liquefied VOC is stored in a pressurised tank (similar to an LPG tank), from which it is delivered to the engine at 400 bar pressure by a membrane-type high pressure pump.

The engine design features for operation on VOC, particularly the injection and control systems, and some of the results of combustion tests with VOC in dual fuel operation of a 50 cm bore research engine are described in the following.

### Engine design features

The internal and external systems needed for operation of the engine on VOC are very similar to the well-proven systems used on the natural gas burning 12K80MC-GI-S high-pressure gas-injection engine, described in detail in [4] and [6].

The cylinder cover (Fig. 6) has bores for two fuel oil valves and two VOC injection valves. Furthermore, there are bores for two more valves that can be used for injection of the gaseous VOCs (methane and ethane) or for injection of water in order to reduce the $NO_x$ emission, if required. On the camshaft side, the cylinder cover has a face for fitting the valve block (Fig. 7). This houses a VOC accumulator, a fast-acting shutdown valve, a non-return valve at the VOC inlet pipe, blow off and purging control valves and the fast-acting NC valve belonging to the Mechatronic VOC injection system (see below).

The preheated and pressurised VOC is injected directly into the combustion chamber immediately after the injection of a small amount of fuel oil (8% of the oil amount at 100% load), acting as pilot oil and securing stable, safe combustion at all engine loads.

The special VOC injection valves are operated by a Mechatronic system which features computer control to allow for the greatly varying properties of the VOC fuel. The concept of this (two-circuit common rail type) system is shown in Fig. 8. A pump station on the engine supplies lube oil at high pressure to an electronically controlled hydraulic valve (NC valve) for each cylinder. VOC is injected by opening the NC valve, admitting high-pressure lube oil to the VOC injection valves. The lube oil pressure opens the VOC injection valves and allows injection of pressurised VOC into the cylinder. When sufficient VOC has been injected, the lube oil pressure is released to the tank by shifting the NC valve to its other position and, as a result, the spring-loaded spindle in the VOC injection valve closes, and VOC injection is terminated. By virtue of this system, the timing of the VOC injection can be freely controlled in relation to the injection of pilot oil so as to adapt to the actual combustion behaviour of the VOC.

A full 'MC-GI' safety system is incorporated (see the detailed description of this in [4] or [6]). The safety system monitors the operation of the engine as well as the Mechatronic system and the pilot oil injection system. If there is no pilot oil injection, the safety system will prevent VOC injection – and at the same time the engine will change over to HFO operation. Similarly, if the VOC supply pressure falls below a pre-set limit, indicating a sticking VOC injection valve or severe leakage of VOC, a fast-acting shutdown valve in the valve block will close immediately and prevent further VOC injection. At the same time the engine will change over to HFO operation. The complete engine control and safety systems have been approved by six major Classification Societies.

**Combustion tests with VOC as the main fuel**

The combustion tests with VOC include tests with dual fuel operation as well as pure VOC operation on a large bore research engine (the 4T50MX 'Intelligent Engine', a 10,000 bhp, 4-cylinder 50-cm-bore engine) in Copenhagen. The engine was equipped with a Mechatronic VOC fuel injection system as described above. The tests served to identify the demands that would be made on the engine and fuel injection control system when using VOC as the main fuel.

As mentioned above, the liquefied VOC consists mainly of propane and higher hydrocarbons for which reason a rather low methane number can be expected. Consequently, the self ignition properties of the VOC might allow operation on pure VOC, i.e. without pilot injection of HFO as the source of ignition, thus offering an attractive possibility of almost eliminating particulate emissions and completely replacing HFO by VOC. Some of the main results of the initial investigations are briefly outlined in the following, accompanied by results of 'adaptation tests' in which the modern research engine was adapted to perform similarly to the 14-year-old 6L55GUCA main engines of the selected test vessel (see below).

Basic combustion behaviour of VOC fuel. The possibilities for operating the engine in 'single fuel' mode on VOC were investigated. The tests were all carried out at 123 r/min, corresponding to the research engine's MCR point (Maximum Continuous Rating, i.e. 100% load and rated engine speed). Combustion at high load is very satisfactory, with a smooth pressure rise in the cylinder and with an almost negligible ignition delay. At lower loads, the situation is completely different, and combustion characteristics resemble those of a small, high speed engine running on a marginal ignition quality fuel. There was audible knock from the engine, the reason being a nearly stepwise initial combustion following a rather long ignition delay period.

Though ignition was rather stable, it is evident that the engine's cylinder condition (in particular the piston ring condition) would suffer from the hard combustion in part load operation. The absolute requirement of shuttle tankers for reliable operation at any load without time limitations, together with the logic of the pertaining safety system, mean that pure VOC operation is not a straightforward

possibility. Consequently, dual fuel operation using VOC as the main fuel and diesel fuel as the source of ignition must be used. The combustion rate curves (Rate Of Heat Release, ROHR) from 25% to 100% load shown in Fig. 9 indicate that stable ignition and quite normal 'diesel type' combustion can be obtained in this way.

Emission characteristics, basic tests. The tests were carried out on one cylinder only (with the remaining three cylinders operating on diesel fuel), so the accuracy of the emission measurements is limited, even when gas samples are taken in the exhaust pipe from the 'VOC' cylinder, before the exhaust gas receiver. Thus, the measurements should be considered only as a rough indication of what can be expected from the engines in a shuttle tanker (see below).

The results from these tests (at 75% load) show a reduction in $NO_x$ emissions in the dual fuel mode of around 27%, compared with the diesel mode, confirming the expected values. In pure VOC mode (without pilot oil injection), the $NO_x$ emission is only around 5% lower than in the diesel mode. This is probably due to the single-fuel diesel combustion cycle being basically the same as with diesel oil. Emissions of carbon monoxide and unburned hydrocarbons were expected to increase in the dual fuel mode because of the increase in the fuel nozzle sac-volume (four fuel valves per cylinder versus two in pure diesel operation). CO and HC emissions were found to increase by some 25 and 40%, respectively, while in the pure VOC mode the CO and HC values were unchanged.

**Combustion adaptation for VOC fuel.** As mentioned above, the 6L55GUCA main engines installed in the selected test vessel are around 15 years old and represent the state of the art at that time. Modern engines have higher compression ratios and operate at much higher mean effective and combustion pressures. As a consequence, the ignition and combustion behaviour might be somewhat different, and in order to prepare properly for the demonstration test, the research engine was modified extensively so as to approach the performance characteristics of the 6L55GUCA engines. Initial tests in this configuration clearly indicated that 'pure VOC' operation would not be acceptable, not even at high load, and the tests were continued in dual fuel operation, to investigate the effects of a number of parameters relevant to the actual engines used. Some results are outlined in the following.

VOC injection pressure: The influence of the VOC injection pressure (between 300 and 400 bar, with constant injection timing) on cylinder pressure, ROHR and $NO_x$ emissions was investigated. Thanks to the slower injection and mixing of the VOC at lower injection pressures, the ROHR is lower, leading to a lower firing pressure and lower $NO_x$ emissions. Combustion, however, is smooth and basically satisfactory in all cases.

Pilot oil amount: It is desirable to use as low an amount of pilot oil as possible in order to replace as much fuel oil as possible by VOC. On the other hand, stable injection and ignition of the pilot oil must be achieved to ensure stable and reliable operation of the engine. The tests show that the combustion process of the VOC is almost identical for the three tested amounts of pilot oil: 5%, 8% (normal value) and 10% of the amount at full load, and there was a tendency towards slightly lower $NO_x$ emission for a low amount of pilot oil. The initial part of the ROHR-curve is slightly different, reflecting the different amount of pilot oil injected initially.

It can be concluded that the lower limit for pilot oil amount is determined by stable functioning of the pilot injection valves, not by the ignition process or the combustion of the VOC. At 5% pilot oil, the pilot oil valve spindle is only partly lifted, and a small variation in pump index, opening pressure for the pilot oil valves or fuel pump wear (leakage) may lead to failure to inject pilot oil through one injection valve or in one cylinder. In this event the safety system will trigger a gas system shutdown and revert to fuel-oil-only operation. Thus, 8% pilot oil will be used so as to ensure stable operation.

Pilot oil/VOC amount: Fig. 10 shows the influence of the ratio between pilot oil amount (with constant injection timing) and VOC amount (with variable injection timing) on cylinder pressure, ROHR and $NO_x$ emissions. To ensure flexible operation of shuttle tankers (and LNG carriers as well) it is necessary to be able to use the available VOC irrespective of the actual load demand on the engine. Thus, if there is not sufficient VOC (or boil off gas) available, the pilot oil amount must be increased so as to provide the required power output from the engine. If this is done with fixed timing for pilot oil and VOC (or gas), the cylinder pressure will increase substantially (by some 15 bar at 50% VOC/50% fuel oil), due to overlapping fuel oil and VOC injection. The increased cylinder pressure thus overloads the engine.

The figure shows the combustion behaviour of the engine with optimised control of VOC injection but fixed timing of the pilot oil - this is injected by the conventional camshaft operated fuel pumps. As can be seen, the Mechatronic system makes it possible to control the VOC injection in such a way that the cylinder pressure and combustion (ROHR) remain virtually unchanged, independent of the ratio between pilot oil amount and VOC amount. The figure also illustrates that $NO_x$ emission in the dual fuel mode is lower than in the pure diesel mode.

It is obvious from the diagram with needle lift for the pilot oil injection valves and the VOC injection valves that this optimal control would hardly be possible with a conventional camshaft operated system for VOC injection.

**Verification of the VOC Fuel concept on a shuttle tanker**

A full-scale demonstration of the technology and concept for shuttle tankers is about to start on *M/T Navion Viking*, a shuttle tanker serving the Norwegian Statfjord oilfield, which provides large amounts of VOC. The vessel's two 6.6 MW 6L55GUCA main engines are both equipped with shaft generators. During a planned dry-docking of the vessel in May 1998, equipment was fitted for converting the two main engines for VOC burning. At the same time, the vessel was prepared for fitting the full-scale VOC collection, storage and supply systems, which will be used to supply VOC fuel to the converted main engines. These systems were fitted during May 1999, and at present the final preparations for starting VOC operation on one of the main engines are in the final phase. The other main engine will follow some six months later, subject to satisfactory operation on VOC of the first engine and satisfactory operation of the VOC collection, storage and utilisation systems. The full-scale trials comprise one year's operation on VOC.

**Environmental advantages of the VOC Fuel concept**

Depending on the composition and amount of the VOC as well as the ship's sailing schedule, up to some 90% of the shuttle tanker's fuel oil consumption may be replaced by the VOC. This will lead to substantial fuel cost reductions (the formerly wasted VOC vapours being considered free of charge) as well as cleaner exhaust gas:

- up to some 90% reduction of $SO_x$ emissions, directly proportional to the percentage of fuel oil substitution. A further economic advantage is that the use of VOC may replace low-sulphur fuels in IMO 'Special areas' that require operation on low-sulphur fuels
- up to some 90% reduction in particulate emissions, due to the lighter and more volatile fuel, which causes less smoke formation
- 20-30% reduction in $NO_x$ emissions due to the dual fuel combustion process and more uniform mixing of fuel and air in the cylinders
- some reduction in $CO_2$ emissions due to the higher hydrogen/carbon ratio in VOC fuel than in fuel oil.

**Availability of the VOC Fuel concept**

The concept will be generally available to interested shipowners after the successful termination of the demonstration test mentioned above. It might, however, be of interest to shipowners to have new shuttle tankers prepared for this technology even before then. For the engine, this means the use of the MC-GI design for the exhaust gas receiver and the cylinder covers:

- The exhaust gas receiver needs to be made of thicker plates (plus changes in some minor design details) to comply with the requirements of the Classification Societies.
- The cylinder covers have to be provided with extra bores for the VOC injection valves and faces for the fitting of a valve block on the camshaft side.

This preparation allows the engines to operate on normal fuel oil until it becomes feasible to carry out the full conversion of the vessel so as to be able to collect, store and burn the VOC. This option has already been selected by a number of owners ordering shuttle tankers, and more than 20 engines (mainly of the 7S50MC type) are currently on order or in service 'prepared for VOC' as described above. It is expected that a number of these will be converted to burn VOC during the next five years.

## CONCLUSION

Environmental friendliness will be one of the dominant development goals in the years to come, and there are well proven methods available for ensuring compliance with international and national regulations for marine and stationary diesel engines. In the special case of VOC emissions from shuttle tankers, the VOC Fuel concept is a particularly attractive solution to the vessels' emission problem, by providing the dual advantage of avoiding pollution of the atmosphere while, at the same time, the VOC is being efficiently utilised to fuel the ship's engines. The use of the high-pressure gas-injection MC-GI engine to burn the VOC furthermore ensures that the main engines of the vessel emit a significantly cleaner exhaust gas than with HFO operation.

## ACKNOWLEDGEMENTS

The VOC Fuel demonstration project is supported financially by most oil companies in Norway in a joint effort to achieve a cleaner environment, and by the European Commission through its Thermie development programme under contract number OG/147/97/NO/DK. The Norwegian shipowners Rasmussen Maritime Services and Navion have played an important role in the development project. Gas emission recordings and analyses from a number of crude oil carriers have been performed over several years by the SINTEF-organisation in Norway. The authors would like to express their appreciation of this support.

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**CAPTIONS:**

*Fig. 1: Comparison of $NO_x$ level in the previous standard fuel optimised nozzles and in Low-$NO_x$ fuel nozzles on a number of MC engines*

*Fig. 2: Cross-section of the conventional type of fuel valve, the mini-sac version with reduced sac-volume and the slide-type valve*

*Fig. 3: Effects on $NO_x$ emission and specific fuel consumption of the injection pattern of the 'Intelligent Engine' using a computer controlled fuel injection pump*

*Fig. 4: Influence on $NO_x$ emission of adding water to the fuel oil in several types of large bore low speed marine engines*

*Fig. 5: Effects on $NO_x$ emission and fuel consumption of combinations of primary emission reduction methods on a 5S70MCE engine*

*Fig. 6: Cylinder cover with bores for fuel oil valves, VOC valves and valves for gas or water injection*

*Fig. 7: Valve block with shutdown valve and VOC accumulator*

*Fig. 8: Concept of the Mechatronic VOC injection system*

*Fig. 9: Cylinder pressure and Rate of Heat Release in dual fuel operation on VOC/gas oil at different engine loads*

*Fig. 10: Effect of VOC/pilot oil ratio on cylinder pressure, Rate of Heat Release and $NO_x$ emission shown together with the lifting curves for pilot oil injection valve and VOC injection valve*

Specification of figures (MAN B&W Diesel Overhead numbers):

| | |
|---|---|
| 1 | L/9123-4.1/0199 |
| 2 | L/9475-6.1/0399 |
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| 5 | L/3840-2.1/0997 |
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# Environmentally Friendly Propulsion Systems

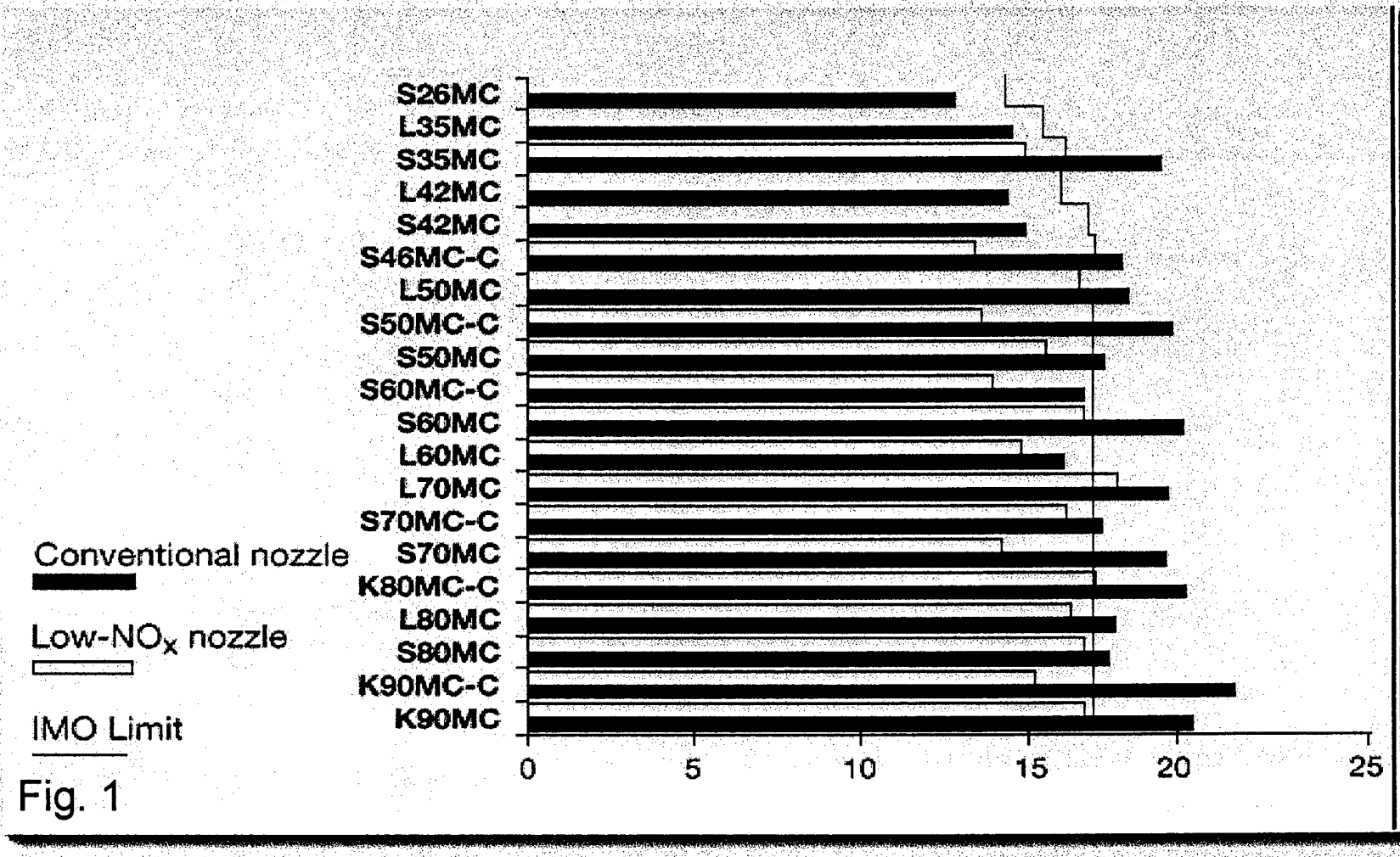



Fig. 1

# Environmentally Friendly Propulsion Systems

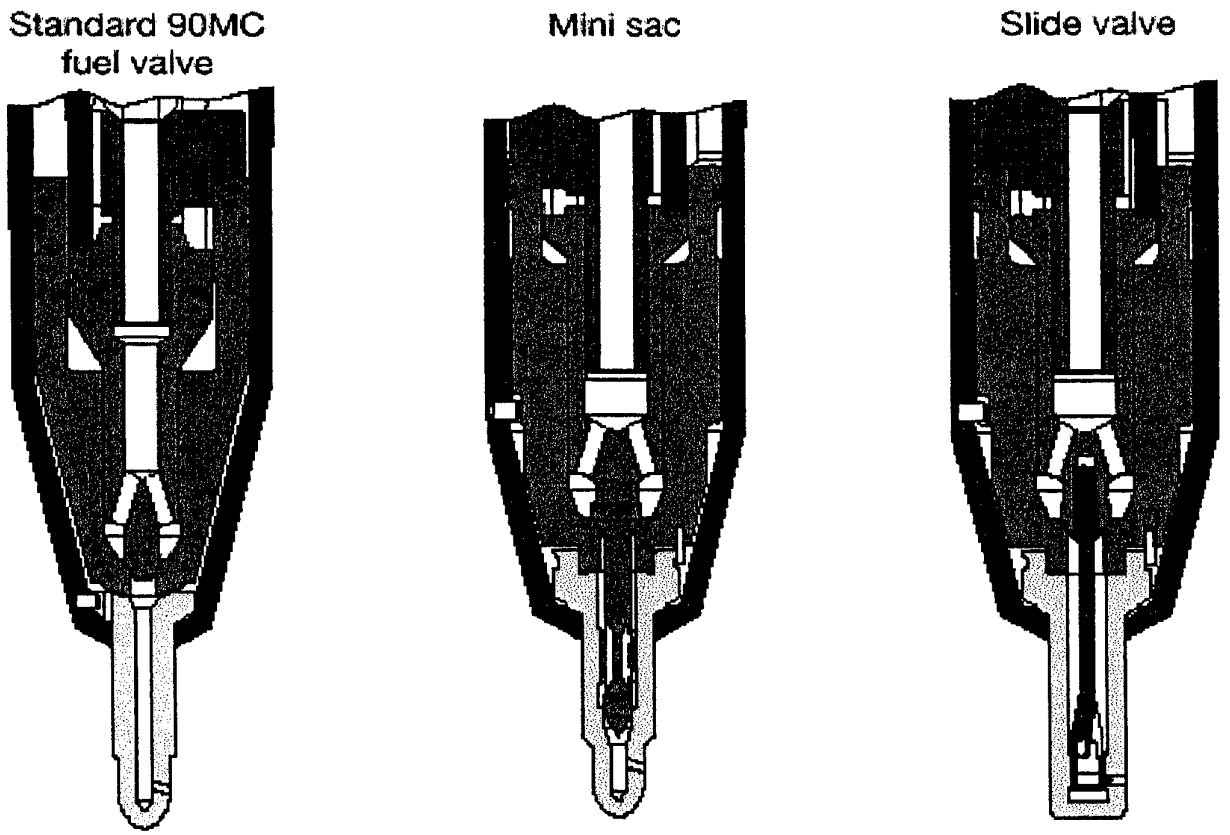



Fig. 2

# Environmentally Friendly Propulsion Systems

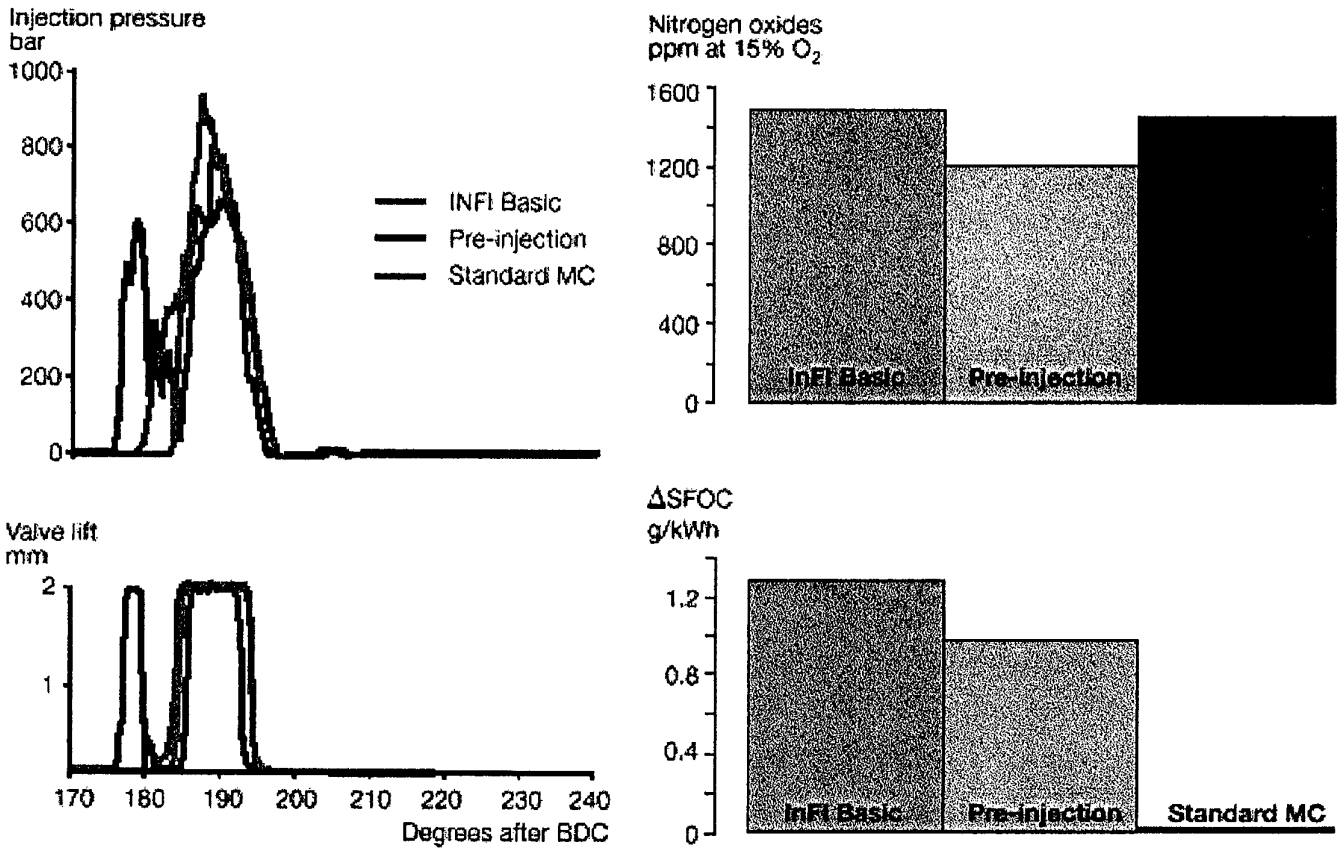



Fig. 3

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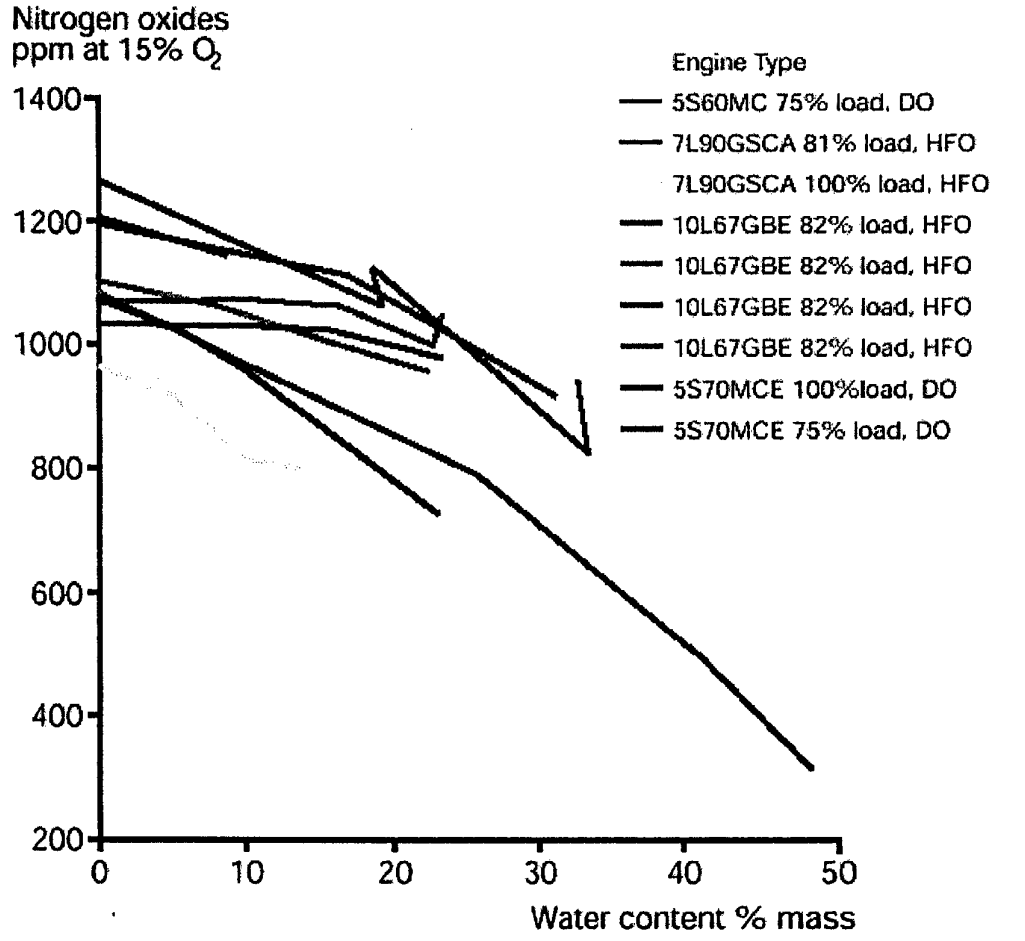



Fig. 4

# Environmentally Friendly Propulsion Systems

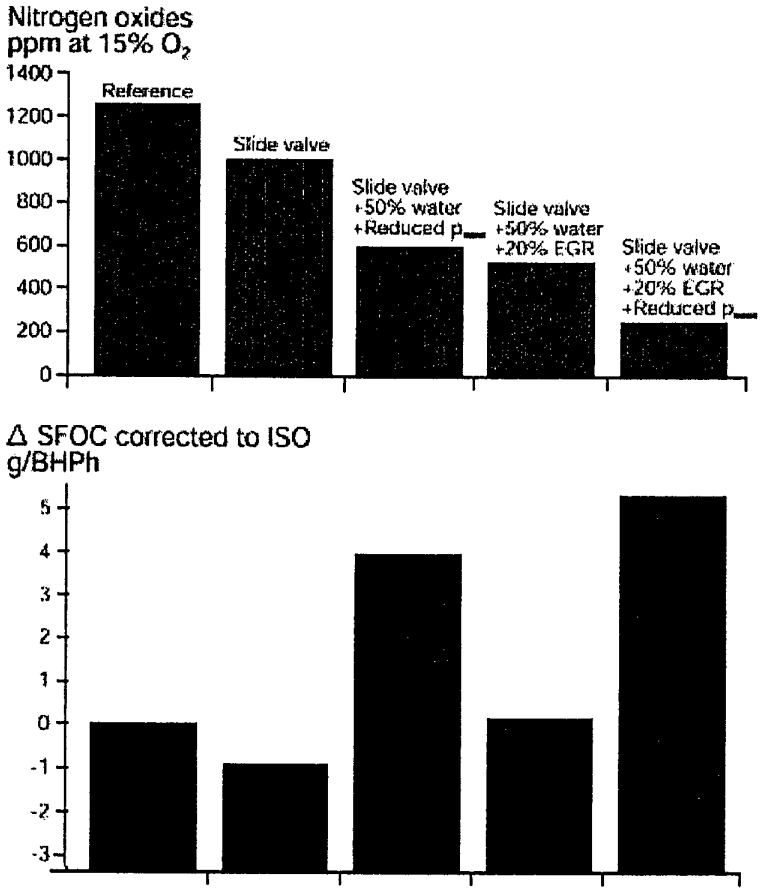



Fig. 5

# Environmentally Friendly Propulsion Systems

MAN B&W

**Cylinder cover**

Injection valve bores:

- Fuel oil
- Gas
- VOC

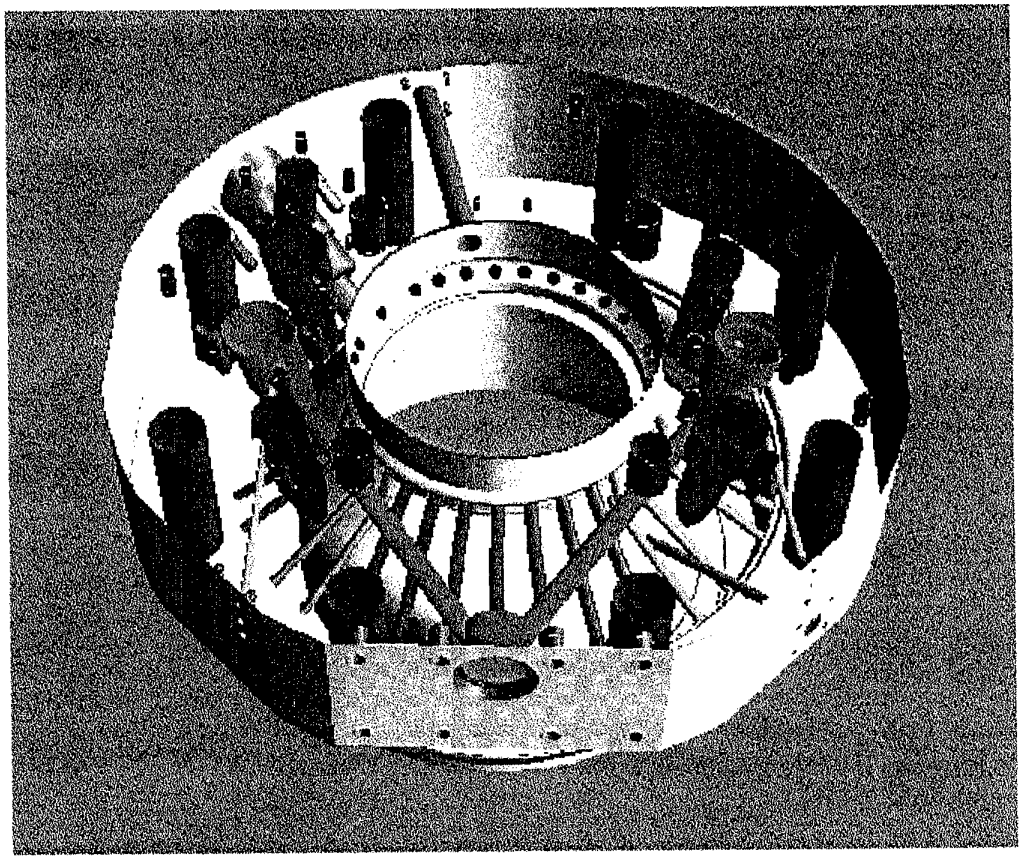


Fig. 6

# Environmentally Friendly Propulsion Systems

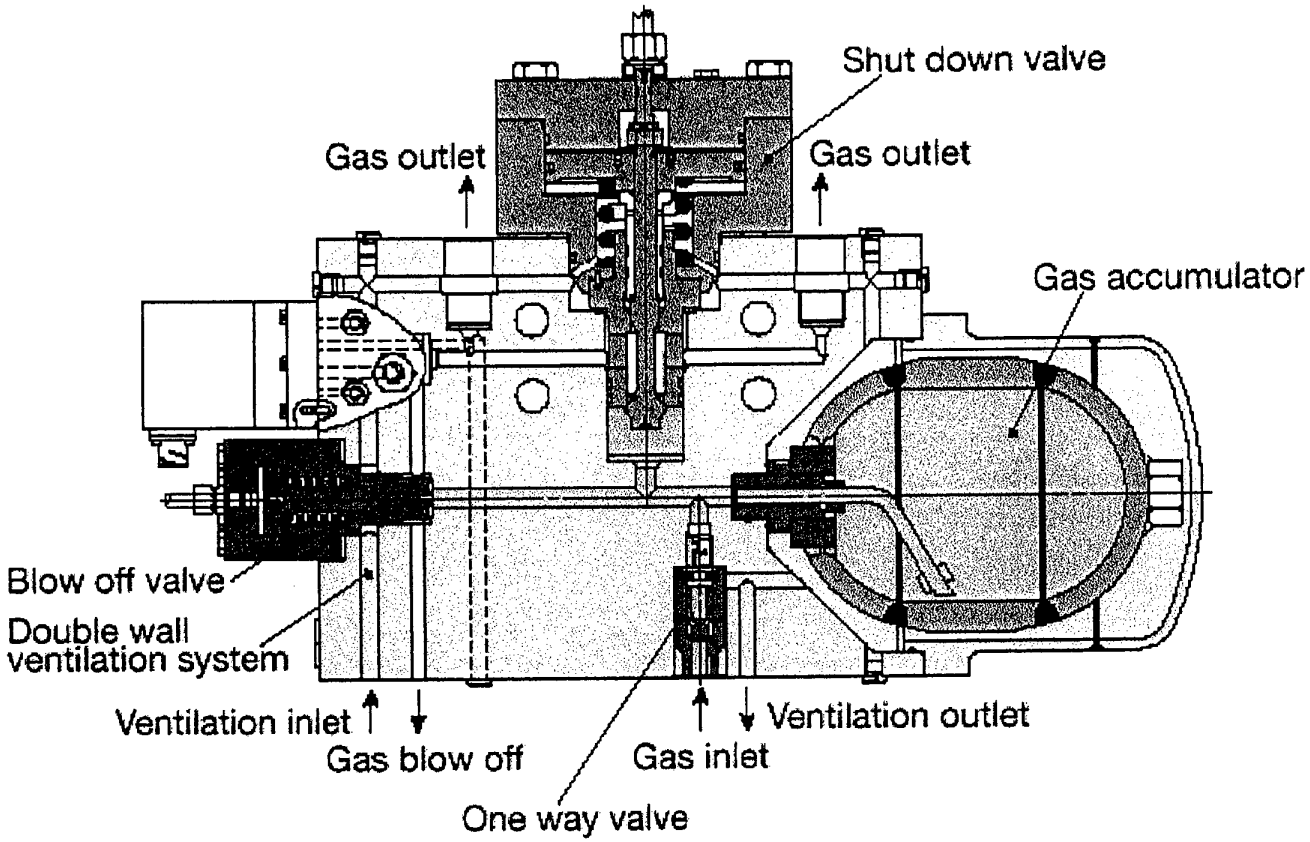



Fig. 7

# Environmentally Friendly Propulsion Systems

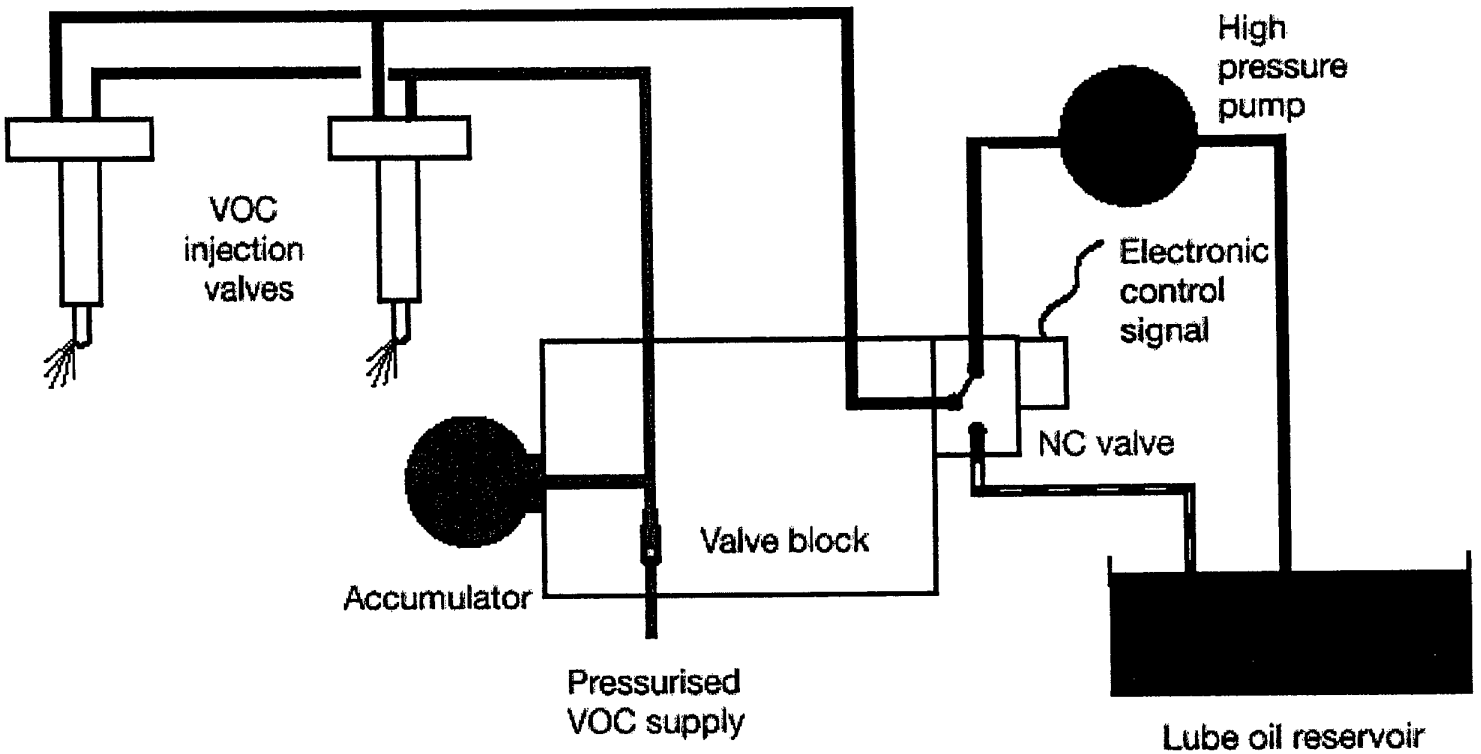



Fig. 8

The Maritime Environment

# Environmentally Friendly Propulsion Systems

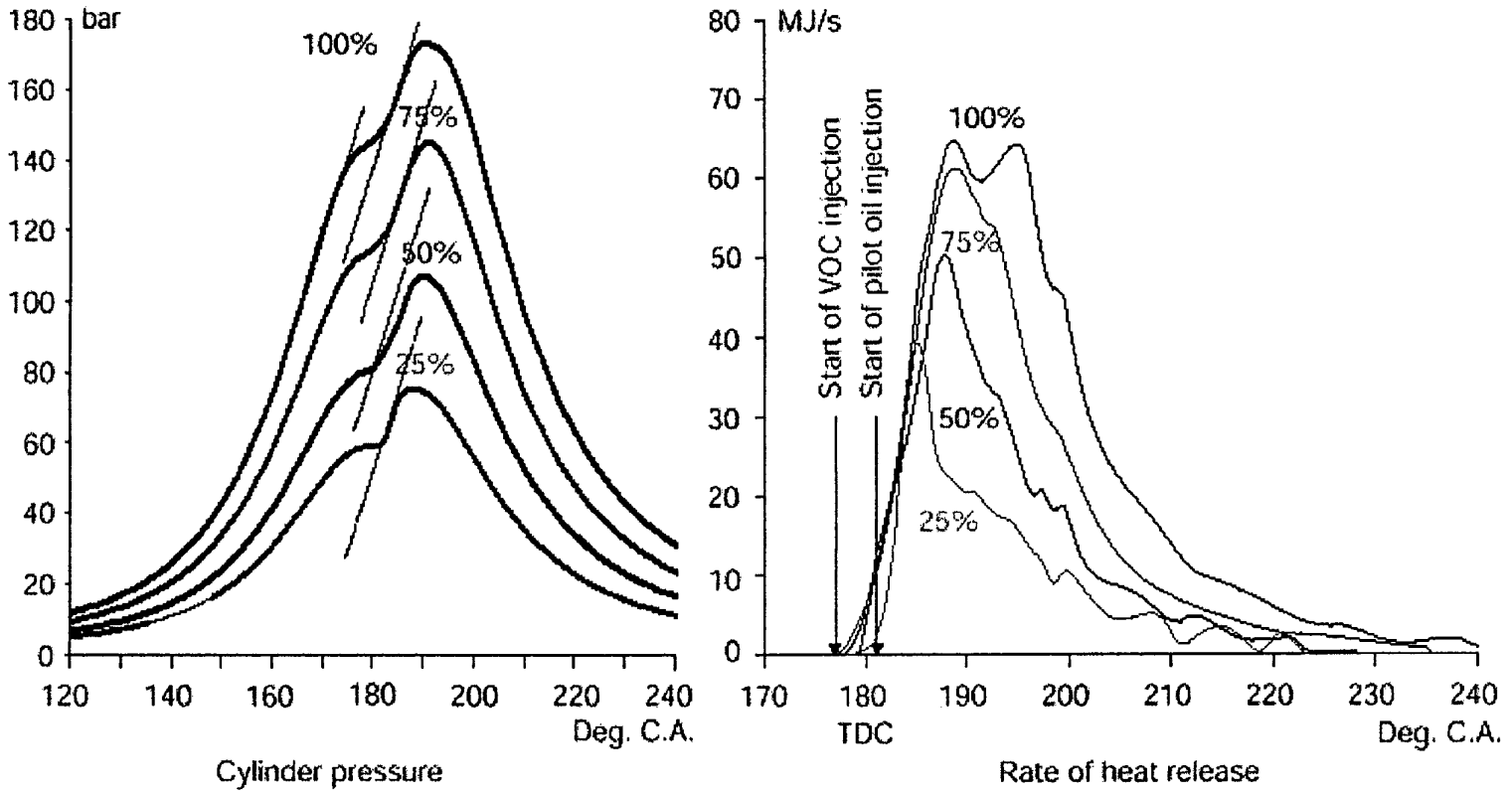
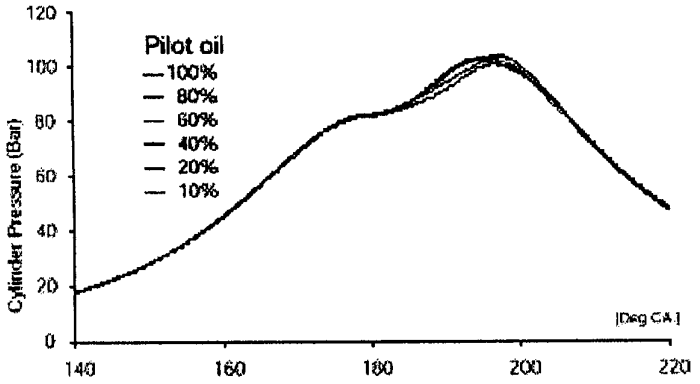
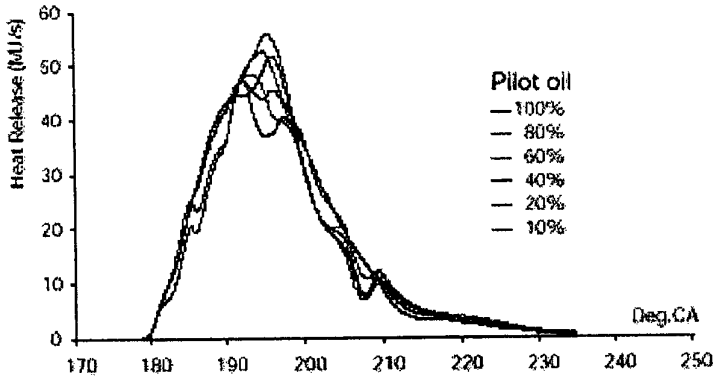


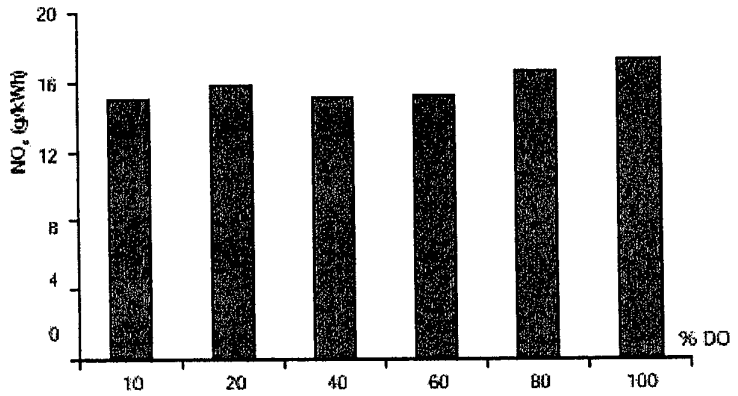

Fig. 9

The Maritime Environment

# Environmentally Friendly Propulsion Systems



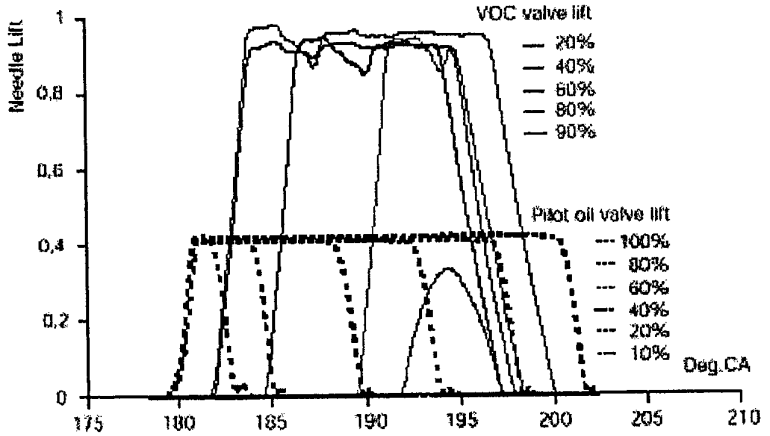




Fig. 10

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The Maritime Environment

# Development of Emission Reduction Technologies for the Future

**Dipl.–Ing. Bert Buchholz, MET GmbH, GE**

## Abstract

The IMO proposal and the Swedish Model on emission-related port fees are just the beginning of emission regulations for marine transport. For the foreseeable future, the emission behaviour of marine diesel engines will stay in the centre of research and development.
NOx-emissions are directly coupled with the combustion process parameters. The high combustion temperatures and pressures in large, state-of-the-art diesel engines are the reason for the high efficiency of these engines on the one hand and the increase of NOx emissions on the other hand.
Engine internal measures bear significant potential for NOx reduction. From a technical and operational point of view they will be preferred to external measures which may be applied to satisfy locally increased regulations. Properly implemented, internal measures will reduce emissions and maintain the high efficiency required today. However, for a further reduction of emissions, a thorough understanding of the engine internal processes is vital. Therefore, standard research and development approaches need to be qualified by and combined with modern simulation tools to speed up development and to decrease costs.
Such an innovative approach was applied to investigate the influence of fuel quality on the NOx emissions of two-stroke crosshead diesel engines. The paper will show the research technique applied and some of the results obtained. Conclusions will be drawn for future emission reduction measures as well as for the research tools to be applied for their development.

Session 4
Speaker Dipl.-Ing. Bert Buchholz
(for Prof. Dr.-Ing. S. Blutzuweit who will not be available)

The second speaker of session 4 will be Mr. Bert Buchholz from MET, Rostock, GE.

Mr. Buchholz joined MET in 1993 as a trainee during his studies at Rostock University.

He has been a full time employee at MET since 1996, working as project engineer and project manager in research and development projects. His main working areas lie in the fields of engine development and in the simulation of engine internal flow and reaction processes.

Mr. Buchholz will present his paper on
"Development of Future Emission Reduction Technologies"

# Development of Future Emission Reduction Technologies

*Abstract*

*The IMO proposal and the Swedish Model on emission-related port fees are just the beginning of emission regulations for marine transport. The emission behaviour of marine engines will stay in the centre of research and development for the foreseeable future.*

*Current and future emission reduction measures have to consider the tough economic conditions in merchant shipping industry. Therefore, high engine efficiency, low operation costs and low installation costs are, beside the emission reduction efficiency, important development targets for emission reduction measures.*

*The huge research and development tasks combined with these targets can only be reached efficiently if modern research and development tools are applied. Modern simulation technologies allow the reliable prediction of complex engine processes and their interaction using virtual computer models. By this means, modern emission reduction measures can be developed, investigated and pre-optimised already in the early development stages which leads to a considerable speed-up in research and development.*

*MET Motoren- und Energietechnik GmbH have gained great experience in efficient commercial application of state-of-the-art simulation tools for the optimisation of engine operation and for the investigation and control of emission generation processes.*

## Introduction

The emissions caused by the combustion of fossile fuels in marine diesel engines have become a topic of increasing public interest. Beginning with the nineties, the emission issue is increasingly influencing the shipping industry, and the engine developer and manufacturer in particular. The emission limits proposed by the IMO and the Swedish regulations on emission-related port fees are but the beginning of emission regulations for marine transport. Therefore, the emission behaviour must be considered as an increasingly decisive sector of research and development for the immediate future. At the same time, the economic situation in merchant shipping industry requires high engine efficiency, operation on HFO and low overall operation costs of the ship propulsion plants. For a rapid and successful application, emission reduction measures have to fulfil the environmental targets without significant negative impact on operation costs.

**CLEAN - Project**

The key point in tackling the $NO_X$ emission problem is a thorough understanding of the internal engine processes which lead to their generation. Therefore, the step has to be made from phenomenological parameter studies towards investigations of the internal combustion process and the $NO_X$ generation combined with it. With respect to the large combustion chambers and the slow combustion process of marine diesel engines (two-stroke engines in particular) this raises the need for spatially and temporally resolved investigation.

The CLEAN project, a joint project for emission reduced ship propulsion systems funded by the German Ministry of Education and Research (Bundesministerium fuer Bildung und Forschung BMBF), combined the efforts of German ship engine developers and producers in order to investigate the basics of pollution production and pollution control measures for ship propulsion systems. /1/;/2/;/3/;/4/;/5/

***The principal $NO_X$ generation process***

The NO generation in diesel engines is governed by the temperatures in the reaction zones, the air excess ratios, and long periods of time in which the gases remain in the reaction zones. Portions of the NO, which was primary generated during the reaction phase, are further oxidised to $NO_2$ after the reaction phase and partly outside the cylinder itself. Three different generation mechanisms of NO are to be distinguished:

- thermal NO
- prompt NO
- fuel NO

Since the thermal NO mechanism is responsible for approx. 90% of the $NO_X$ emissions it will form the centre of the further presentation.

In the regions of the combustion chamber with more than 1300 °C and an air excess the following coupled reactions take place:

$O + N_2 \Leftrightarrow NO + N$

$N + O_2 \Leftrightarrow NO + O.$

In the fuel enriched zones within the flame front the reaction

$N + OH \Leftrightarrow NO + H$

takes place.

Unfortunately, the $NO_X$ generation process is extremely increased at high temperatures, high air excess, and increases additionally with the action time of the high temperatures. On the other hand, these conditions lead to a high overall efficiency of the engine. Therefore, measures adopted to reduce the $NO_X$ emissions face the problem that changing the internal process conditions to minimise $NO_X$ emissions is likely to decrease the efficiency of the engines and will consequently increase the fuel consumption and $CO_2$ production.

**Other emissions**

*$SO_X$*

The emissions of $SO_2$ and $SO_3$ are directly linked to the content of sulphur in the fuel as virtually all sulphur contained in the fuel is oxidised to $SO_2$ and $SO_3$ during and immediately after the combustion. The sulphur content of fuels can vary widely from 0.05% for distilled automotive diesel fuels to more than 4% for HFO. The separation of sulphur from the fuel oil or the separation of $SO_X$ from exhaust gases is not feasible aboard ships. The main problem is the handling of the separated $SO_X$. $SO_X$ dissolves in water producing sulphuric acid, which must be stored aboard the vessel and handed over in the port for final treatment. A disposal of the sulphuric acid in the sea will not cause any short term problems, but should not be a part of a future concept.

Therefore, bunkering of low-sulphur fuel is the only possible way to reduce $SO_X$ emissions. Consequently, the key to reduce these emissions is in the hands of the oil companies which will eventually face a situation were additional investments may be necessary to reduce the sulphur content of residual oils. Such a situation will be enforced by local legislation which limits the sulphur content in the fuel as is the case for the Baltic Sea (maximum sulphur content in the fuel 1.5% / 0.5% for some ferry routes). Additionally, low sulphur contents will be appreciated by engine manufacturers and operators with respect to the corrosion problems combined with high sulphur contents. Minor problems combined with increased running-in wear when using low sulphur fuels can be overcome by special lubricating oil additives /12/.

In addition to the production of $SO_X$, the sulphur content of the fuel also has significant impact on the particulate emissions.

*Particles*

Particulate emission consists primarily of soot, metal oxides, and sulphates, and they originate from incomplete combustion or impurities in the fuel and lubricating oil.

The reduction of particulate emissions will become an issue especially in areas with dense ship traffic and high population densities, such as ferry ports, ports within big cities or certain water ways (English Channel). Two-stroke engines produce relatively small particulate emissions, at least in stationary operation mode, since the long time interval available for combustion, the high temperature levels and the air excess lead to an almost complete combustion process. Nevertheless, given the size of the engines even smallest percentages of particulate emissions can amount to quite impressive quantities. For engines with an output of approx. 40MW the total particulate emission during 24 hours of operation can exceed 1000 kg. High sulphur content in the fuel oil as well as transient operation of the engine which is usually the case in coastal waters can lead to increased particulate emissions. Apart from the environmental impact of particulate emissions, they also have an unwanted influence on the efficiency and reliability of SCR plants (agglomeration of particles at the catalyst surface) and the efficiency of exhaust gas boilers.

High sulphur content in the fuel will, as argued above, lead to high $SO_X$ emissions. Unfortunately, $SO_X$ significantly increases the particle production. The $SO_X$ molecules act as condensation points for water, soot and metal oxides. Low sulphur fuel will thus have a positive influence on particle emission, too.

*HC and CO*

Hydrocarbons and CO emissions are the result of incomplete combustion which is no significant problem with large two-stroke diesel engines. Increased emissions of these components can occur during instationary engine operation but can be overcome with improved engine management systems.

*$CO_2$*

$CO_2$ is a natural product of the combustion of fossile fuels. The production of $CO_2$ can only be decreased by less consumption of these fuels, i. e. by increased engine efficiency. As already mentioned, the very high efficiency of two-stroke diesel engine guarantees relatively little $CO_2$ emissions. But it is worth mentioning, that every increase in fuel consumption caused by emission reduction measures will invariaby lead to increased $CO_2$ emissions.

Future emission regulation will consider other emission components than $NO_X$, too. For this reason and due to general environmental consideration, future research and development has to consider not

only single components but all major components of the exhaust gas and their interconnections. Measures, which decrease one exhaust gas component and cause an increase of another component may be less acceptable in the future.

**Internal measures**

*Homogenisation of fuel injection and distribution*

The inhomogeneous distribution of fuel in the combustion chambers of diesel engines and in two-stroke engines in particular lead to very uneven temporal and spatial temperature distribution within the cylinders. Therefore, the temperatures averaged over the whole cylinder volume are not decisive for the $NO_X$ production. $NO_X$ is primarily generated in the hot areas of the combustion chamber even if these areas are small compared to the overall cylinder volume. /5/ The temperature distribution inside 2-stroke engine cylinders during combustion is especially uneven. Given this situation, a more even distribution of fuel inside the cylinder and consequently a more even temperature distribution during combustion would minimise local temperature peaks and decrease the $NO_X$ generation.

Practical measurements at large two-stroke engines prove this theory.

Generally, a more homogeneous fuel distribution can reduce $NO_X$ without increasing the specific fuel consumption. An adaptation of the complete injection system (number of nozzles, number of nozzle holes, nozzle positioning, injection pressures, injection control and so on) could reduce the $NO_X$ emission without an increase in specific fuel consumption. The key here is, to reduce local temperature peaks (responsible for the main part of $NO_X$ emissions) without decreasing the overall process temperature.

The $NO_X$ emission limits proposed by the IMO can obviously met by internal modifications of the injection system. /1/ The additional costs to apply these measures are negligible. They will, however, require considerable research and development efforts.

*Variable injection timing*

If the injection and consequently the start of combustion is moved towards later crank angles the $NO_X$ emissions will decrease considerably. /2/ The engine efficiency decreases in the same way. Nevertheless, this measure has its advantages. If the injection system and the engine management system allow the adjustment of injection timing, then the ship engine can be adjusted to locally differentiated pollution limits. This measure can be sensible and economical, if the periods of time in which a vessel is operated in stricter limited waters is relatively short. Variable injection timing could be integrated in sophisticated engine management systems which will be discussed later.

*Fuel-water emulsions*

The injection of fuel-water emulsions instead of pure fuel bears a significant potential for $NO_X$ reduction. /1/ It will require some investment for additional equipment. The water must not only be mixed with the fuel and injected in the cylinder, additional facilities to supply the considerable amounts of water, up to 50% of the injected fuel volume, will be necessary, too. Two effects decrease the $NO_X$ emission if fuel-water emulsions are applied. Firstly, the water decreases the temperature level inside the engine during combustion which limits the $NO_X$ production. The high heat capacity and evaporation energy of water is utilised for this target. Secondly, the water enhances the fuel distribution process. The injected volume of fuel-water emulsion is bigger than that for pure fuel, which improves injection, and the early evaporation of the water leads to an additional expansion of the fuel-water spray cloud.

Generally, the percentage of $NO_X$ reduction reached with this method is approx. the same as the water percentage in the emulsion.

Retrofit kits for fuel-water emulsion injection are available for some engines for water percentages of up to approx. 20%.

Since the reduction of the process temperature by means of water is the mechanism which is used to reduce the $NO_X$ emissions, a efficiency loss cannot be avoided with this method.

*Water injection*

Water injection reduces $NO_X$ in the same way as fuel-water emulsions. The water will be injected separately from the fuel and the mixing of fuel and water takes place inside the cylinder. With two-stroke engines special difficulties arise in applying this measure due to the large cylinders. The water would have to be injected into the hot reaction zone inside the cylinder. This requires detailed knowledge about the location of the "hot spots" in the combustion chamber, a correct timing of the water injection as well as an alignment of the water nozzles according to the location of the "hot spots" and the flow processes inside the cylinder.

*External measures*

Selective Catalytic Reduction (SCR) plants have a high $NO_X$ reduction potential /1/;/5/. Their design, functionality, operation and onboard experience will be discussed in detail in other presentations.

SCR-plants have a $NO_X$ reduction potential of 90% and higher (for special applications). In the presence of catalysts, ammonia or urea is used to reduce $NO_X$ to $N_2$ and gaseous water. The reactions take place at temperatures between 150°C and 450°C.

Although SCR plants are not necessary to meet the emission limits proposed by the IMO, they are necessary to comply with local limits as introduced by Sweden and California, USA.

The temperature level at which the chemical reactions in a SCR plant take place depends directly on the sulphur content of the fuel. Increased sulphur content increases the temperature level which is necessary for efficient $NO_X$ conversion inside the SCR plant. This can lead to situations where the SCR plant does not reach the appropriate conversion rates or the exhaust gases must be additionally heated to reach the same conversion rates as for low-sulphur fuel. High sulphur content in the fuel also increases the particle emission of the engine which leads to increased particle agglomeration at the surfaces of the catalyst. This can decrease the SCR efficiency, increase the consumption of ammonia or urea and may shorten the lifetime of the catalyst. Consequently, it may be sensible to operate engines on low-sulphur fuel if they are supplied with a SCR plant.

**Strategies to meet further reduced emission limits**

As already mentioned above, the authors are convinced that the currently discussed emission regulations proposed by the IMO as well as the Swedish Model are just the beginning of a process which will lead to ever decreasing emission limits and to ongoing research and development on the engine builder/developer side.

When discussing further reductions of the emissions from marine diesel engines the main emphasis should be on the reduction of engine raw emissions. Consequently, internal measures should be preferred to reduce the emissions below the current limits. These internal measures bear significant potential for $NO_X$ reduction already at the present state of the art. The key to the development and successful application of internal measures for emission reduction lies in a thorough understanding of the internal combustion and the combined emission generation processes.

Facing the huge costs and the significant problems of temporally and spatially resolved measurements inside diesel engines it is vital to increasingly utilise modern simulation tools to complement and explain experimental results. Only by this way the understanding of the processes needed to optimise emission behaviour can be obtained within the given time and cost frames.

During the first phase of the CLEAN–project the AVL Graz GmbH developed new tools for their CFRD-package FIRE to fulfil the special requirements of the simulation of internal combustion processes inside marine diesel engines /4/. These tools predict the fuel injection, fuel preparation,

combustion and emission production processes. Special adaptations of these tools for large two-stroke cross-head diesel engines were carried out by MET GmbH and evaluated by means of experimental results. The simulation software FIRE will now be applied by MET GmbH to investigate the internal combustion processes during transient engine operation.

An important measure for a further reduction of emissions from the operation of large two-stroke diesel engines is, as mentioned above, the improvement of the current control systems. Sophisticated engine management systems will have to include several parameters in order to obtain optimum efficiency *and* compliance with the emission limits which apply for the waters the vessel is currently operated in. On one hand, this leads to the need for more parameters to be monitored and controlled (e.g. injection and valve timing, percentage of water in fuel), where on the other hand also the target functions may differ frequently due to locally different emission limits.

For the development of such advanced management systems, simulation tools have to be utilised to predict transient behaviour of these complex systems (i. e. ship propulsion systems) and to speed up their development. The picture shows the transient behaviour of a ship propulsion system during a reverse manoeuvre. The interaction of all system components was optimised by means of a mathematical model which represented all components of the propulsion system and their individual behaviour /11/.

Since all measures to reduce emissions will not lead to zero-emission ships (at least not today and in the near future) controlling the remaining emissions is becoming a topic of serious interest. The emissions which are given off into the ambient air through funnels, exhaust pipes, ventilation and outlet openings must not molest passengers and crew aboard ships. Traditionally, the exhaust gas distribution from the main funnel is investigated at small models of the ship in wind tunnel experiments. Flow simulation tools as applied by MET GmbH (e.g. the CFD-software TASCflow) predict the flow field around the real scale ship and can take an arbitrary number of outlets into consideration. This is a considerable advantage for the investigation of modern cruise liners with complex superstructures and many outlet openings from different service appliances. Other vessels, especially non-conventional ships or ships with sensitive cargo, can also be optimised by means of this tool. Furthermore, the flow field simulations deliver not only the flow phenomena but also full three-dimensional fields of the dependent variables of the flow field (e.g. velocities, pressure) and of the mixing processes (e.g. exhaust gas concentrations, temperatures, particle paths). Thus, they allow not only to detect the shortfalls in the design, but to find directly the appropriate means to

improve the design. Changes to the virtual computer model can be carried out very fast allowing to verify design changes immediately. /9/;/10/

**Conclusions**

The IMO proposals as well as the Swedish model on emission related port fees are just the beginning of emission legislation for international marine transport. At the current stage, the $NO_X$ emissions are in the centre of interest.

Strategies for an efficient and environmentally optimised engine and propulsion plant management can especially be obtained by simulation of the stationary and transient behaviour of the complex propulsion system. In addition, CFD/CFRD simulation tools provide an opportunity to predict the complex internal processes in the cylinder of IC-engines as well as the distribution of emissions aboard ships, in order to offer proposals for an improvement of the internal processes, the engine design, and vessel construction.

A consequent application of these innovative tools will lead to an acceleration of R&D tasks, to a reduction of costs and a significant reduction of environmentally dangerous emissions from marine engines.

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THE MARITIME ENVIRONMENT
Treatment Technologies for Gaseous Emissions from Ships
18 & 19 October 1999, Brussels

# Development of Future Emission Reduction Technologies

**Prof. Dr.-Ing. habil. S. Bludszuweit**
**MET Motoren- und Energietechnik GmbH**

**Dipl.-Ing. Bert Buchholz**
**MET Motoren- und Energietechnik GmbH**

# Contents

- **Current Situation**
  - Regulations
  - Emissions
  - Reduction Technologies
- **Problems**
  - Regulations
  - Reduction Technologies
  - Ship Operation
- **Solutions**
  - Demands on R&D-tools
  - Simulation Technologies
  - Examples



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# Current Situation - Regulations

➡ IMO-proposal ($NO_x$)
- ► 30% reduction of $NO_x$ compared to 1992
- ► internal measures

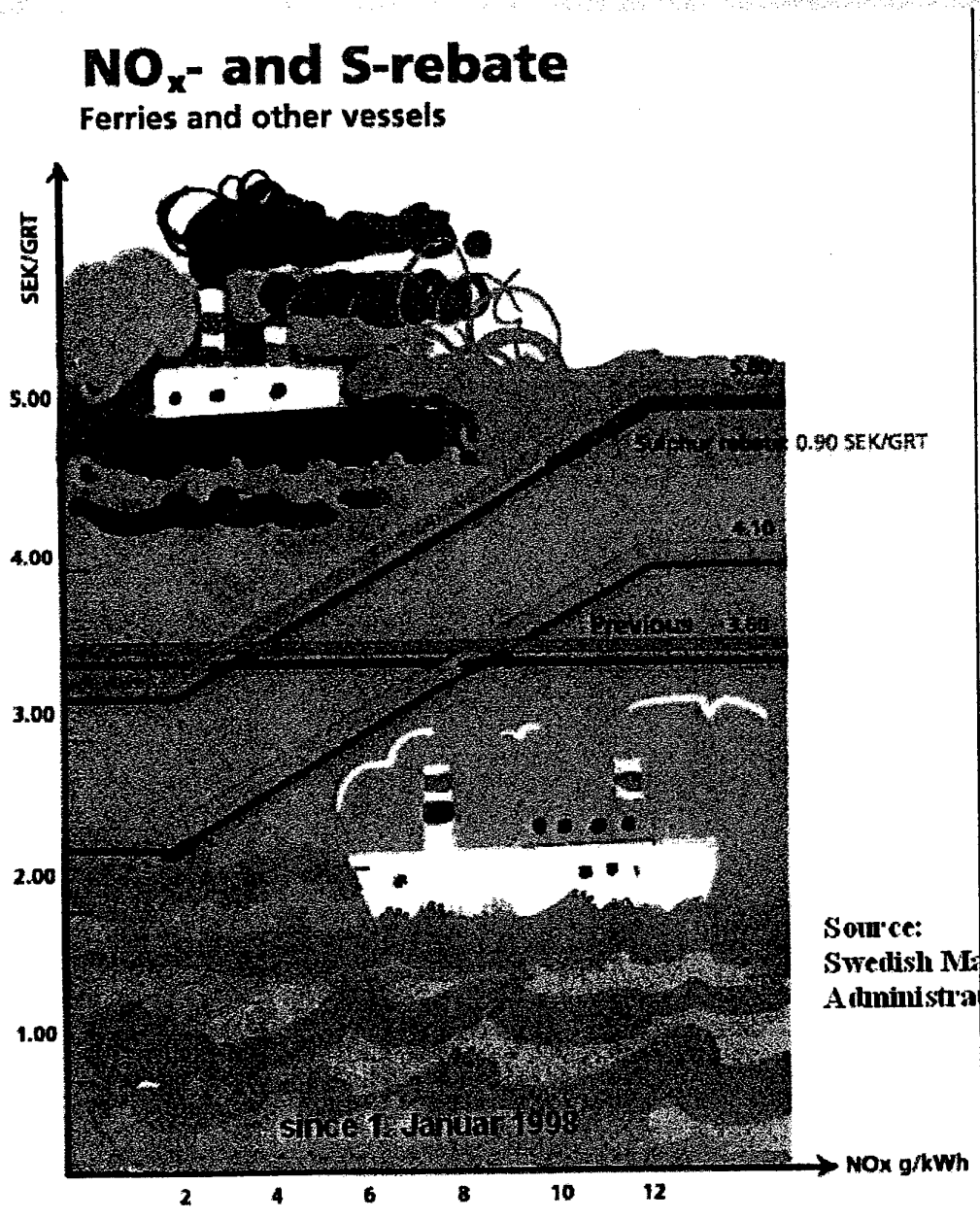
➡ Swedish model ($NO_x$, $SO_x$)
- ► emission related port fees
- ► external measures

➡ Local regulations on S-content of fuels ($SO_x$)

➡ emission reduction / control will stay in the centre of development for the next future

# Current Situation - Regulations

## Swedish System of Emission-related Port Fees




Source:
Swedish Maritime Administration

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# Current Situation - Emissions

**NO:** generated during reaction phase

**$NO_2$:** after the reaction; partly outside the cylinder

- prompt NO
- fuel NO
- thermal NO (approx. 90%)

## Generation of thermal NO

at temperatures above 1300 °C

air excess

action time

$$O + N_2 \leftrightarrow NO + N$$

$$N + O_2 \leftrightarrow NO + O$$

$$N + OH \leftrightarrow NO + H$$

# Current Situation - Emissions

## $SO_X$

- directly linked to sulphur content of fuel
- onboard treatment not feasible
- application of low-sulphur fuel necessary
- local limits on sulphur content already exist

## Particles

- consist of soot, metal oxides, sulphates
- lower for 2-stroke engines (stationary mode)
- increased by high sulphur content in fuel
- very likely to become a topic in the future

## HC, CO

- originate from incomplete combustion
- lower for 2-stroke engine

## $CO_2$

- directly linked to engine efficiency, fossile fuel consumption



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# Current Situation - Internal Measures

- **Homogeneous fuel injection and distribution**
- **Variable injection timing, pre-injection**
- **Fuel water emulsions**
- **Water injection**
  - **direct influence on the combustion process**
  - **combined with engine efficiency loss (at the current state of the art)**
  - **little or none installation costs**
  - **operational costs can be low**



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## External measures

# SCR plants

- extremely high $NO_x$ reduction rates (up to 90%)
- installation costs significant
- operational costs considerable (reducing agent, fuel costs, heating, service, engine operation)
- decrease of overall efficiency

**appropriate measure to comply with locally reduced limits**



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## Problem - Regulations

- further reduced limits
- limits on other exhaust gas components
  - $SO_X$
  - Particle
- locally different regulations
  - Sweden
  - USA, California
  - Japan



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## Problem - Reduction Measures

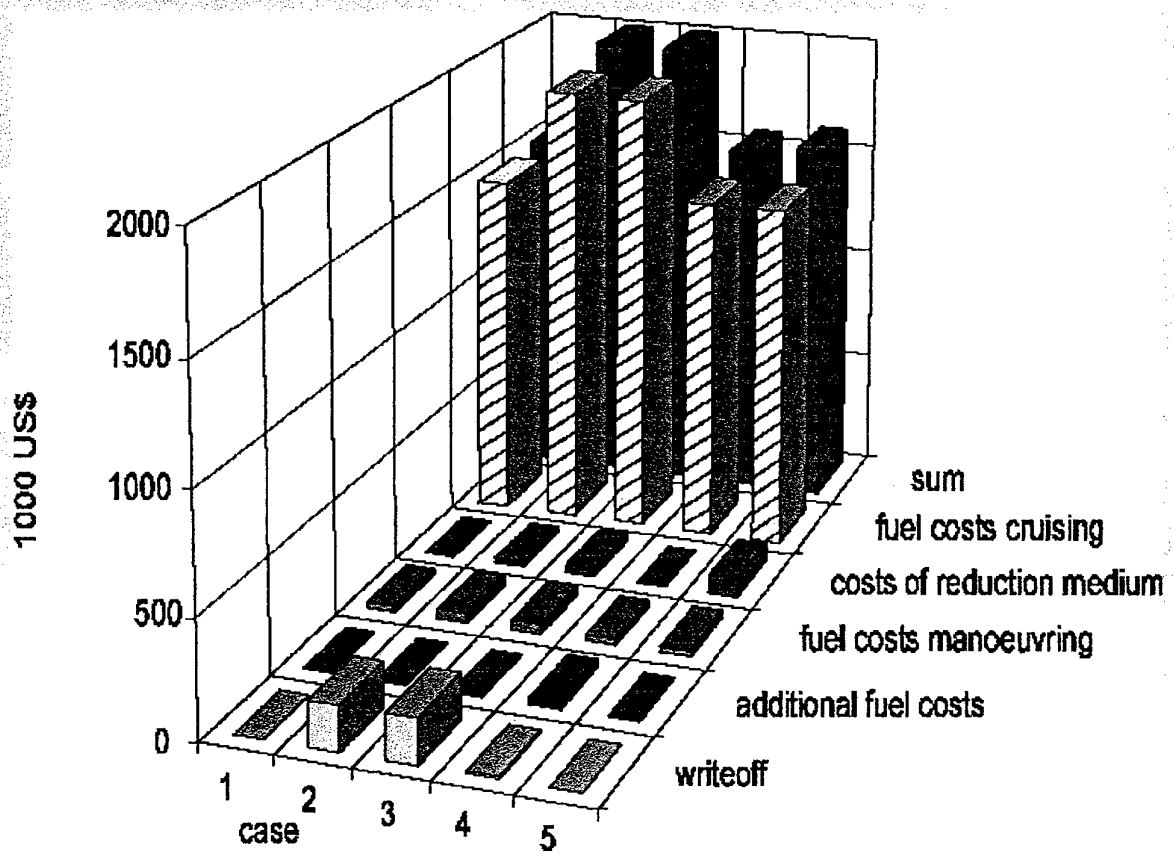
- ➡ considerable installation costs
- ➡ $NO_x$-reduction only
- ➡ expensive operation
  - ► reducing agent, fuel costs, heating, service
- ➡ combined with efficiency loss/ increase in $CO_2$-emissions



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# Problem - Operational costs

## Operational costs for a 7L60 engine / 90-day journey




**Case 1: without any system**

**Case 2: SCR plant, reducing agent $NH_3$**

**Case 3: SCR plant, reducing agent urea**

**Case 4: engine with separate water injector**

**Case 5: SNCR**

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## Solution Strategy - Demands

- ➡ scientific approach / end of "trial and error"
- ➡ fast parameter variations
- ➡ prediction of complex processes, consideration of interactions / interconnections
- ➡ increased knowledge about internal processes
- ➡ reduced / targeted experiments
- ➡ pre-optimised prototypes
- ➡ rapid and reliable solutions

# Solution Strategy - Simulation Technologies

- ➡ industrial application of simulation tools and technologies
- ➡ combination of simulation tools
- ➡ visualisation of internal processes
- ➡ experiments guided by simulation-based investigations
- ➡ optimisation at virtual prototypes

⇨ innovative solution at competitive costs (time & money)

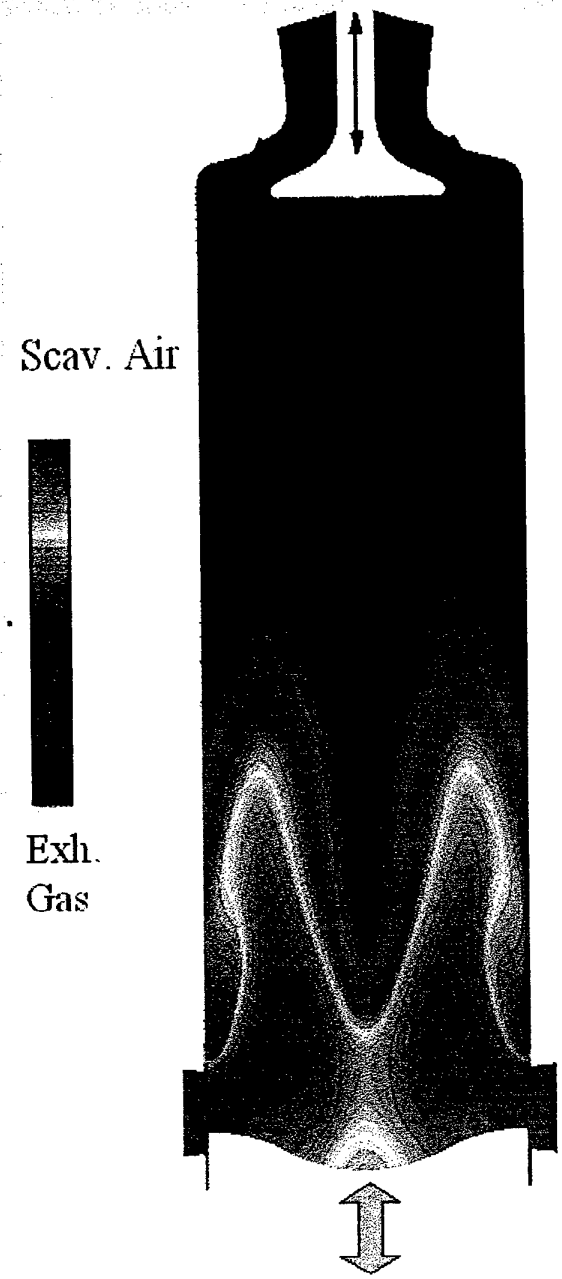


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# Solution Strategy - Process optimisation by modern CFD-tools

## Simulation of engine internal processes

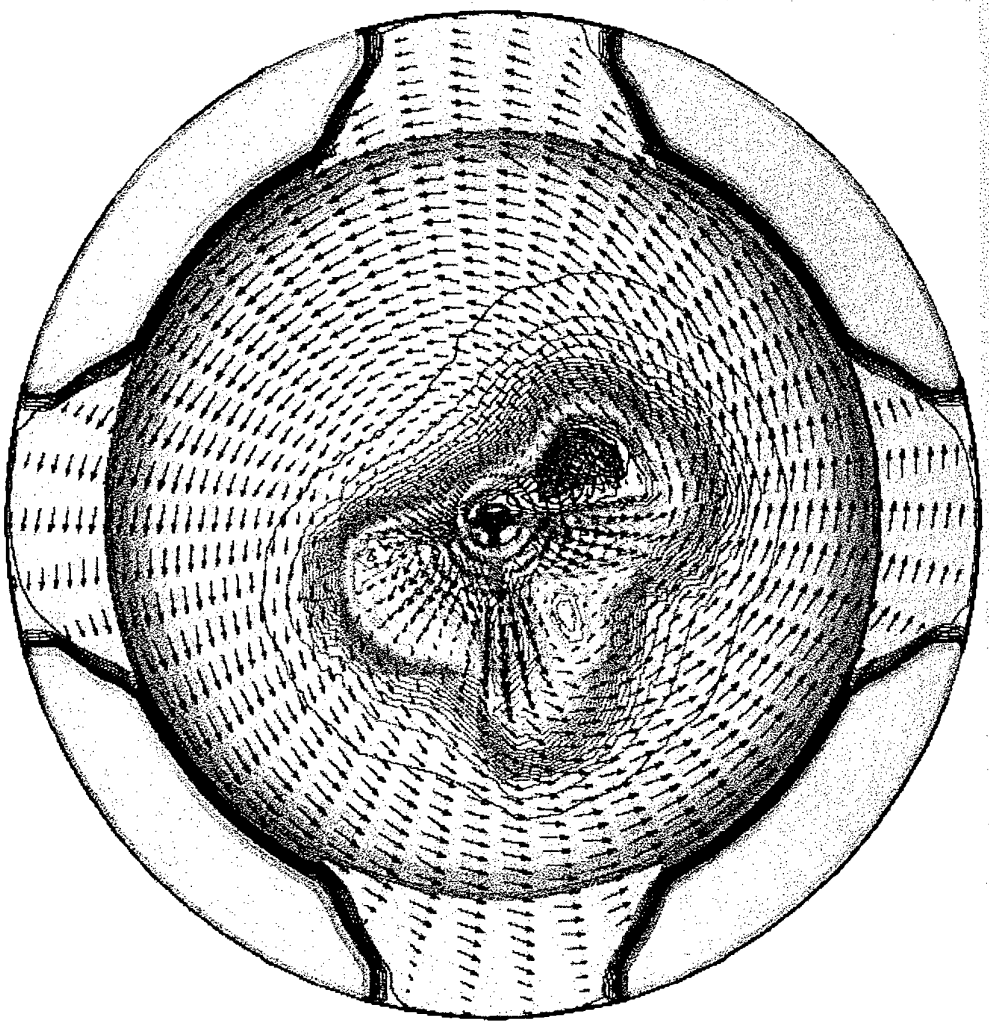



- scavenging
- compression
- fuel injection
- fuel distribution
- auto-ignition
- combustion
- emission generation

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# Solution Strategy - Combined Simulation and Experiment



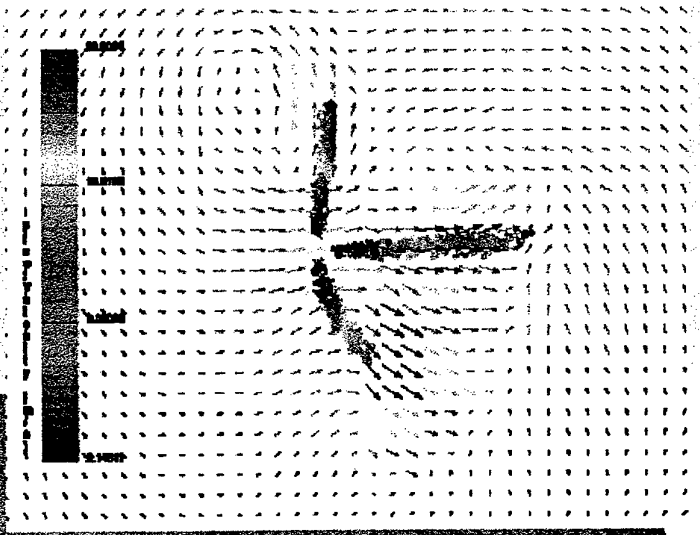
## 4-stroke research engine with asymmetric injection nozzle for flame propagation and temperature measurements

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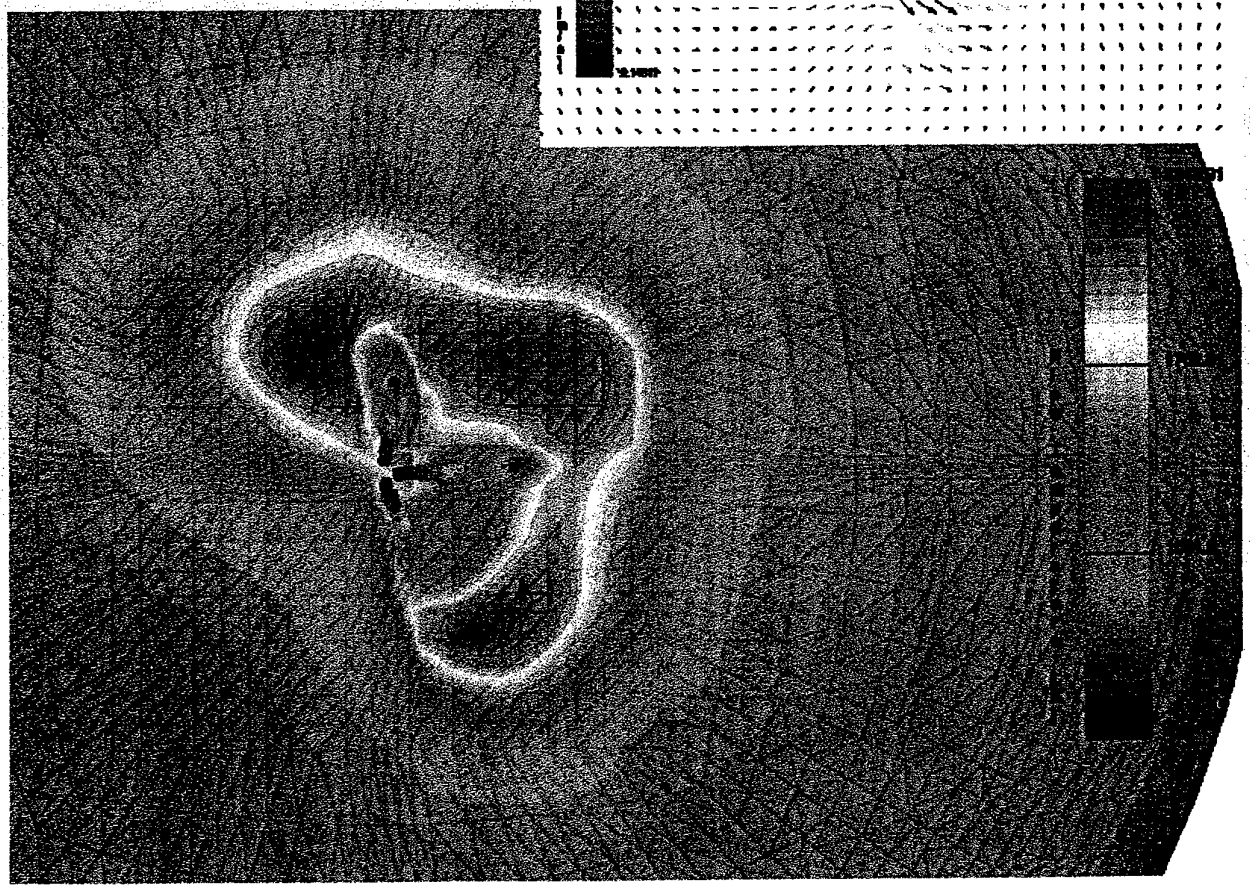
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# Solution Strategy - Combined Simulation and Experiment

## Swirl and injection interaction



## Injection and combustion temperatures

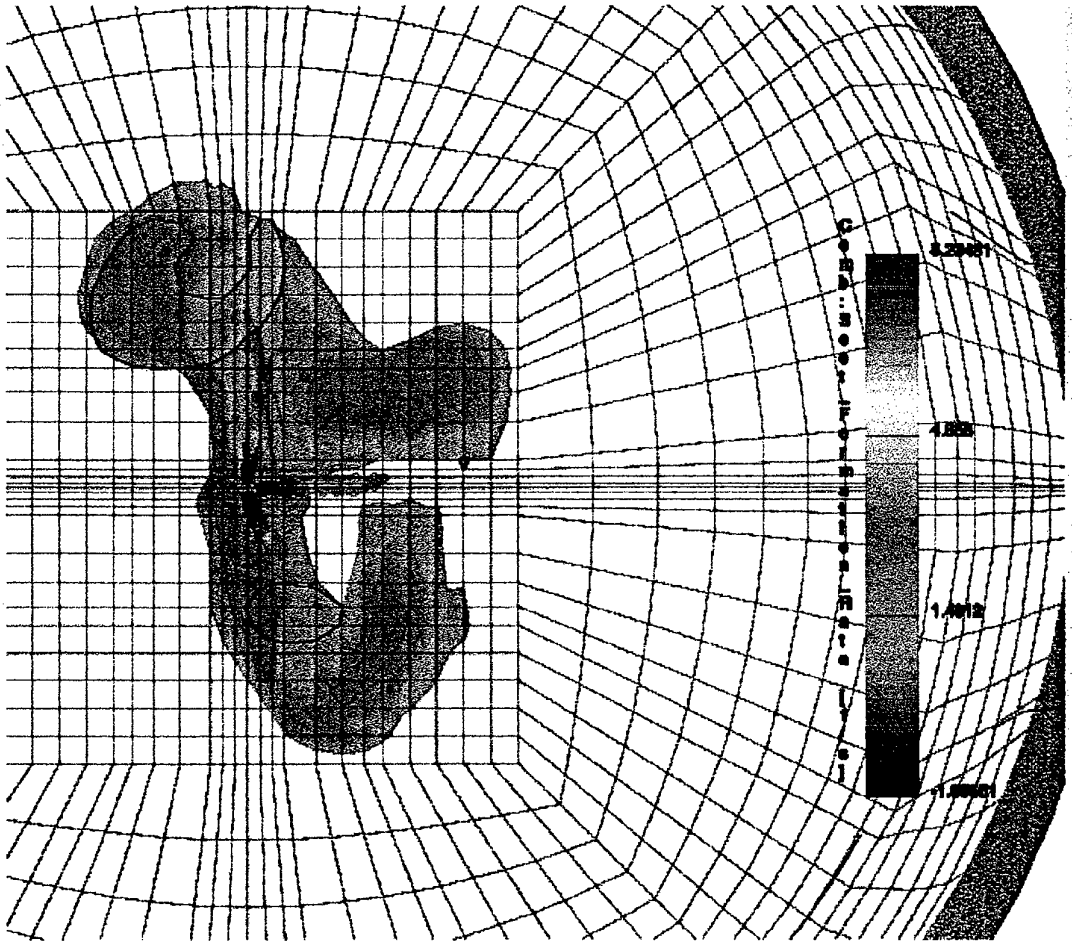


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# Solution Strategy - Combined Simulation and Experiment

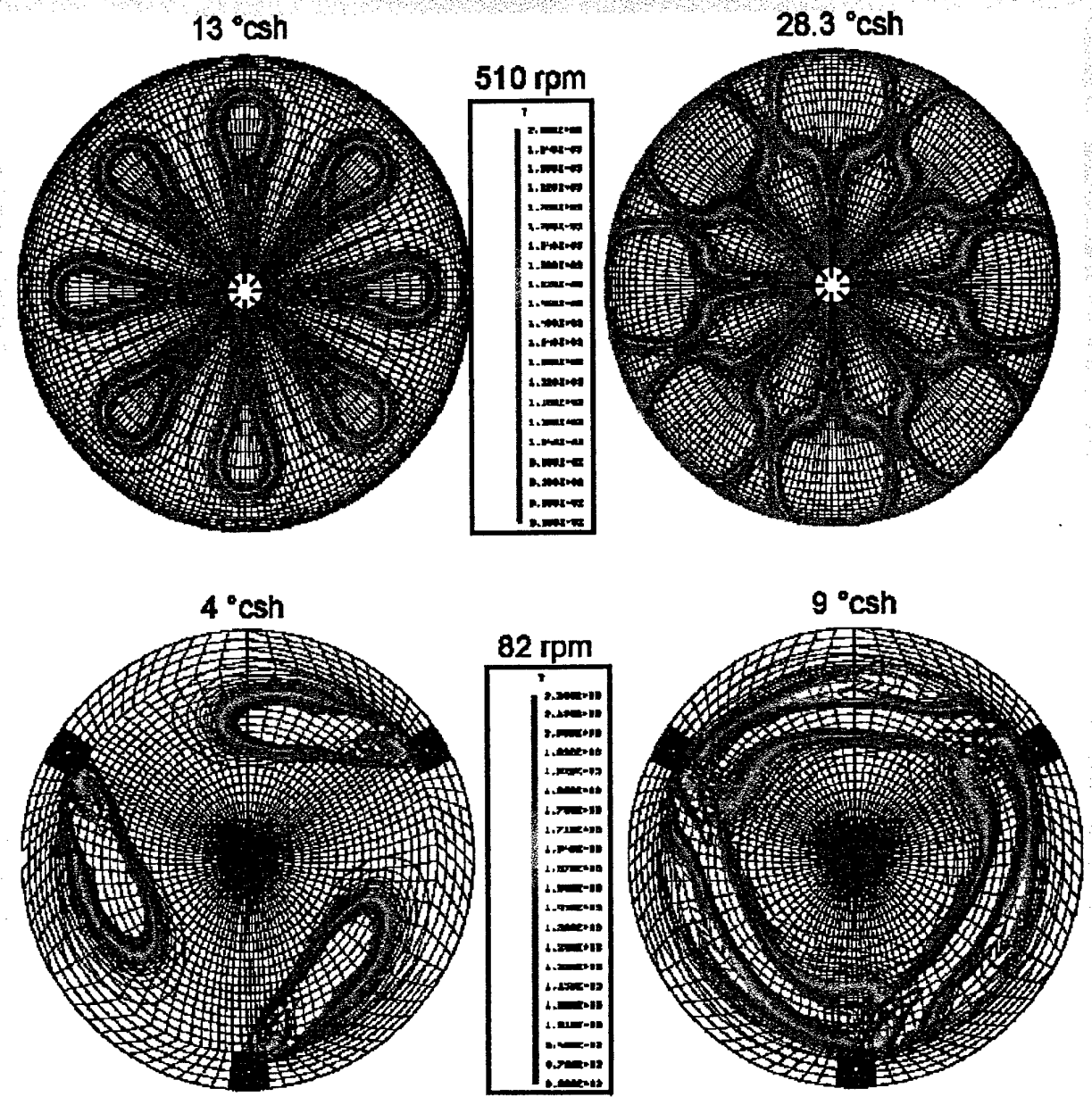
## Soot formation at beginning of combustion



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# Solution Strategy - Simulation-based Basic Research



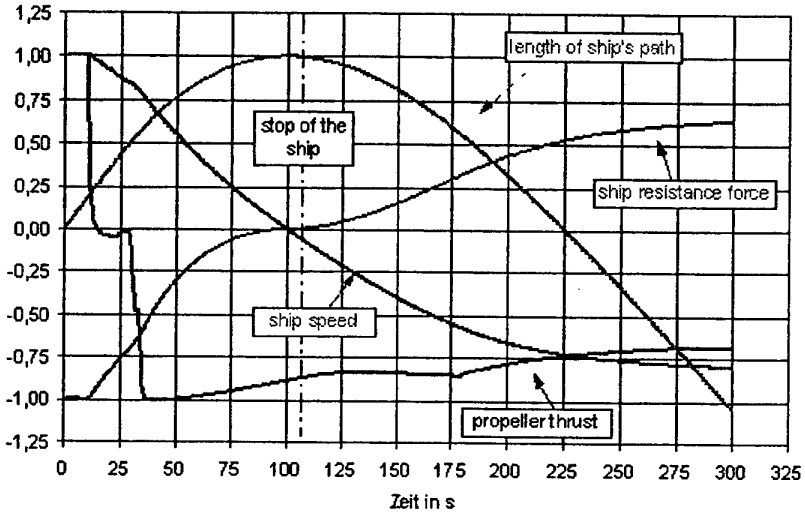

## Simulation of Hydrogen Combustion in 4- and 2-stroke Ship Diesel Engines

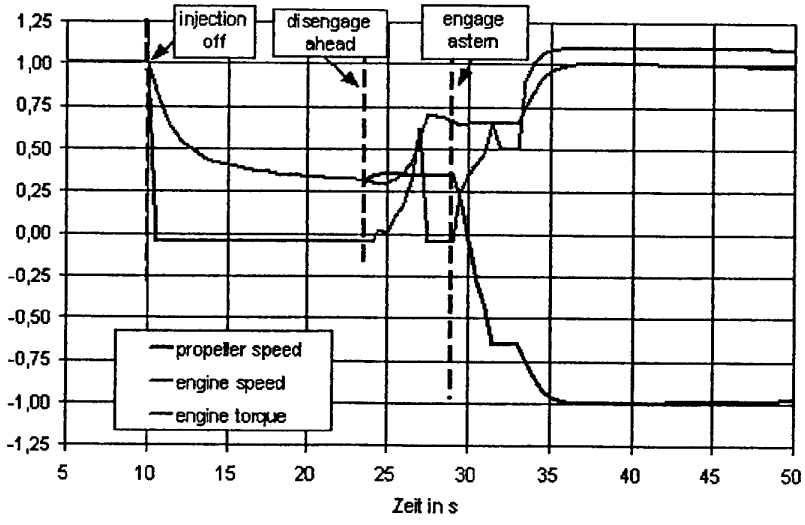
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# Solution Strategy - Simulation-based Optimisation of Propulsion Plant Management

## Simulation of transient propulsion plant/ship behaviour



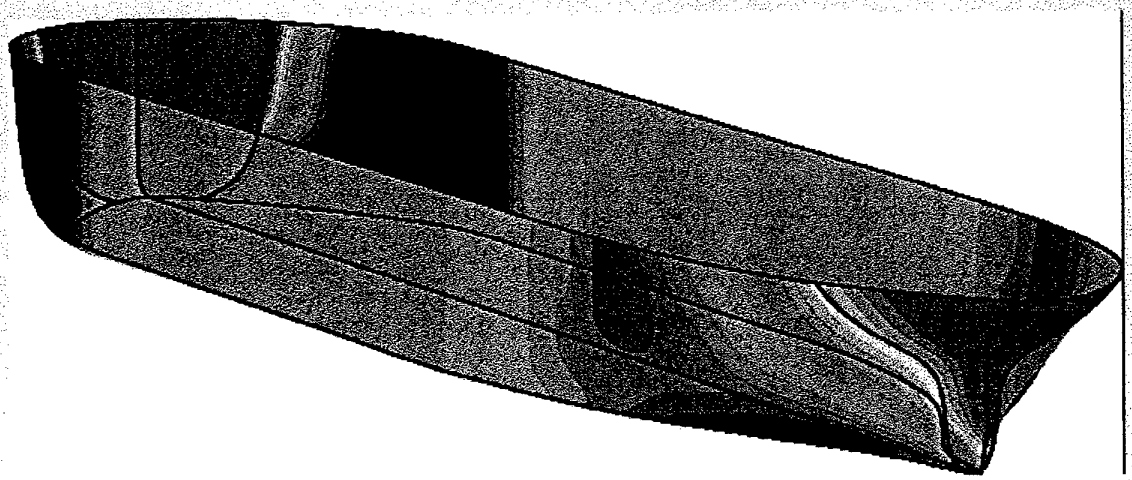




- emission aspects
- safety aspects
- consideration of broad range of parameters
- fast and reliable development of advanced engine management

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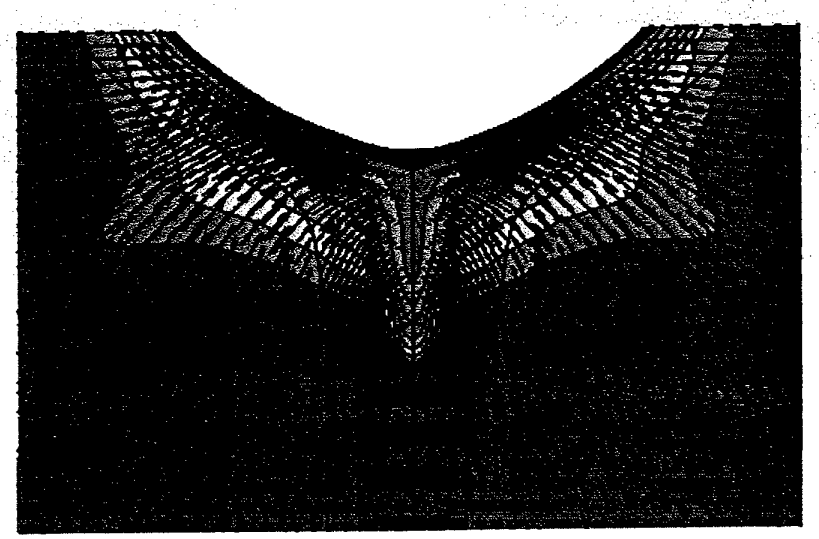
# Solution Strategy - Simulation-based Optimisation of Ship and Propulsion Concepts



**reduction of required power**

**=**

**reduction of emissions**

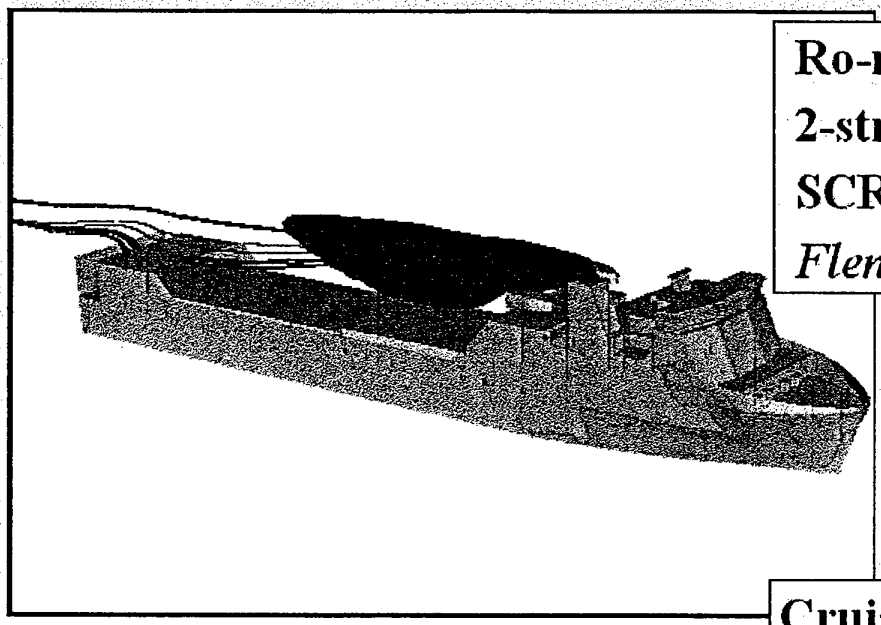


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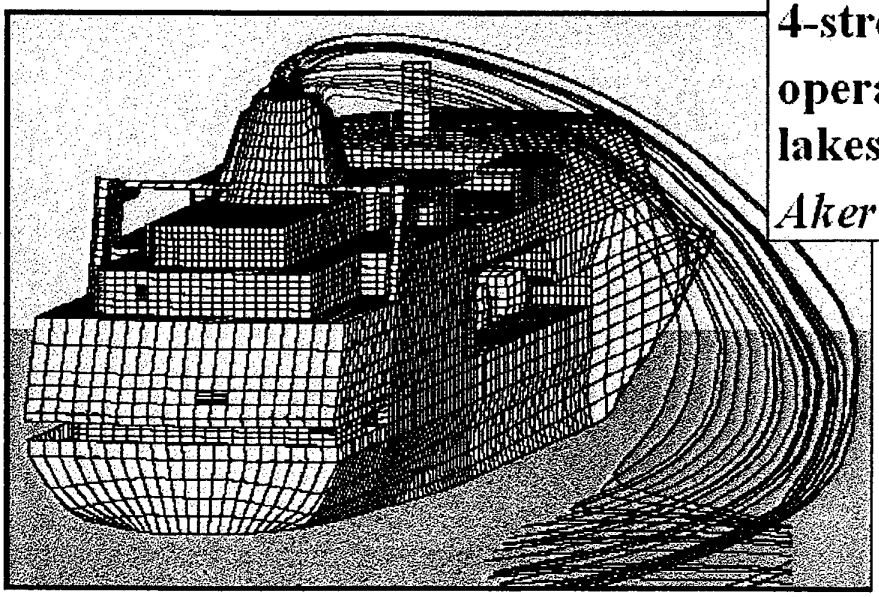
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# Solution Strategy - Simulation of remaining emissions

## Minimisation of advert effects of emissions on passengers, crew, and cargo



**Ro-ro paper carrier**
**2-stroke main engine**
**SCR-plant**
*Flender-Werft AG*



**Cruise vessel**
**4-stroke main engine**
**operated in American lakes**
*Aker MTW Werft*

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# Summary

- emission reduction will be in centre of R&D in the future
- new emission regulations and strong competition in shipbuilding make new solutions necessary
- professional application of simulation technologies will be necessary to reach complex development targets
- simulation tools speed up R&D already today
- maritime industry needs enforced application and development of simulation tools



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# The H.A.M. (Humid Air Motor) Concept -- A novel way to reduce NOx

**Jan Wettergård / Lars–O. Olsson, Munters Euroform GmbH, SE**

## Abstract

Environmental awareness is continuously increasing in all businesses, and the marine sector is no exception. Regulations directed at decreasing emissions from diesel engines are becoming more stringent all over the world.

Many governments have imposed strict regulations and fees regarding the release of harmful emissions to the environment. The Swedish Maritime Administration has recently reduced its fees for vessels with reduced NOx emissions.

The H.A.M. concept relies upon the principle that water vapour increases the heat capacity of the intake air, thereby decreasing the formation of NOx..

The H.A.M. concept makes it possible to deliver up to three times more water vapour to the engine than fuel when compared on a mass flow basis.

The water is evaporated in a "humidification vessel" that is mounted between the turbo-compressor and the air receiver.

The energy required for the phase conversion of water-liquid to water-vapour is taken from waste heat from the engine (i.e., jacket cooling and exhaust) and from the temperature increase caused by the turbo-compressor. This process takes place outside the cylinder and hence, no fuel energy is used. The water is vaporised via a distillation process, which makes it possible to use ordinary sea water in the H.A.M. system.

The H.A.M. system has been tested both in engine laboratories as well as in field tests, on both big and small engines with very good results. A minimum of 70% NOx reduction is typical with no significant increase in fuel consumption or other emissions.

Session 4
Speaker Mr. Jan Wettergård

I wished I could introduce our next speaker as detailed as he deserved it.

Unfortunately Mr. Jan Wettergård did not tell us very much about himself.
We know he is a Mechanical Engineer who specialised in heat transfer and who is working as Product Manager, HAM Systems, at Munters Euroform GmbH, Office Stockholm, Sweden.

Perhaps we can ask you to tell us a little bit more about you and your background.

Mr. Wettergård will give the first part of the H.A.M. Concept Presentation:
"A Novel Way to Reduce Nox"

# H.A.M. - an effective method reducing NOx, for marine diesels

By Jan Wettergård, Munters Euroform GmbH, October1999

**Background:**
Diesel engines are very effective energy sources. However, one disadvantage is that they produce a large amount of nitrogen oxides, called NOx. Higher efficiency engines require higher temperatures creating more NOx. Nitrogen oxides are produced at high temperatures and pressure, therefor the higher the diesel engine's efficiency, the higher the NOx emission will be.
Munters Euroform has succeeded in reducing emissions of NOx above 70%. The Munters method, called **H.A.M.** (**H**umid **A**ir **M**otor), has the advantage of maintaining the engine's efficiency with equal fuel economy.
Our H.A.M.-method is protected by Patents in most countries throughout the world. It can be used for all types of internal combustion engines, but has been specifically engineered for diesel engines. It is of particular benefit for engines used within the shipping industry.

**How does it work?**
The Munters H.A.M.-method pre-treats the combustion air in a way that prevents NOx from being formed. The compressed and heated turbo air passes through a specially designed cell that humidifies and chills the air with pure water vapour. The system uses waste heat from the engine's internal cooling system or exhaust pipe as energy source. By humidifying the air a higher mass flow takes place, thus helping maintain the efficiency of the engine.
The engine's inter-cooler is by-passed or closed as the H.A.M.-system fulfils this role. The resulting combustion will be smoother and the combustion temperature more uniform. Prevention of so called "hot spots", ensures that NOx levels are significantly reduced.
Injection timing and turbo matching may need to be adjusted but apart from this, the H.A.M..-system has a similar reduction also for varying load conditions.
Other engine emissions and fuel consumption are not significantly influenced by the H.A.M.-method.

**Normal sea water:**
For marine applications we can use seawater. As the process relies on evaporation or distillation, it is only the water vapour that is released to the combustion air. Minerals and salt concentrations are not a problem as a bleed off system provides a continues feed of new seawater. This means there is no operating cost for water.

**Ongoing and planned actions:**
A Pilot boat has been in operation since January -98. To date about 1000 hours. The system works well and is conducted together with the Swedish Maritime Administration.
We have also a road ferry in Stockholm, with more than 1200 hours in operation, as well as an auxiliary genset in Norway converted utilising H.A.M. Engines in field tests have been 11 - 14 litre

Scanias. At Scania we also have made trials in their test bed, with very good results, more than 70% reduction.
In preparation to one of our stakeholders, the company Viking Line AB, transporting passangers and cars between Finland and Sweden, we first made performance trials in a test bed. Tests were made at S.E.M.T. Pielstick in Paris, on a 2 MW engine, with excellent results. The ferryboat, Mariella from Viking Line with 4 main engines, each 6 MW Pielstick, has then been equipped with H.A.M. on one of the engines. To date in operation about 900 hours with an average of more than 70% reduction of NOx.

**Contact person at Munters Euroform GmbH:**

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e-mail: jan.wettergard@munters.se

# The Humid Air Motor

H.A.M. a method reducing

NOx in diesel engines

**Presentation 19th October in Brussels at**

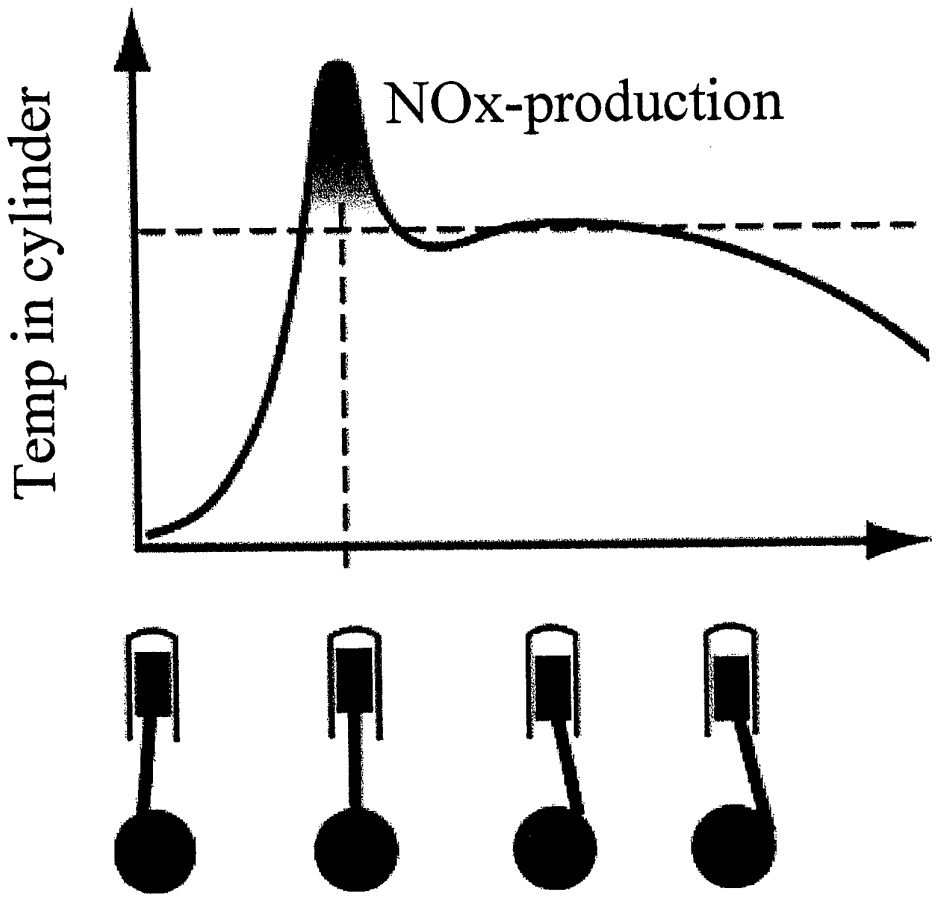
## The Maritime Environment

**by Jan Wettergård**

**Munters Euroform GmbH**

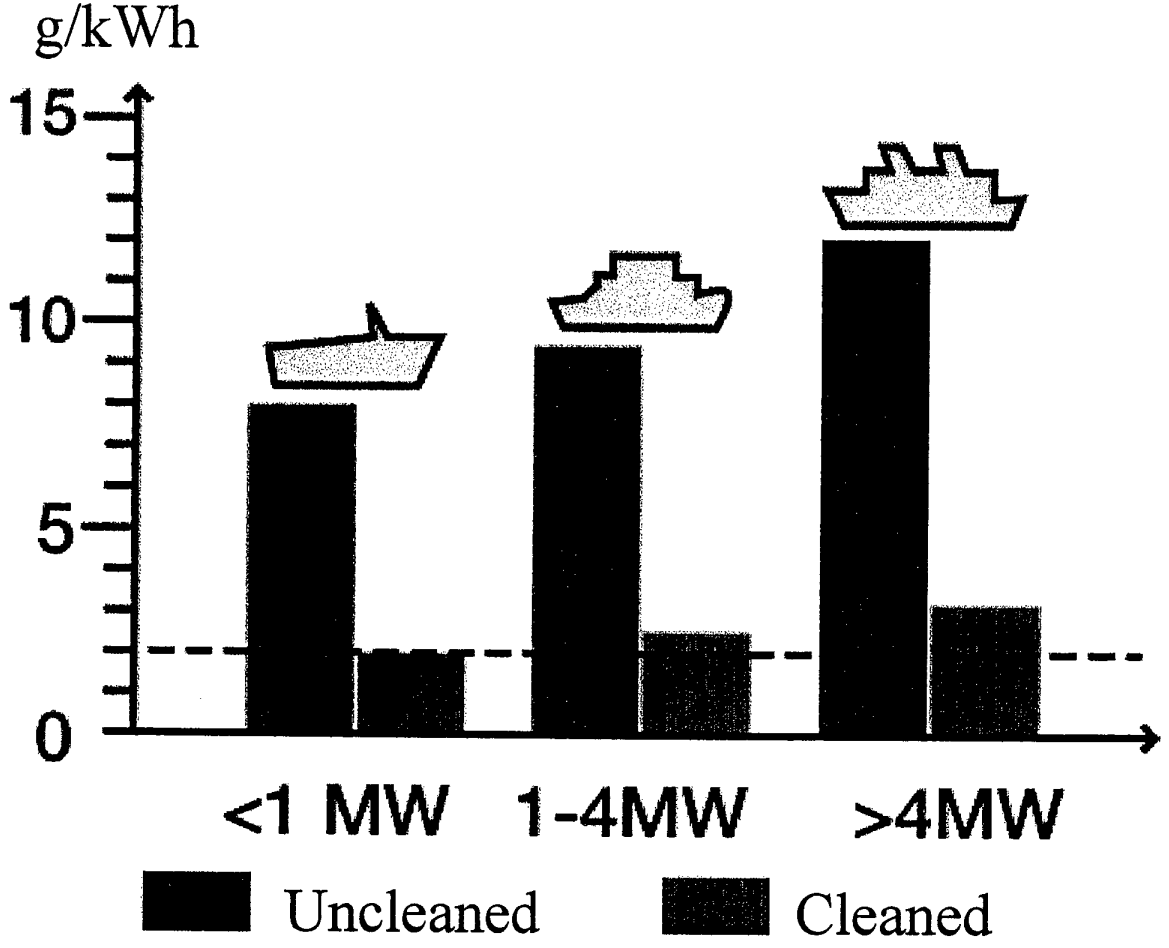
Munters

# Why all this NOx?

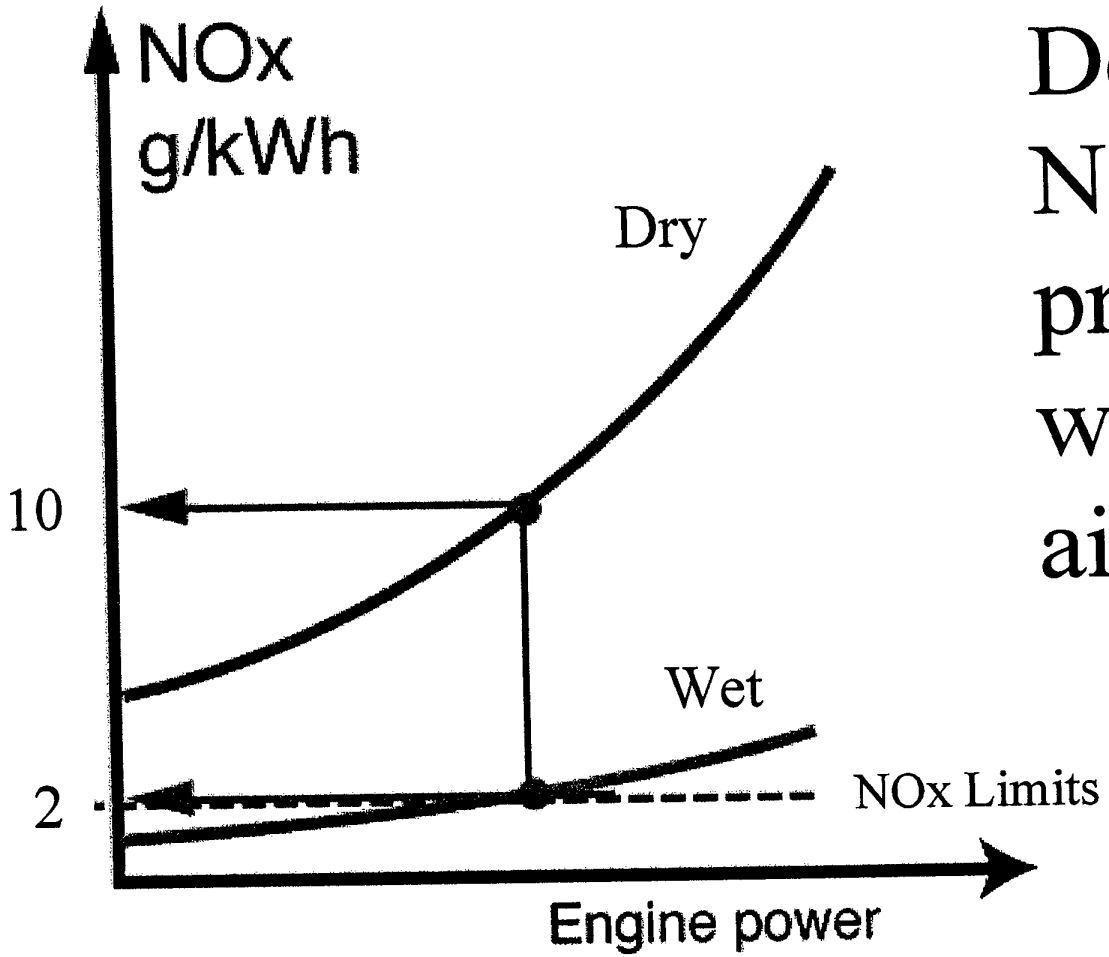



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# NOx-emissions




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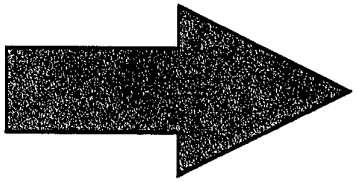

# Decreased NOx production with humid air

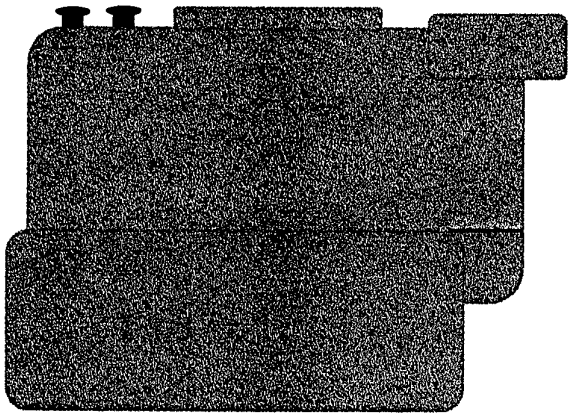
Munters

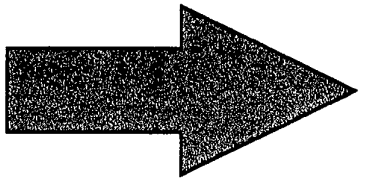
# What has been done

**Pre-treatment** **Engine** **After-treatment**

Fuel treatment



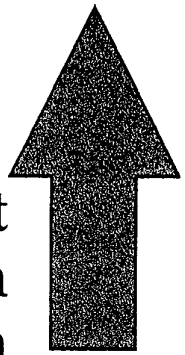




Air
pre-treatment
**H.A.M.**

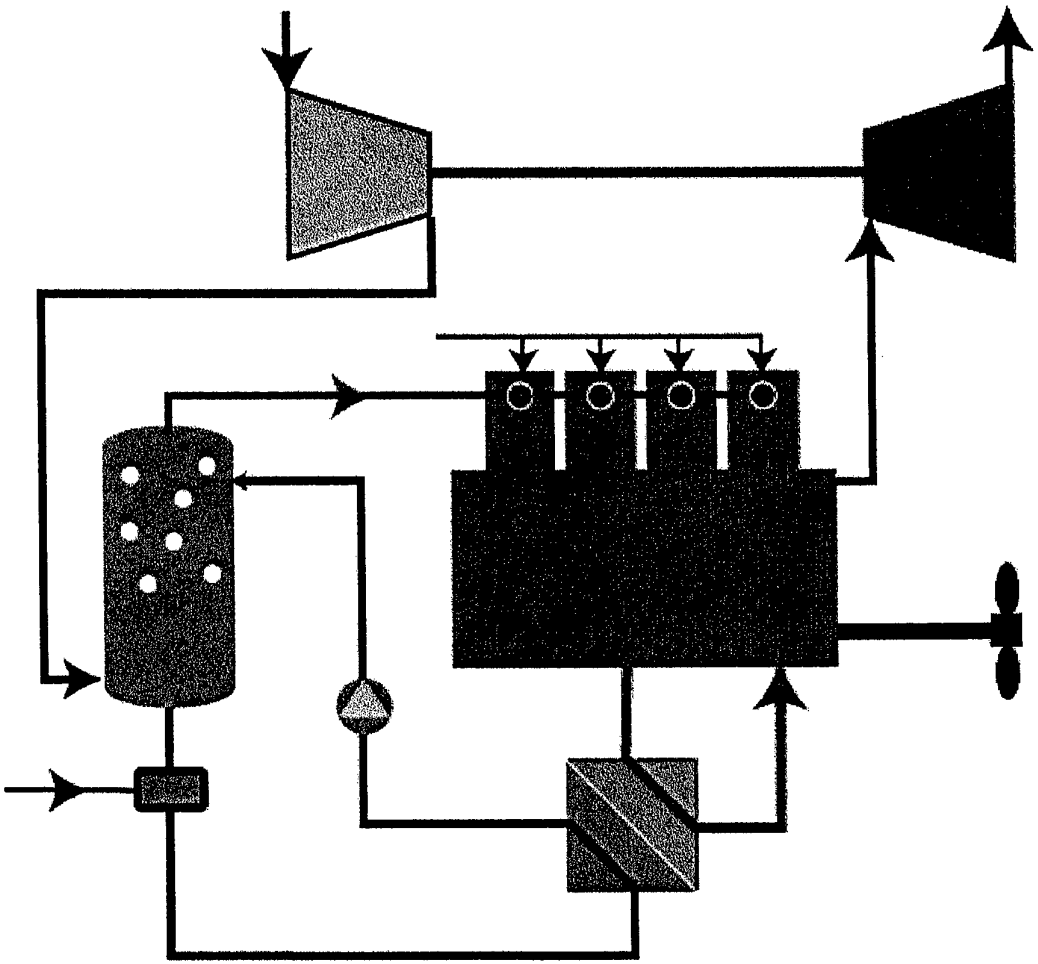
SCR =
Selective
Catalytic
Reduction

EGR =Exhaust
gas recirculation
Water injection



Engine
design
development

Munters

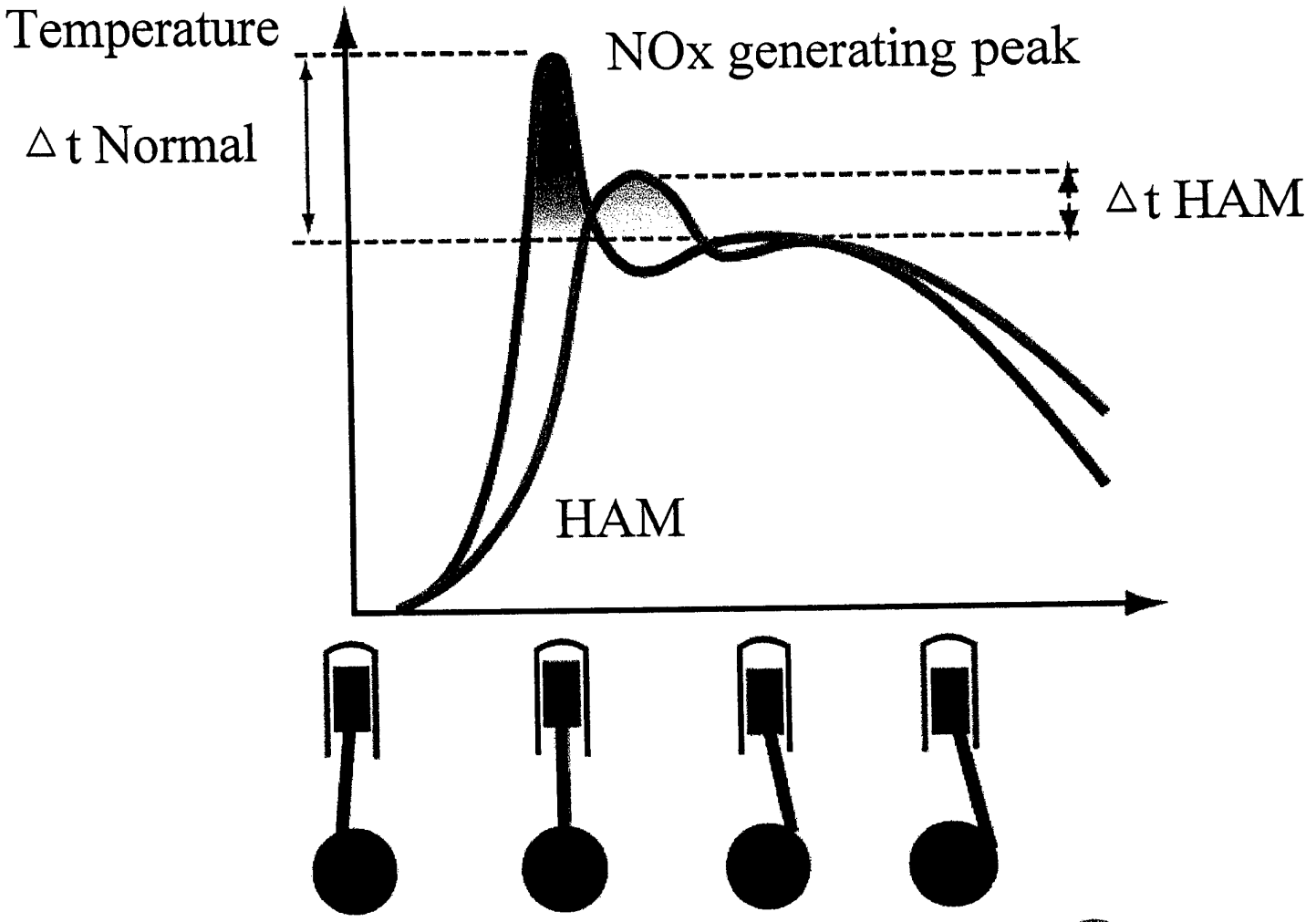


# The diesel engine with humid air **H.A.M.** - principle

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Ordinary water is the key

# Cutting NOx with humid air



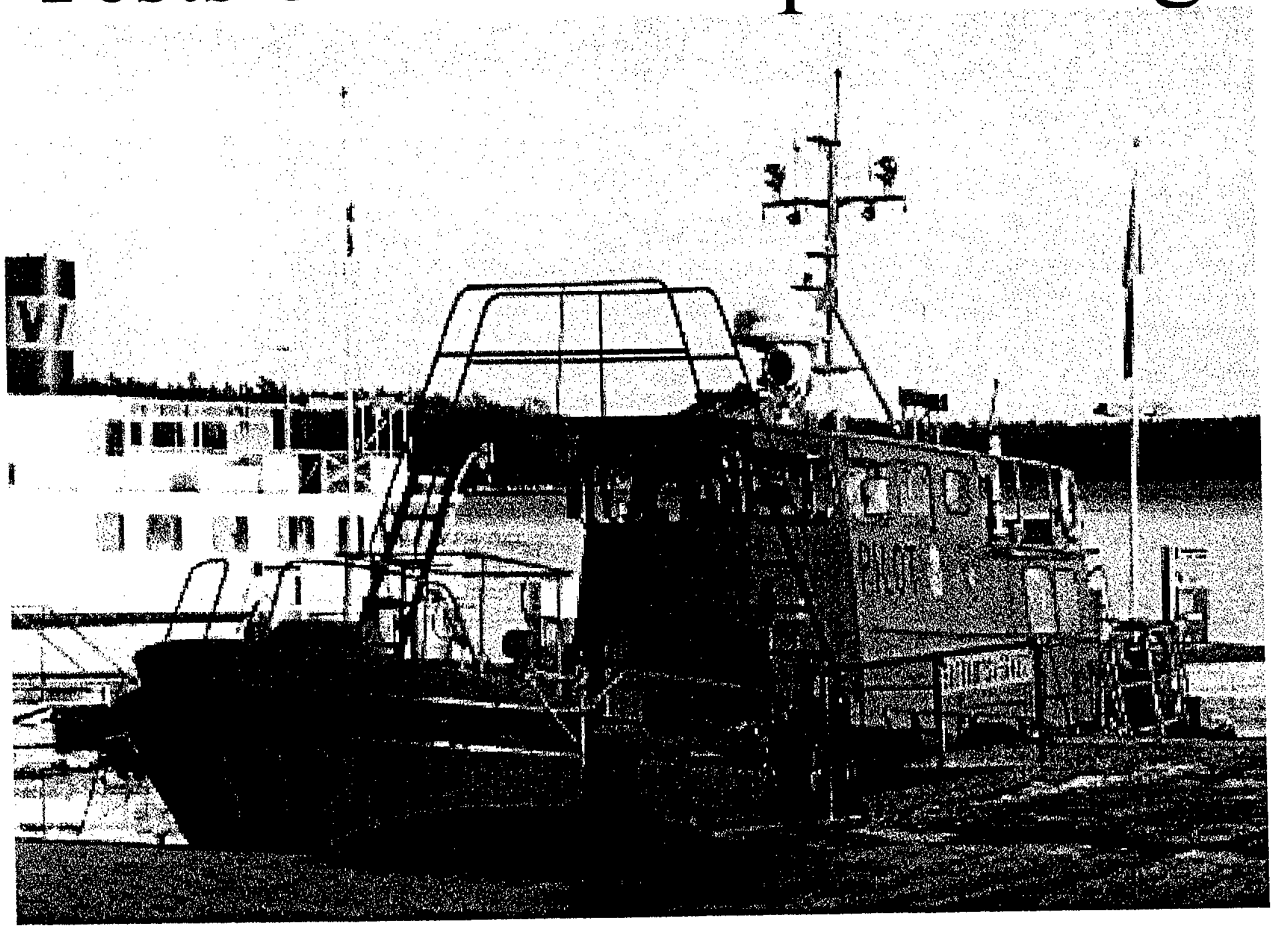

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# HAM reduces NOX dramatically

- Replaces the intercooler
- **Cools** and **humidifies** combustion air
- Uses water or sea water - No chemicals
- Proven techniques
- Prevent NOX creation - Reduces "hot spots"
- Uses waste energy
- Self regulating - Simple control
- Easy to retrofit in most cases

Munters

# Tests onboard are promising!

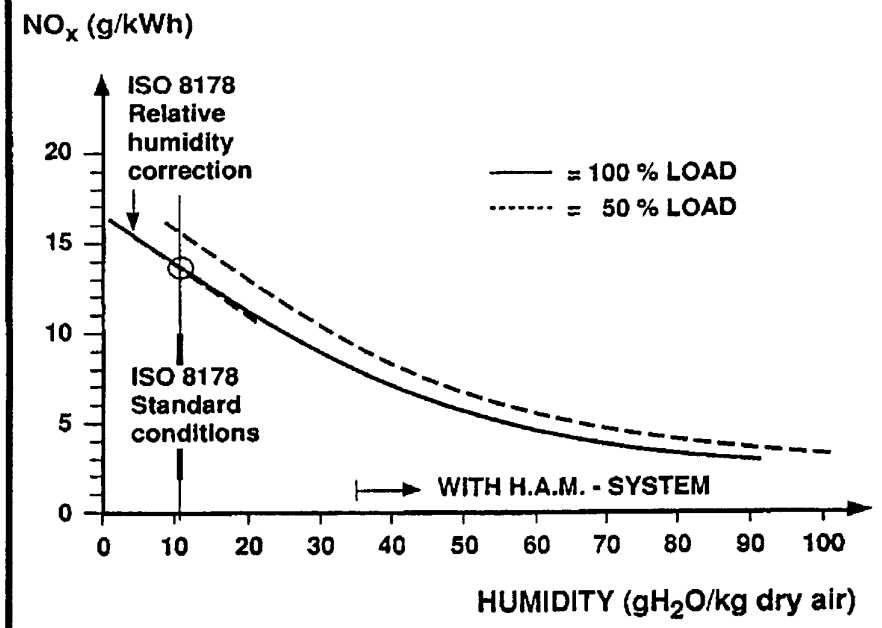




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ANNEX II / 2

TYPICAL RESULTS
UNDER TEST ENGINE CONDITIONS




SEMT PIELSTICK

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*Comments from Pielstick after test of a 3 cylinder PC 2-6B engine of 2 MW June 1998;*

**HUMID AIR MOTOR**

**A FRIENDLY DEVICE**

**80 % NOx reduction**

**No real changes to other parameters such as:**

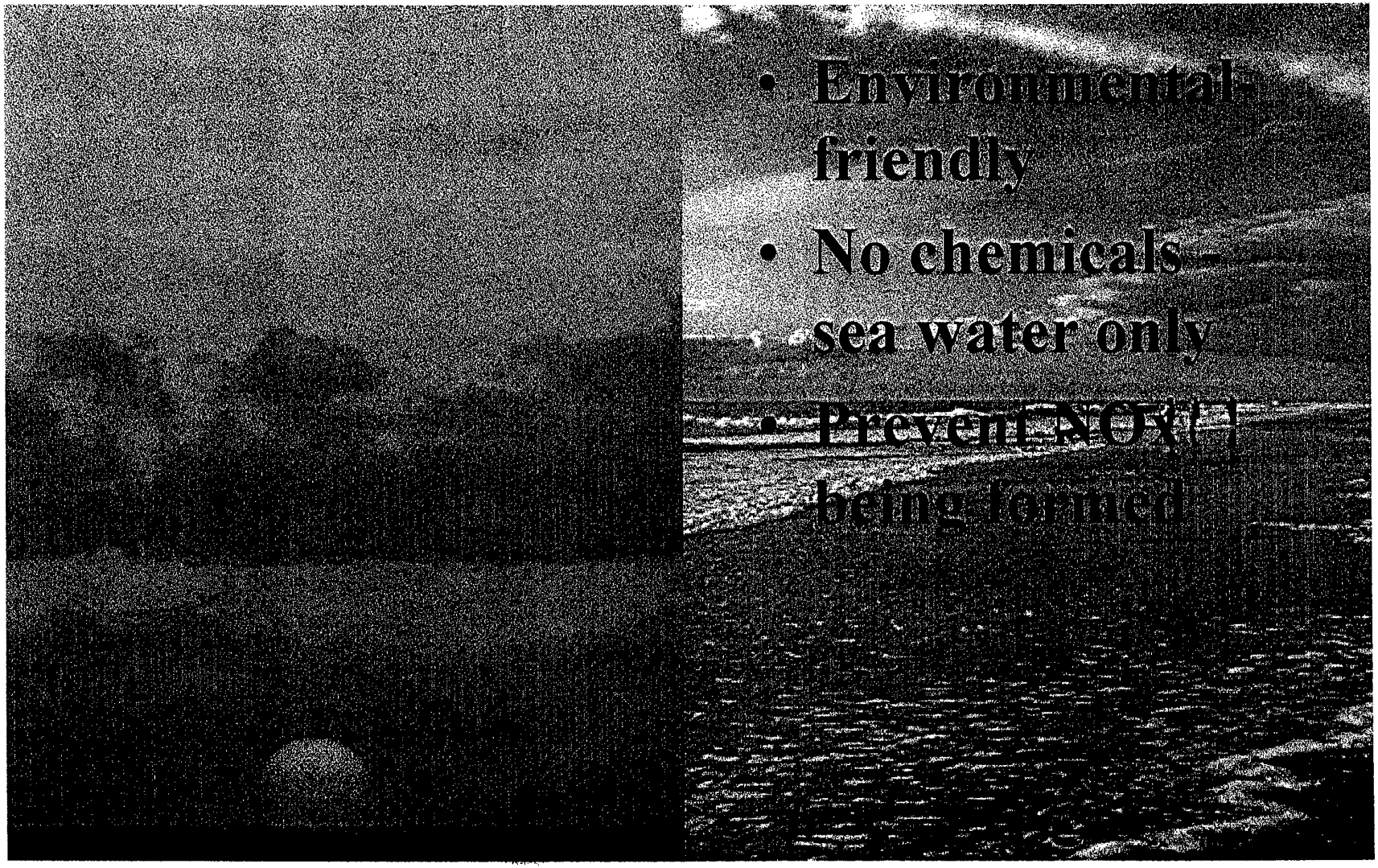
**CO or HC**

**Fuel consumption**

**Combustion cycle**

Munters

# Conclusions for H.A.M.



Session 4
Speaker Mr. Emmanuel Riom

The second half of the H.A.M. Presentation with the title "Experience from Field Tests on a 6 MW Pielstick Engine" will be given by Mr. Emmanuel Riom from S.E.M.T. Pielstick, FR.

Mr. Riom graduated as Engineer at "Ecole Nationale Supérieure d'Arts et Métiers". He became a Test Bench Engineer in the Research and Development Department of S.E.M.T., Saint Denis

Since 1998 he is responsible for After Sales Engineering Service, S.E.M.T. Saint Nazaire and acts as Project Manager for the industrialisation of the H.A.M. System on Pielstick engine.

The floor is yours, Mr. Riom.

Treatment Technologies for Gaseous Emissions from Ships

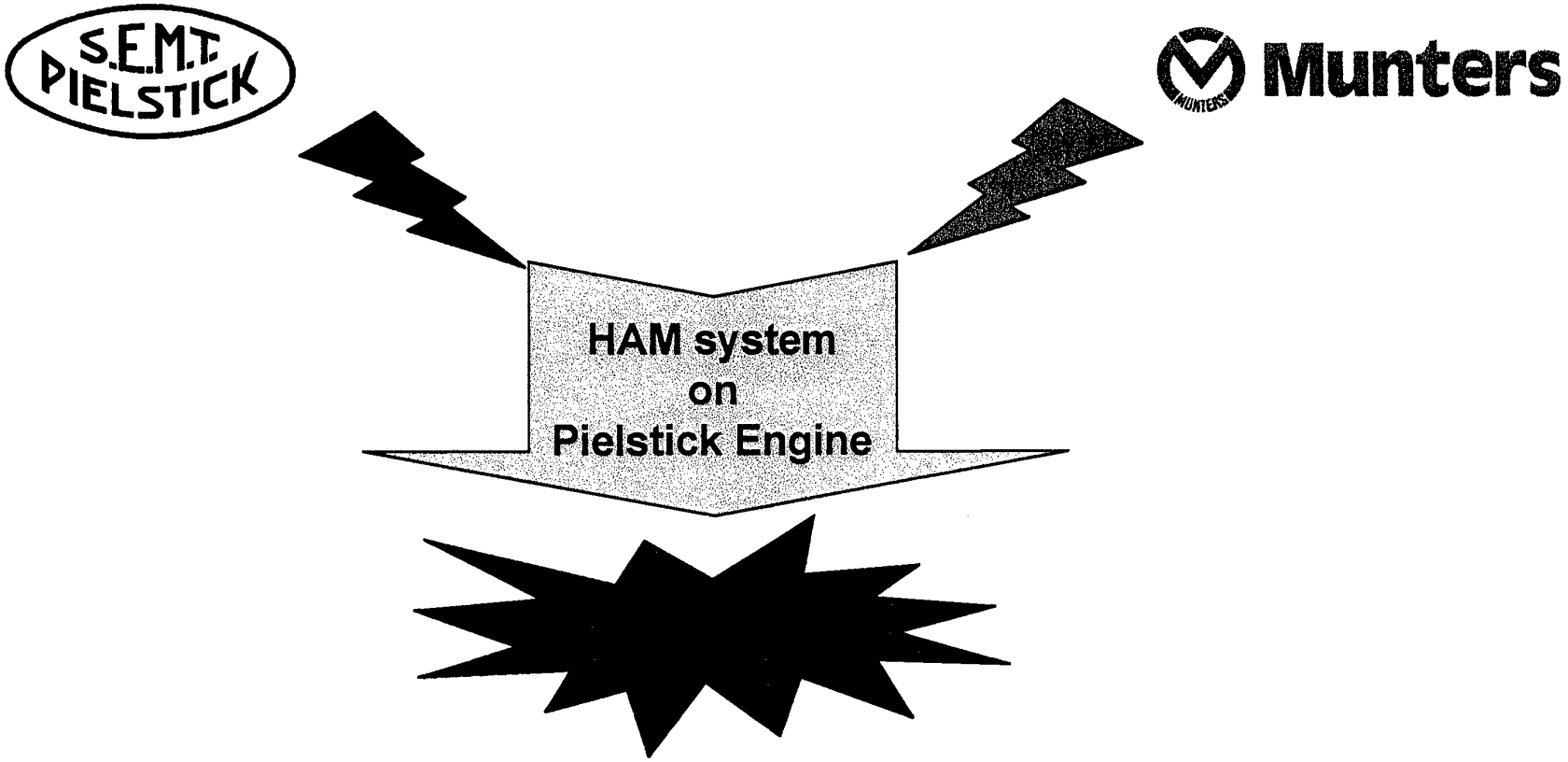



# NOx Emission Reduction with HAM SYSTEM Experience from Field Tests

Brussels - 18th 19th October 1999

E. RIOM

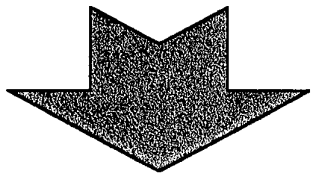
# SEMT - Munters Collaboration



# HAM system principle

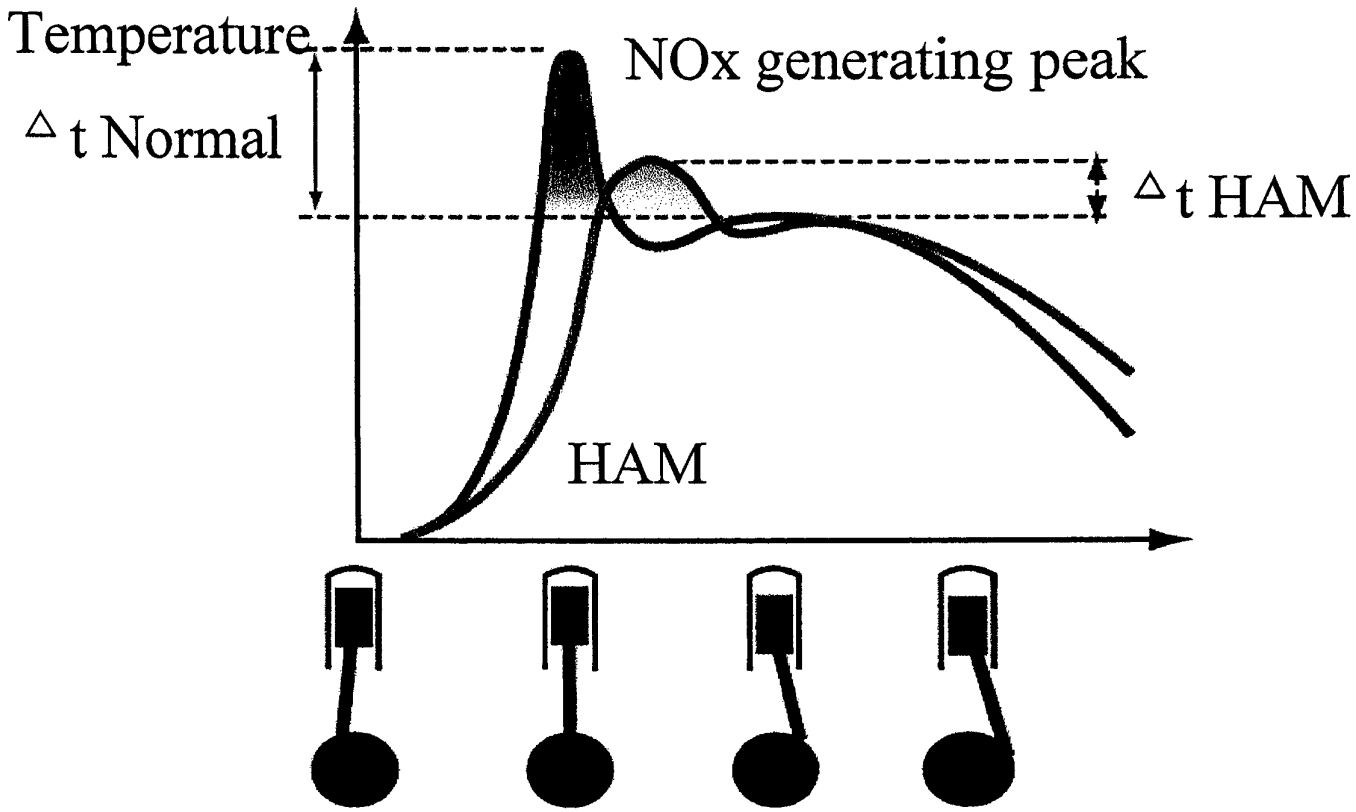
**To use water vapour capability to reduce NOx**

**To change thermodynamical properties of combustion in avoiding hot spots which is the main cause of NOx formation**



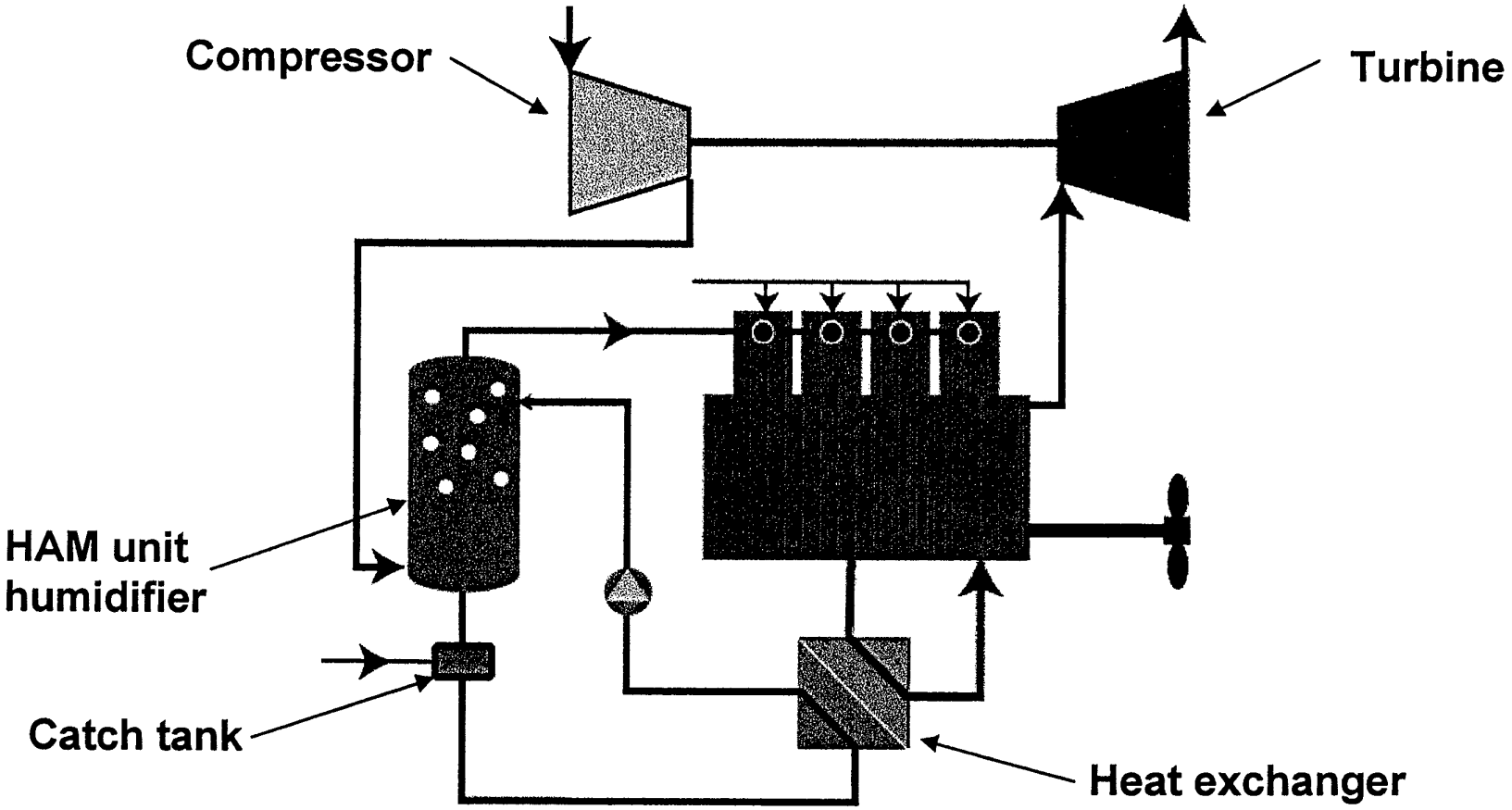
**To increase humidity of air charging with water vapour**

# HAM system principle




982

# Diesel engine with HAM principle




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# 1st TEST SERIE ON 3 PC2.6 B

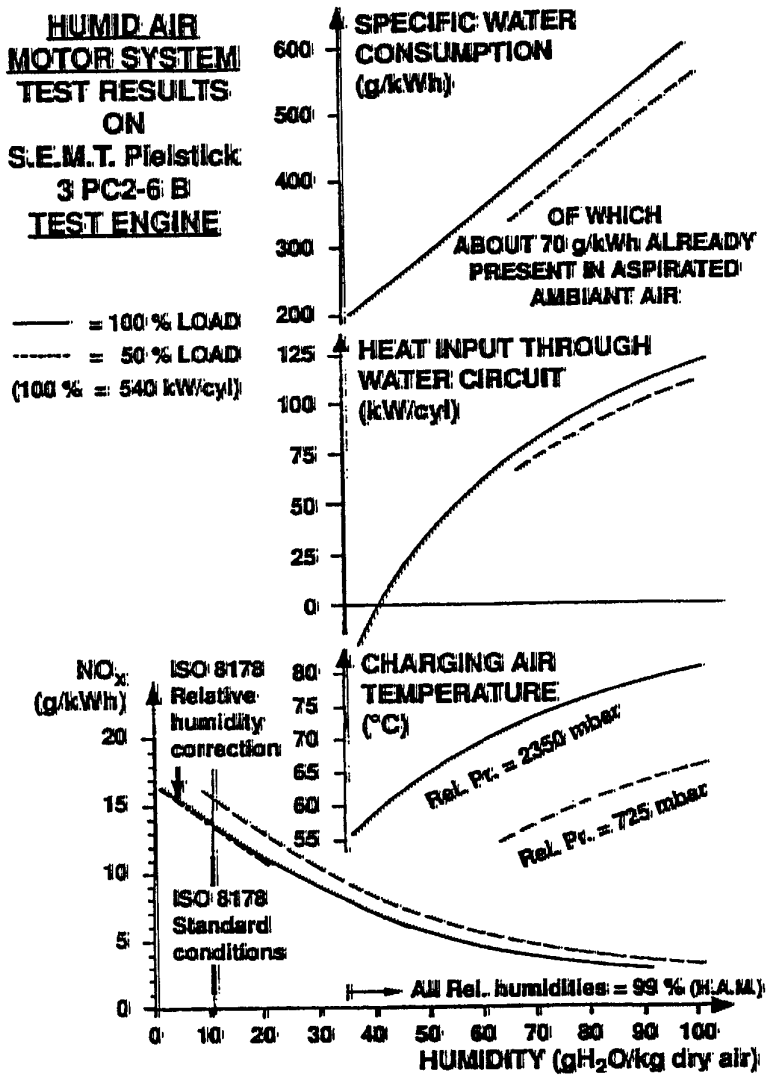
- 3 cylinders PC2.6 B in Saint Denis - June 1998
- 540 kW/cyl - 540 rpm
- Bore : 400 mm - stroke : 500 mm
- Test with Heavy Fuel
- Test with salt water

# 1st TEST SERIE ON 3 PC2.6 B Results

- NOx reduction : 13.5 g/kWh → 3.5 g/kWh
- Slight influence on fuel consumption
- No significant increase of CO and HC
- No smoke deterioration
- Decrease in cylinder temperatures (more than 20°C)
- Decrease in valve temperatures (more than 30°C)
- No water in lubricating oil
- No main additional effect on engine components

# NOx Emission Reduction with HAM system

## 1st TEST SERIE ON 3 PC2.6 B



# 2nd TEST SERIE ON 3 PC2.6 B

- **3 cylinders PC2.6 B in Saint Denis - January 1999**
- **750 kW/cyl - 600 rpm**
- **Bore : 400 mm - Stroke : 500 mm**
- **Aim :**
  - to confirm NOx reduction
  - to test the system in emergency situations
  - to test the system with reduction on injection timing

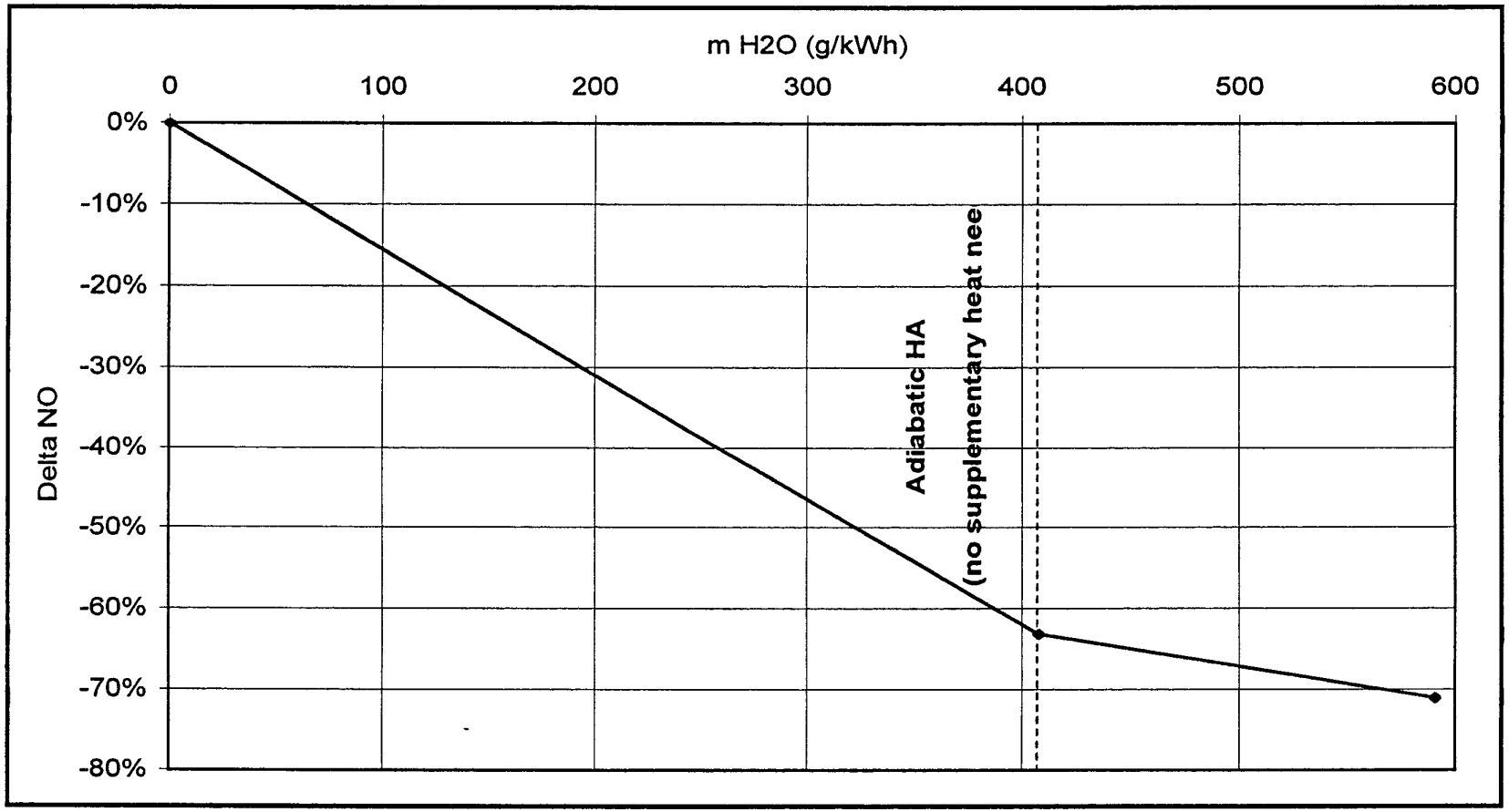
# 2nd TEST SERIE ON 3 PC2.6 B
# Results

- **HAM system is as effective as that of the running condition of the previous test**
- **HAM system follows the engine load variation at once**
- **Emergency situation :**
  - Engine at full load and sudden stop with HAM still in operation
  - Engine running at full load and sudden HAM stop

  **does not involve either dangerous or irreversible consequences for the engine + HAM**
- **No main additional effect on engine components**

# NOx Emission Reduction with HAM system

## 2nd TEST SERIE ON 3 PC2.6 B
## Results - 100% Load



# HAM system on board Mariella
# Field test on one engine of a ferry

- Viking Line AB Car Ferry : M/S Mariella
- Pielstick Engine : 12 PC 2.6
- 5750 kW - 500 rpm
- Bore : 400 mm - Stroke : 460 mm

S.E.M.T. PIELSTICK

# NOx Emission Reduction with HAM system

## M/S Mariella



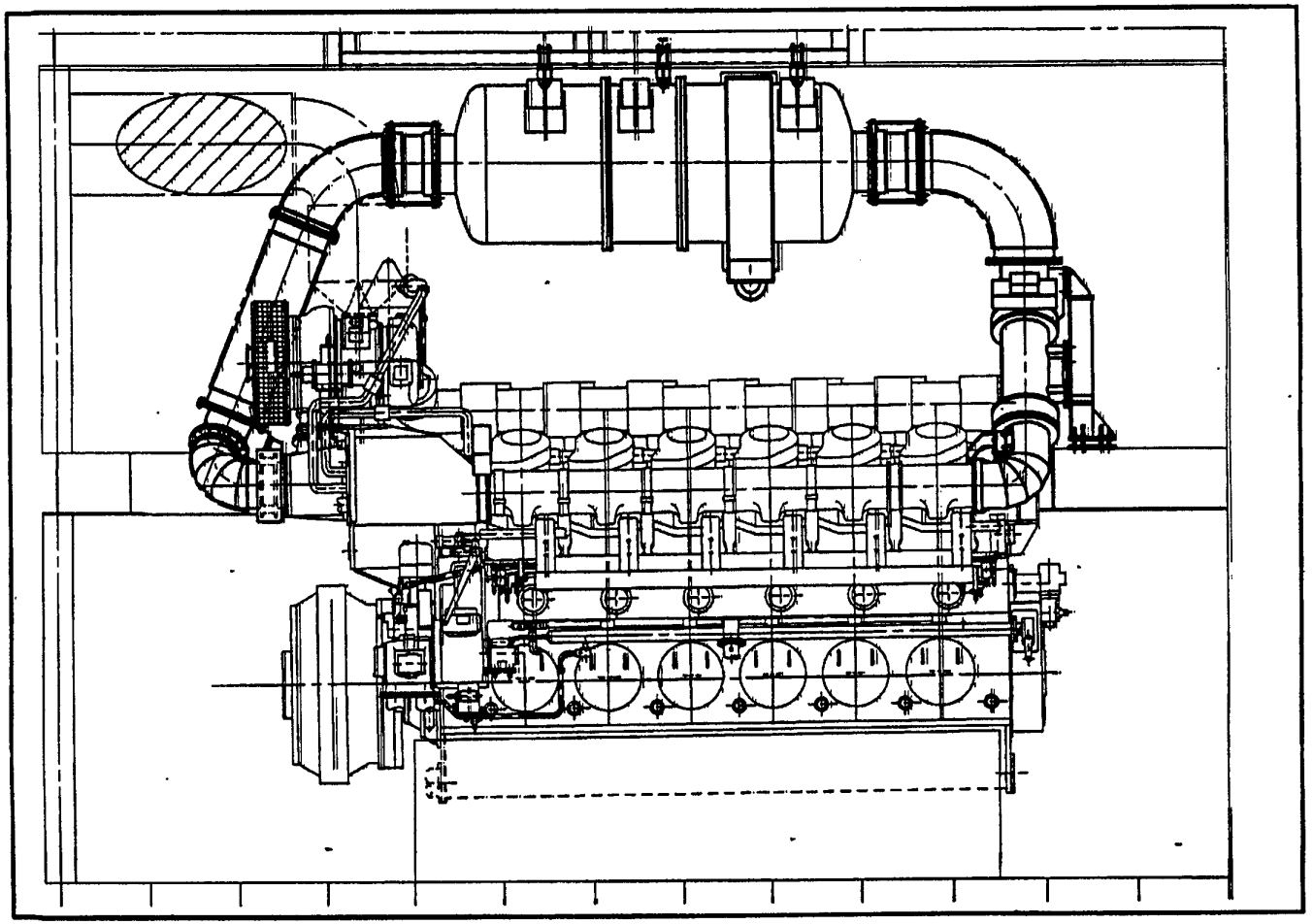

- Length : 177 m
- Width : 29 m
- GT : 37 799 tons
- Engines : 4 x 12 PC2.6
- Speed : 22 knots
- Passengers : 2 700
- Cars + Lorries : 480 + 60

295

S.E.M.T. PIELSTICK

# NOx Emission Reduction with HAM system

## HAM system on board Mariella

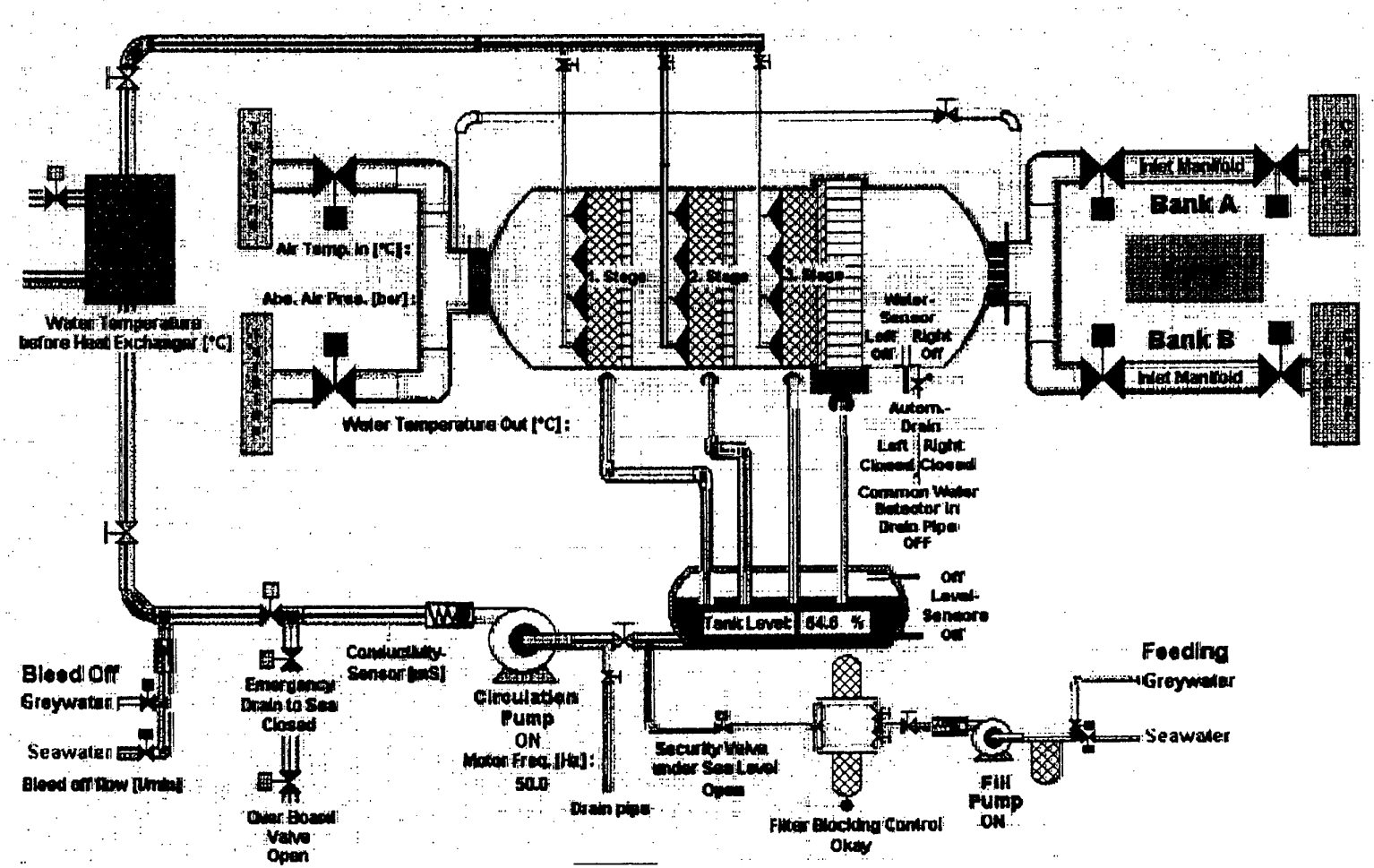


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S.E.M.T. PIELSTICK

# NOx Emission Reduction with HAM system

## HAM system on board Mariella - Flow scheme

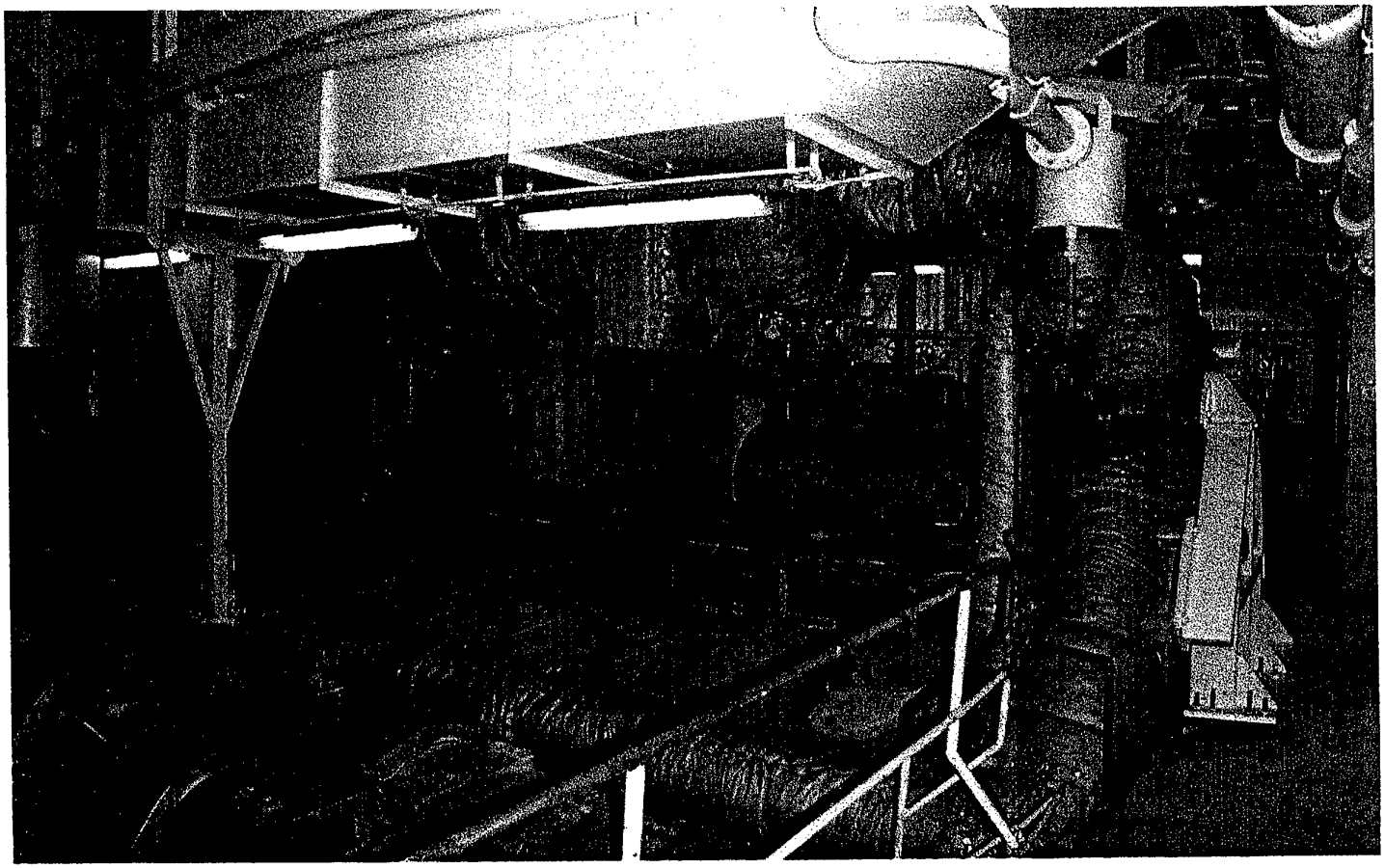



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S.E.M.T. PIELSTICK

# NOx Emission Reduction with HAM system

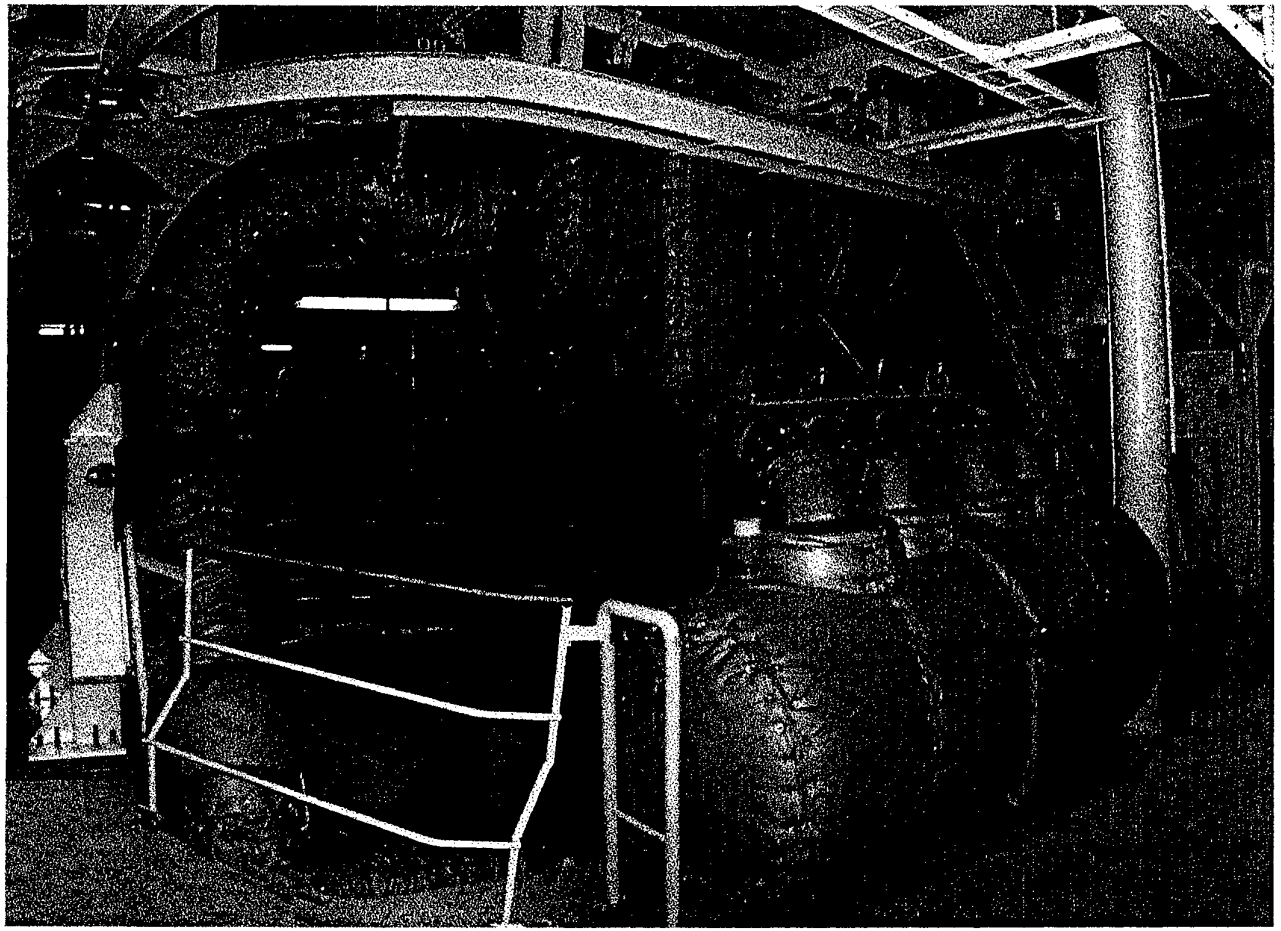
## HAM system on board Mariella



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# NOx Emission Reduction with HAM system

## HAM system on board Mariella



# HAM system on board Mariella Results

- Δ NOX = - 70% is confirmed
- No trace of water in lube oil
- No corrosion
- Decrease of cylinder temperatures
- No significant change in consumption
- Engine is cleaner

# NOx Emission Reduction with HAM system

## HAM on board Mariella
## Oil analysis

RLA RAPID LUBRICANTS ANALYSIS

### ANALYSIS REPORT

MARIELLA - CHIEF ENGINEER,
VIKING LINE TERMINAL,
TEGELVIKSHAMNEN,
S-116 30 STOCKHOLM,
SWEDEN.

Fax : +46 8 6426607

Ship: MARIELLA
Owner: VIKING LINE AB
Machine: M.ENG.NO.1
Machine Make: PIELSTICK (SEMT)
Type: PC 2.6
Vessel number: BI145
Oil grade: SHELL ARGINA T OIL 40
Our ref.: R-4070043SAF.13/290999E0

| Sample number | 979889 | 147350 | 147342 | 148004 | 147341 | 148003 |
|---|---|---|---|---|---|---|
| Date drawn | 240999 | 230999 | 230999 | 290999 | 230999 | 290999 |
| Date received | 280999 | 230999 | 230999 | 230999 | 230999 | 230999 |
| Date analysed | 290999 | 240999 | 240999 | 240999 | 240999 | 240999 |
| Engine hours | 68580 | 68548 | 68594 | 68622 | 68580 | 68606 |
| Oil hours | | | | | | |
| Oil added, l. | | | | | | |
| Fuel in use | MF | MF | MF | MF | MF | MF |
| Visc. cSt/100° C | 15.2 | 15.3 | 15.3 | 15.2 | 15.2 | 15.3 |
| Water, % | lt 0.05 | lt 0.05 | lt 0.05 | lt 0.05 | lt 0.05 | lt 0.05 |
| Flash point, °C | mt 190 | mt 190 | mt 190 | mt 190 | mt 190 | mt 190 |
| TBN, mg KOH/g | 21.7 | 21.7 | 22.1 | 21.8 | 24.0 | 22.3 |
| I.C. | 0.80 | 0.80 | 0.60 | 0.70 | 0.70 | 0.60 |
| M.D. | 85.0 | 82.0 | 93.0 | 79.0 | 82.0 | 80.0 |
| D.P. | 12 | 14 | 4 | 15 | 13 | 12 |
| Ca, % | 0.90 | 0.77 | 0.76 | 0.82 | 0.81 | 0.80 |
| Ba, % | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| P , % | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Zn, % | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Fe, mg/kg | 12 | 11 | 10 | 11 | 11 | 11 |
| Cr, mg/kg | 2 | 1 | 1 | 2 | 1 | 1 |
| Mo, mg/kg | 0 | 1 | 1 | 0 | 0 | 1 |
| Sn, mg/kg | 0 | 0 | 0 | 0 | 0 | 0 |
| Pb, mg/kg | 0 | 1 | 1 | 0 | 0 | 0 |
| Cu, mg/kg | 2 | 2 | 2 | 2 | 2 | 2 |
| Na, mg/kg | 24 | 23 | 22 | 23 | 23 | 23 |
| Mg, mg/kg | 45 | 38 | 38 | 40 | 40 | 45 |
| Al, mg/kg | 4 | 4 | 4 | 4 | 4 | 4 |
| Si, mg/kg | 6 | 5 | 6 | 6 | 6 | 6 |
| V , mg/kg | 5 | 5 | 5 | 5 | 5 | 5 |
| Comments * | 00 | 00 | 00 | 00 | 00 | 00 |

# Synthesis of benefits and performances

- NOx reduction : 70 %
- No significant influence on SFC
- No significant increase of CO and HC
- No smoke deterioration
- Valve and cylinder temperature decrease
- Only water is consumed
- Less carbon deposit
- Water cooler is no longer necessary

# HAM system on a Pielstick Engine is truly an ecological way to reduce NOx emission efficiently whilst optimizing engine performances

# Design and Testing of a Bubble-Scrubber for SOx and Particulate from Marine Engines and Incinerators

**Dr. A. Trivett, Sc.D., P.Eng.,Marine Energy Ltd.**

## Abstract

Marine Energy Limited (MEL) has developed a novel technology which is ideally suited to ship engine exhaust gas scrubbing. The MEL exhaust scrubber successfully removes soot, SOx, a small percentage of NOx, and a large proportion of waste heat from exhaust. The MEL technology offers a chance to burn high-sulfur fuel (up to 5% sulfur content) in a diesel
engine, and produce emissions that are lower in sulfur than those from engines burning low sulfur fuels (0.5% sulfur content) without an MEL scrubber. This will ensure that fuel costs are kept to a minimum, engine efficiency to a maximum, while minimizing the environmental impact of diesel exhaust from both soot and SOx. The system is compatible for use in conjunction with certain low-NOx systems, offering the potential for a full-spectrum solution to diesel exhaust while burning residual fuels.

The MEL Exhaust Scrubber for Marine Diesel Engines uses a novel arrangement for mixing hot exhaust gas and liquid to produce a distribution of fine bubbles at the surface of a shallow water tank. The fine bubbles are effective for bringing hot exhaust gas and scrubbing liquid into close turbulent contact, enabling effective transfer of particulate and SOx from the exhaust to the liquid. The system is designed for a large amount of recirculation, keeping trapped particulate in suspension, and minimizing wastewater from the scrubber to the point where shipboard wastewater systems can effectively handle the soot sludge.

Pilot-plant trials of the technology were completed in 1998 aboard the Canadian Coast Guard Icebreaker Louis S. St.-Laurent, the largest diesel-powered icebreaker in the world. Our system was shown in pilot plant trials to reduce SO2 in diesel exhaust by 95% and particulate from the exhaust of a marine diesel engine by 70-80% with insertion back-pressures as low 15-20 mBar. Several new demonstration installations are in progress, and
will be described in the paper.

Dr. D. Andrew Trivett, Sc. D., President and Chief Technical Officer of Marine Energy Ltd., has developed advanced technology for the marine and oceanographic industry for the past 10 years. Dr. Trivett, a Professional Engineer, holds a Doctor of Science degree from the Ocean Engineering Department of the Massachusetts Institute of Technology in a joint program with the Woods Hole Oceanographic Institution. He has developed instrumentation for the measurement of a wide variety of parameters in regard to the chemical and physical properties of air and water, particularly for turbulence research in the ocean. Dr. Trivett has led the MEL development efforts to design and test diesel exhaust emissions control technology since 1997.

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Session 4
Speaker Dr. D. Andrew Trivett

I should like to welcome our next speaker which is Dr. Andrew Trivett.

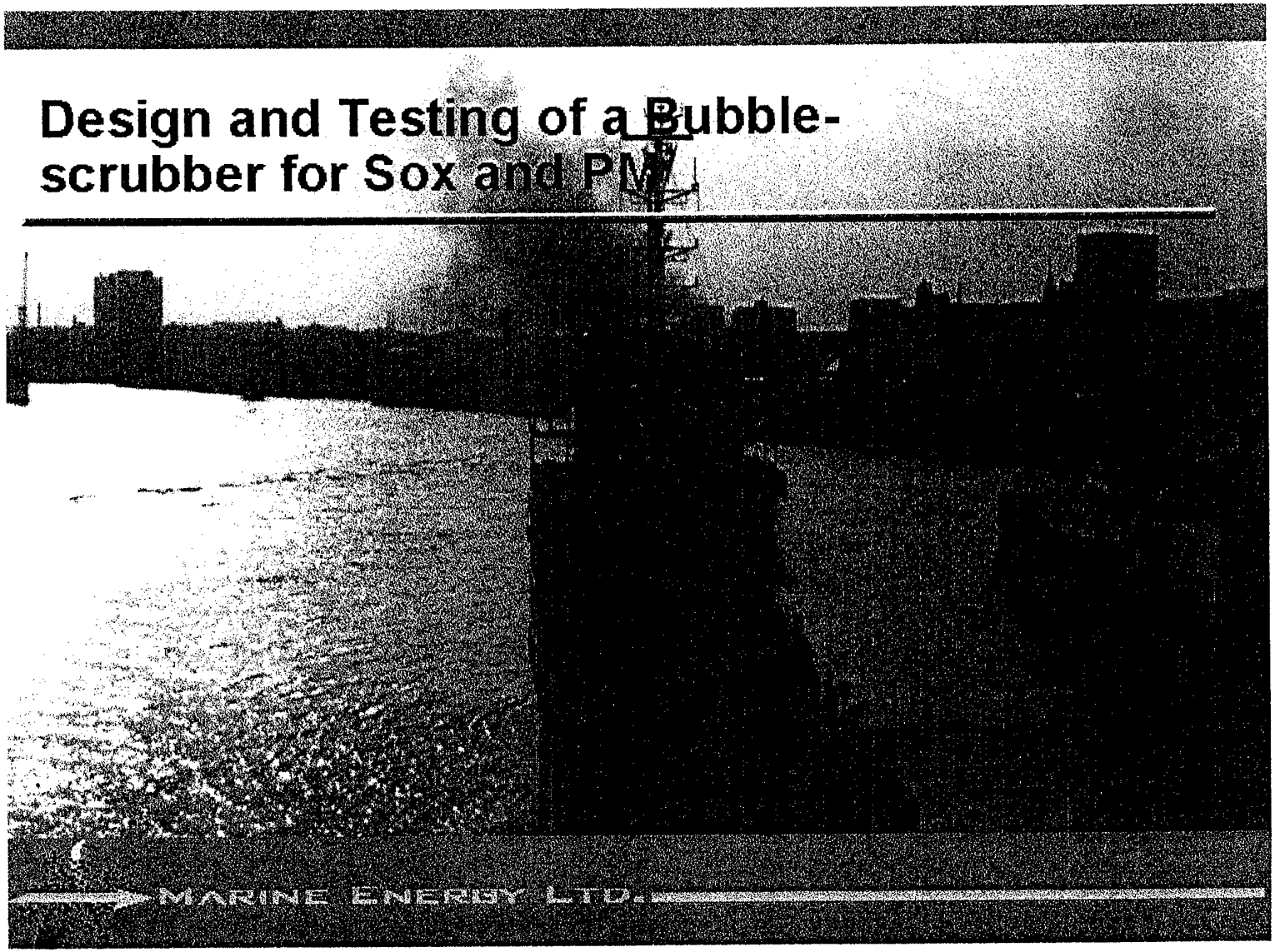
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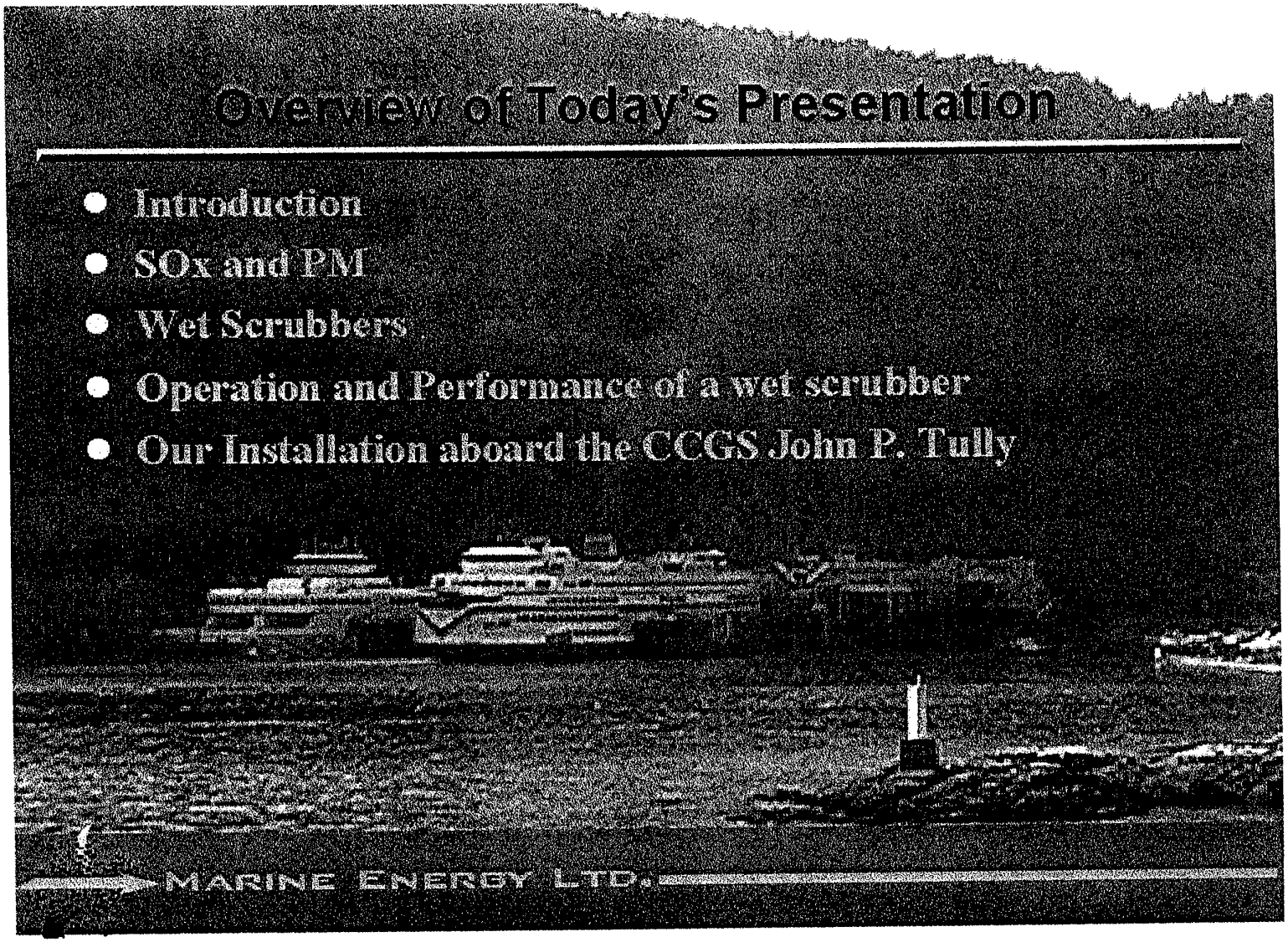
As a Professional Engineer he holds a Doctor of Science degree from the Ocean Engineering Department of the Massachusetts Institute of Technology in a joint program with the Woods Hole Oceanographic Institution.

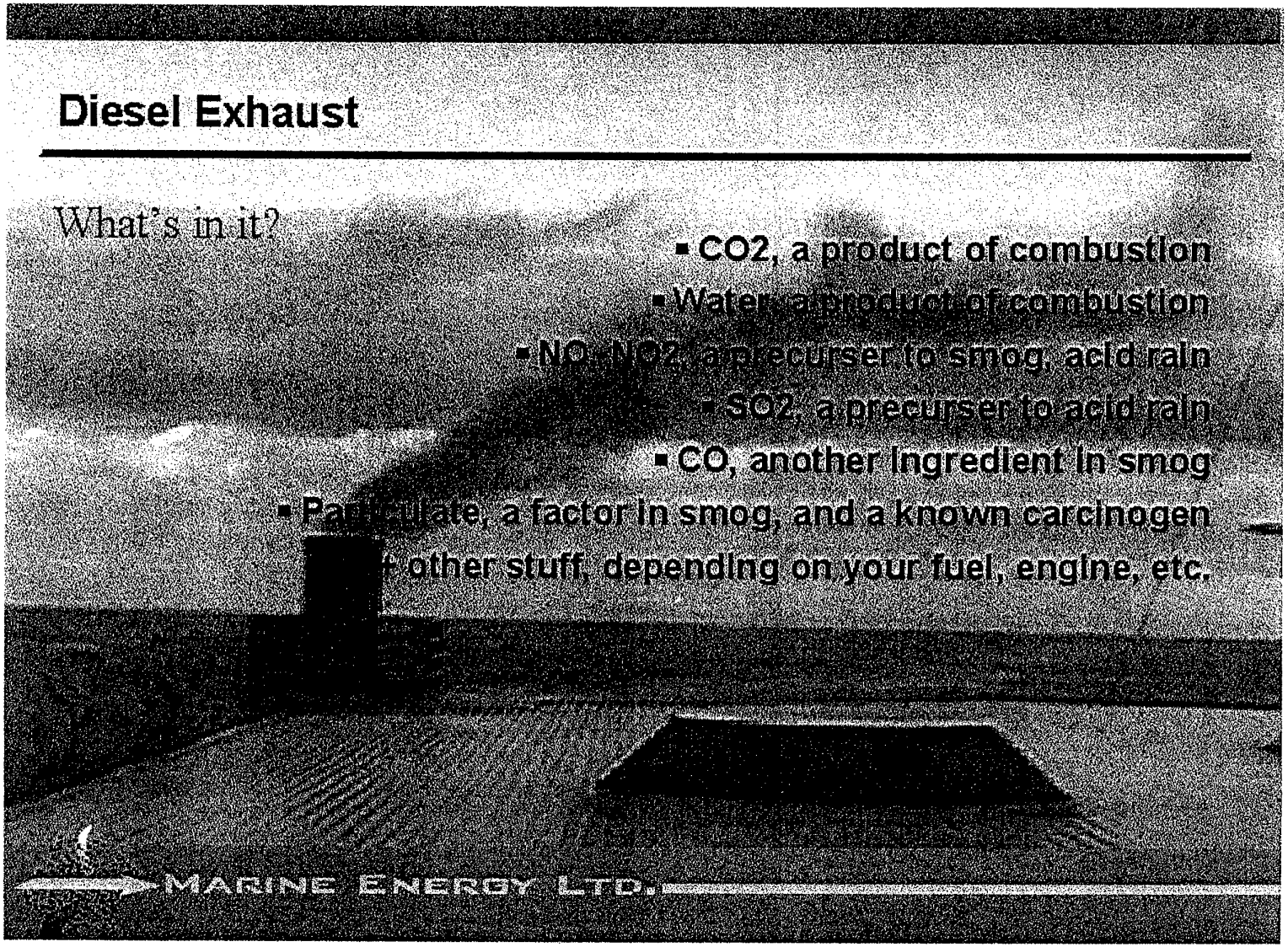
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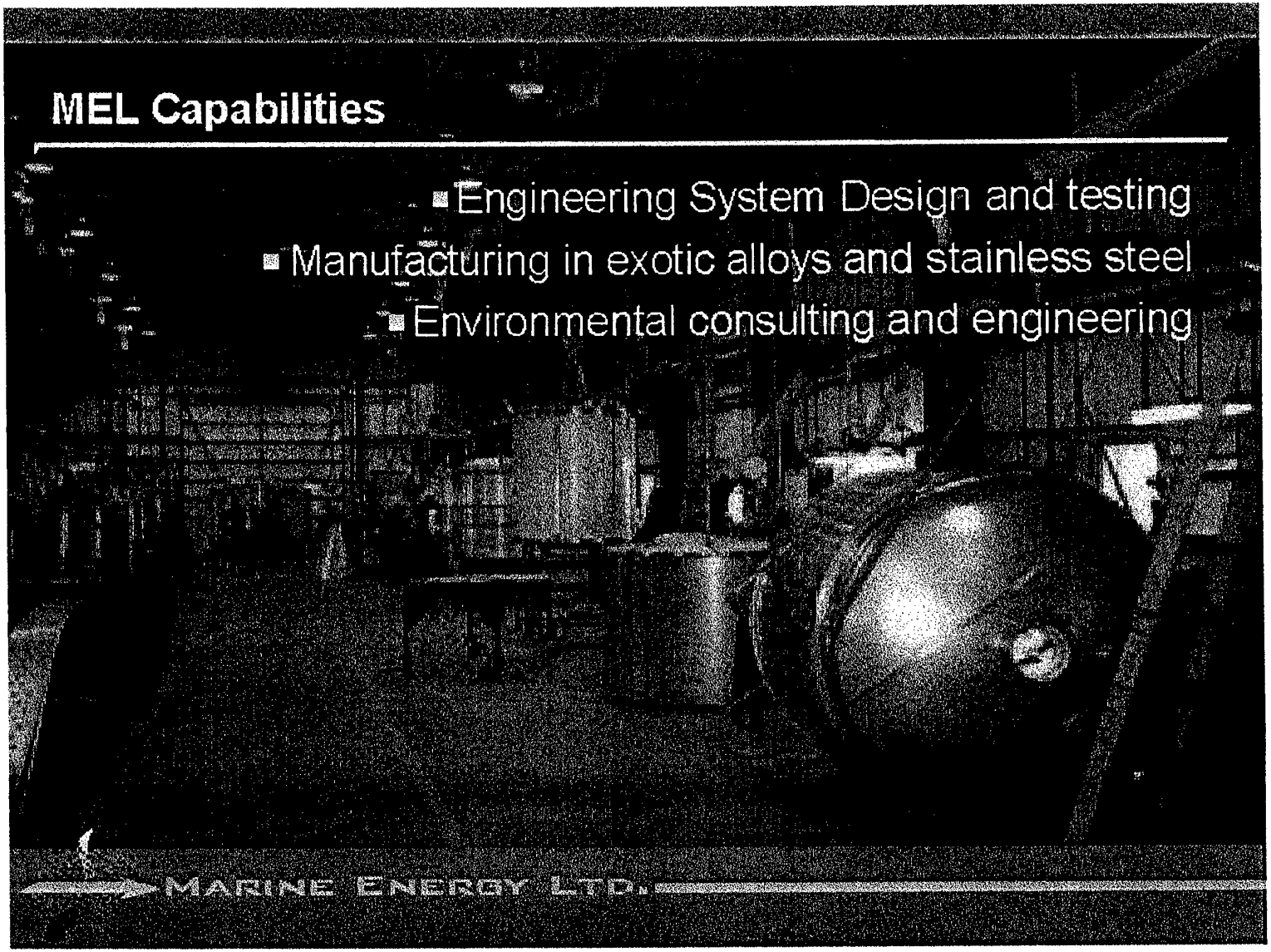
He has led the MEL development efforts to design and test diesel exhaust emissions control technology since 1997.

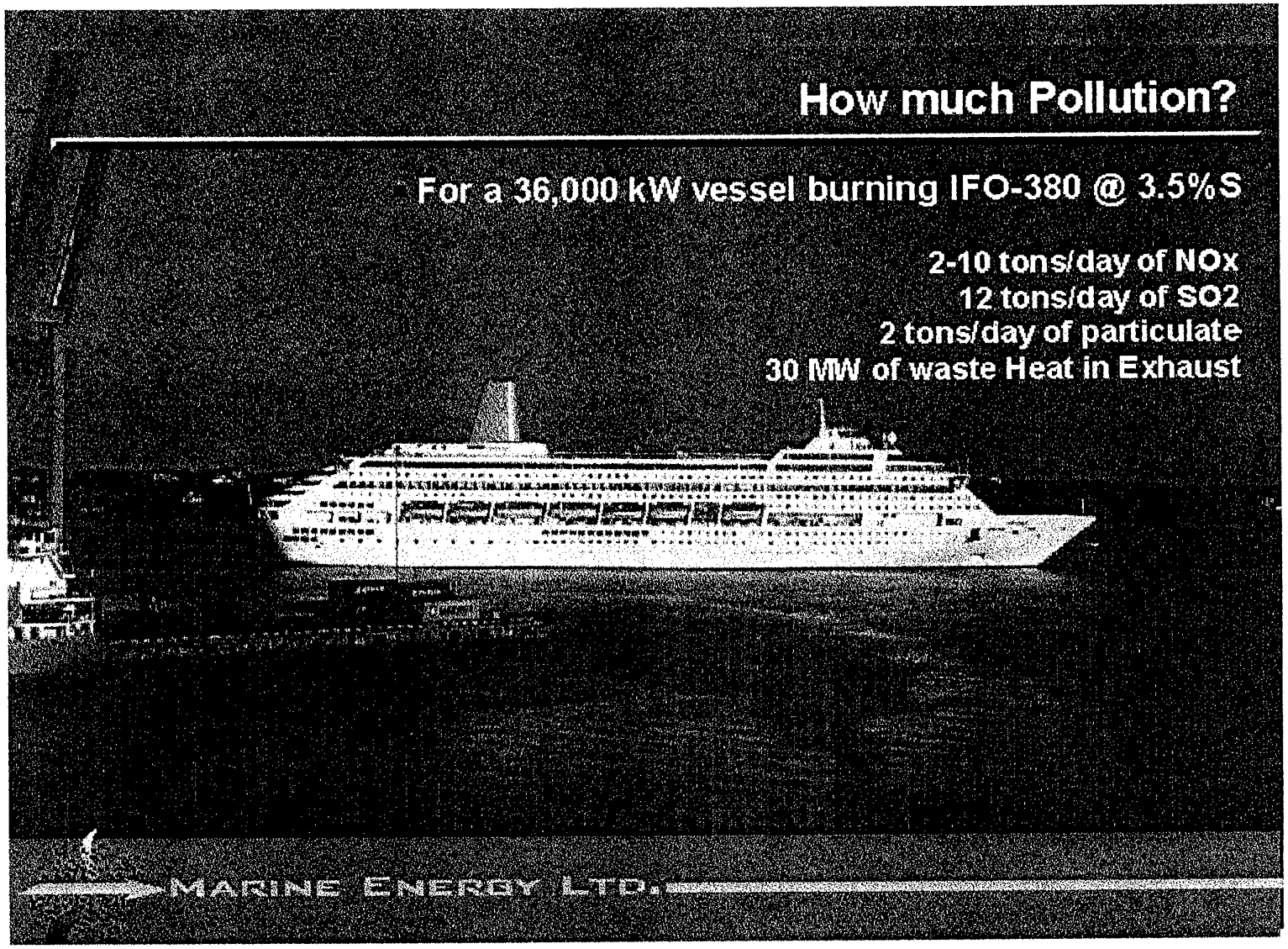
Dr. Trivett will now present his paper on
"Design and Testing of a Bubble-Scrubber for SOx and Particulate from Marine Engines and Incinerators"


Design and Testing of a Bubble-scrubber for Sox and PM
MARINE ENERGY LTD.


Overview of Today's Presentation
Introduction
SOx and PM
Wet Scrubbers
Operation and Performance of a wet scrubber
Our Installation aboard the CCGS John P. Tully
MARINE ENERGY LTD.


Diesel Exhaust
What's in it?
▪ CO2, a product of combustion
▪ Water, a product of combustion
▪ NO, NO2, a precurser to smog, acid rain
▪ SO2, a precurser to acid rain
▪ CO, another Ingredient in smog
▪ Particulate, a factor in smog, and a known carcinogen
+ other stuff, depending on your fuel, engine, etc.
MARINE ENERGY LTD.


MEL Capabilities
Engineering System Design and testing
Manufacturing in exotic alloys and stainless steel
Environmental consulting and engineering
MARINE ENERGY LTD.


How much Pollution?
For a 36,000 kW vessel burning IFO-380 @ 3.5%S
2-10 tons/day of NOx
12 tons/day of SO2
2 tons/day of particulate
30 MW of waste Heat in Exhaust
MARINE ENERGY LTD.

# Emissions Budget for a ship burning Heavy Fuel

| | Power (kW) | SO2 Emissions (MT/yr) | Soot Emissions (MT/yr) | Fuel Costs (US$/Yr) |
|---|---|---|---|---|
| Engines | | | | |
| Main 1 | 9450 | 483 | 41 | $402,854 |
| 2 | 9450 | 483 | 41 | $402,854 |
| 3 | 9450 | 483 | 41 | $402,854 |
| 4 | 9450 | 483 | 41 | $402,854 |
| Auxiliary | 2360 | 160 | 12 | $133,217 |
| 2 | 2360 | 160 | 12 | $133,217 |
| 3 | 2360 | 160 | 12 | $133,217 |
| 4 | 2360 | 160 | 12 | $133,217 |
| Boiler1 | 3500 | 35 | 13 | $29,060 |
| 2 | 3500 | 35 | 13 | $29,060 |
| Incinerator | 650 | 3 | 1 | $2,698 |
| | | **2,646** | **238** | **$2,205,101** |

# Emissions Budget for a Ship Burning Low-Sulfur Distillate Fuel

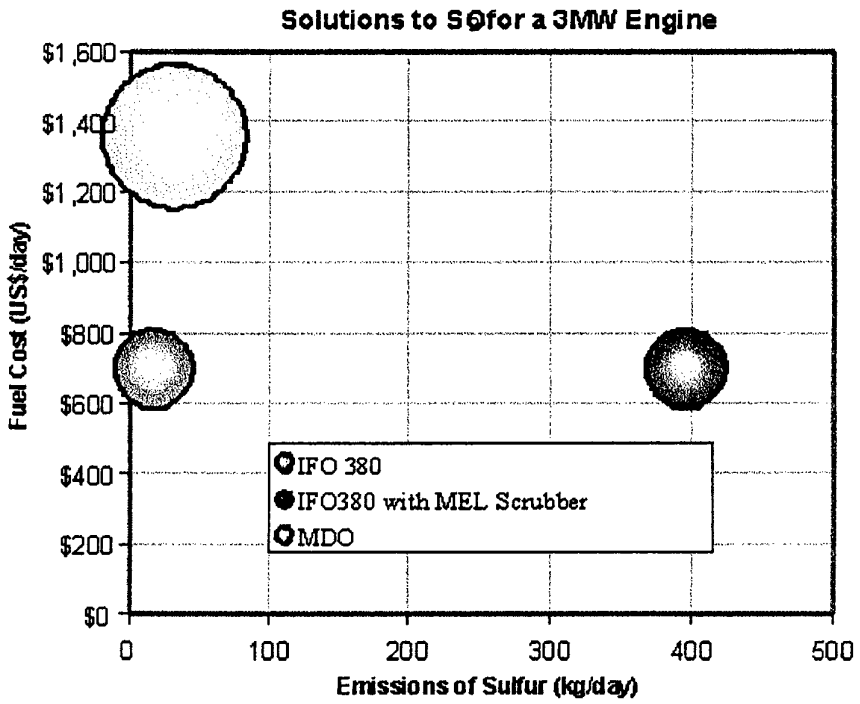
| | | Power (kW) | SO2 Emissions (MT/yr) | Soot Emissions (MT/yr) | Fuel Costs (US$/Yr) |
|---|---|---|---|---|---|
| Engines | | | | | |
| Main | 1 | 9450 | 14 | 41 | $920,808 |
| | 2 | 9450 | 14 | 41 | $920,808 |
| | 3 | 9450 | 14 | 41 | $920,808 |
| | 4 | 9450 | 14 | 41 | $920,808 |
| Auxiliary | 1 | 2360 | 5 | 12 | $304,497 |
| | 2 | 2360 | 5 | 12 | $304,497 |
| | 3 | 2360 | 5 | 12 | $304,497 |
| | 4 | 2360 | 5 | 12 | $304,497 |
| Boiler | 1 | 3500 | 1 | 13 | $66,422 |
| | 2 | 3500 | 1 | 13 | $66,422 |
| Incinerator | | 650 | 0 | 1 | $6,168 |
| | | | **76** | **238** | **$5,040,231** |

# Emission Budget for a ship Burning Heavy Fuel and Equipped with a MEL Scrubber

| | | Power (kW) | SO2 Emissions (MT/yr) | Soot Emissions (MT/yr) | Fuel Costs (US$/Yr) |
|---|---|---|---|---|---|
| Engines | | | | | |
| Main | 1 | 9450 | 15 | 8 | $402,854 |
| | 2 | 9450 | 15 | 8 | $402,854 |
| | 3 | 9450 | 15 | 8 | $402,854 |
| | 4 | 9450 | 15 | 8 | $402,854 |
| Auxiliary | 1 | 2360 | 5 | 2 | $133,217 |
| | 2 | 2360 | 5 | 2 | $133,217 |
| | 3 | 2360 | 5 | 2 | $133,217 |
| | 4 | 2360 | 5 | 2 | $133,217 |
| Boiler | 1 | 3500 | 1 | 3 | $29,060 |
| | 2 | 3500 | 1 | 3 | $29,060 |
| Incinerator | | 650 | 0 | 0 | $2,698 |
| | | | **79** | **48** | **$2,205,101** |

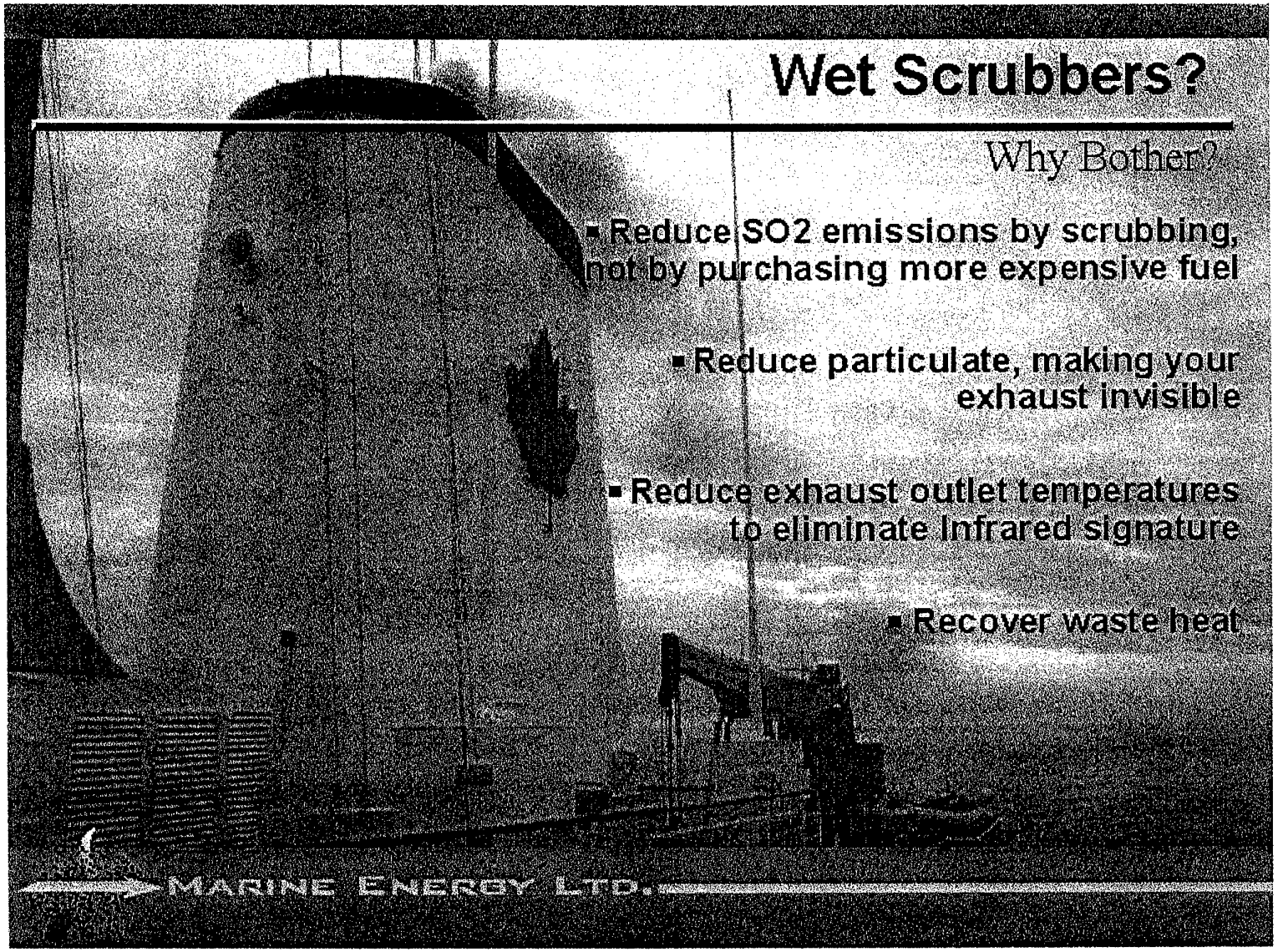
## Reduction of SO2 Emissions

Shipowners are resistant to changing to low-sulfur MDO due to bunker prices





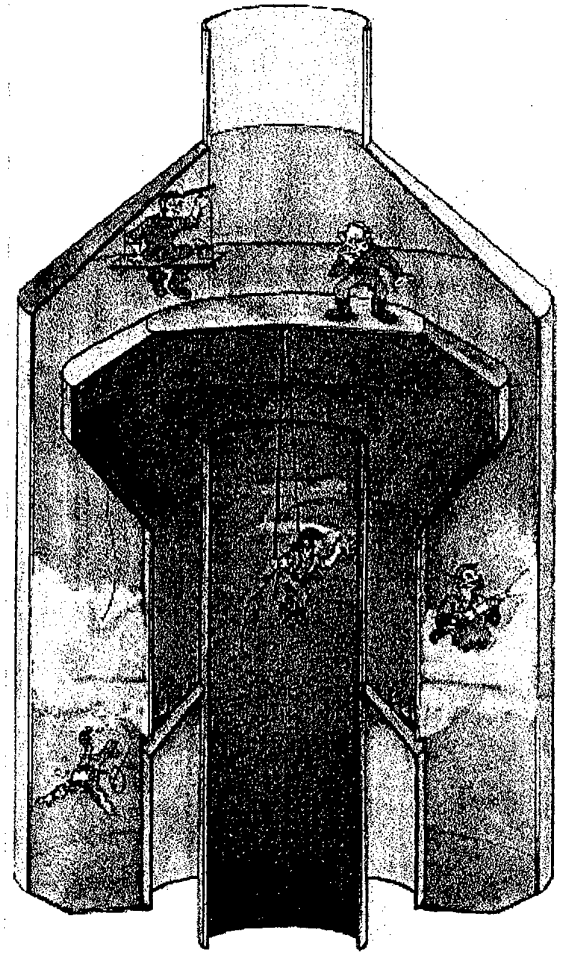

345


Wet Scrubbers?
Why Bother?
▪ Reduce SO2 emissions by scrubbing, not by purchasing more expensive fuel
▪ Reduce particulate, making your exhaust invisible
▪ Reduce exhaust outlet temperatures to eliminate Infrared signature
▪ Recover waste heat
MARINE ENERGY LTD.

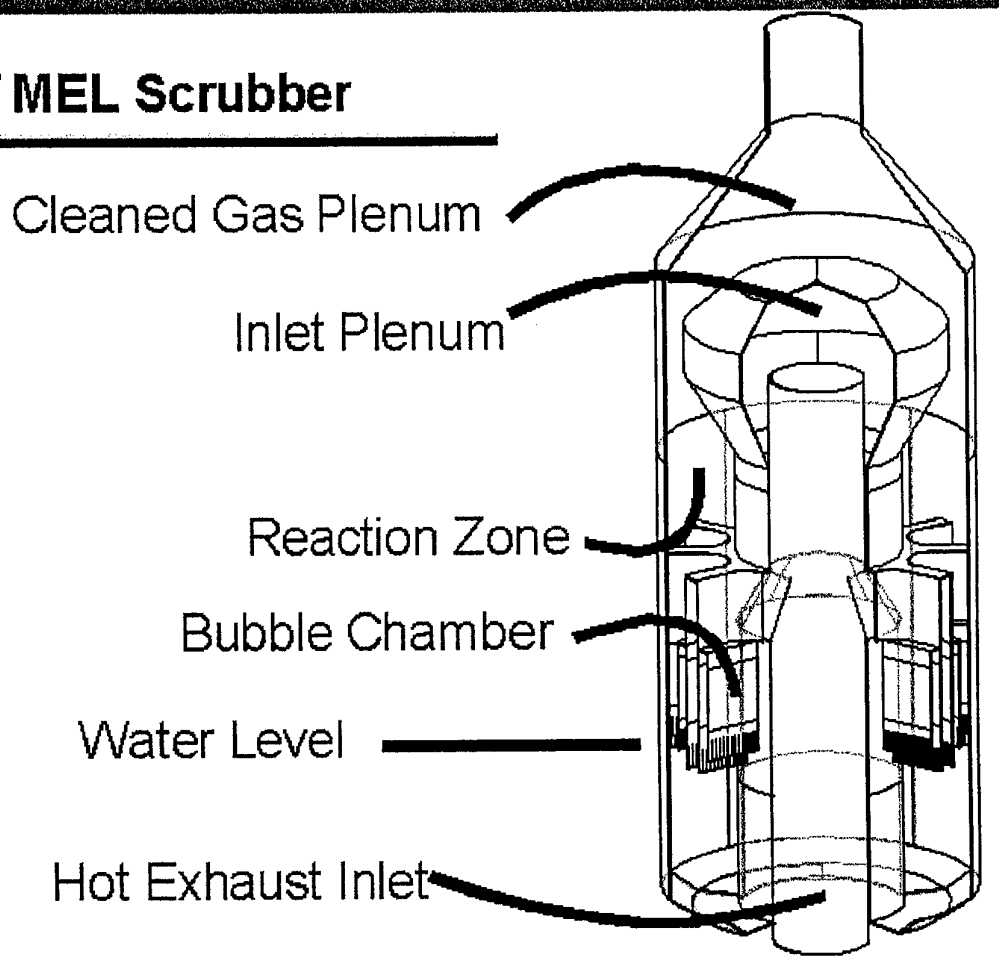
## The MEL Scrubber

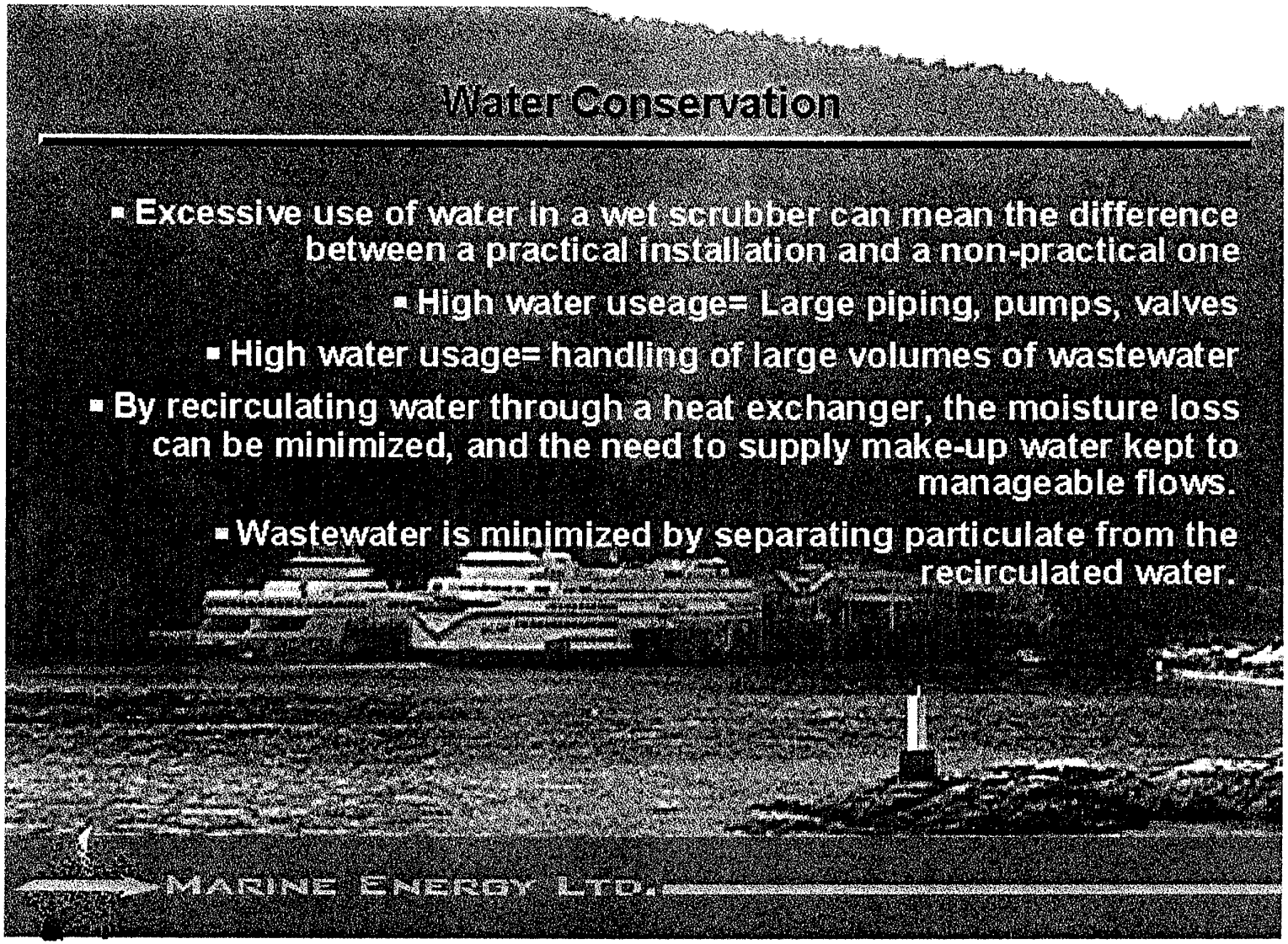
Turbulence Generation is Key

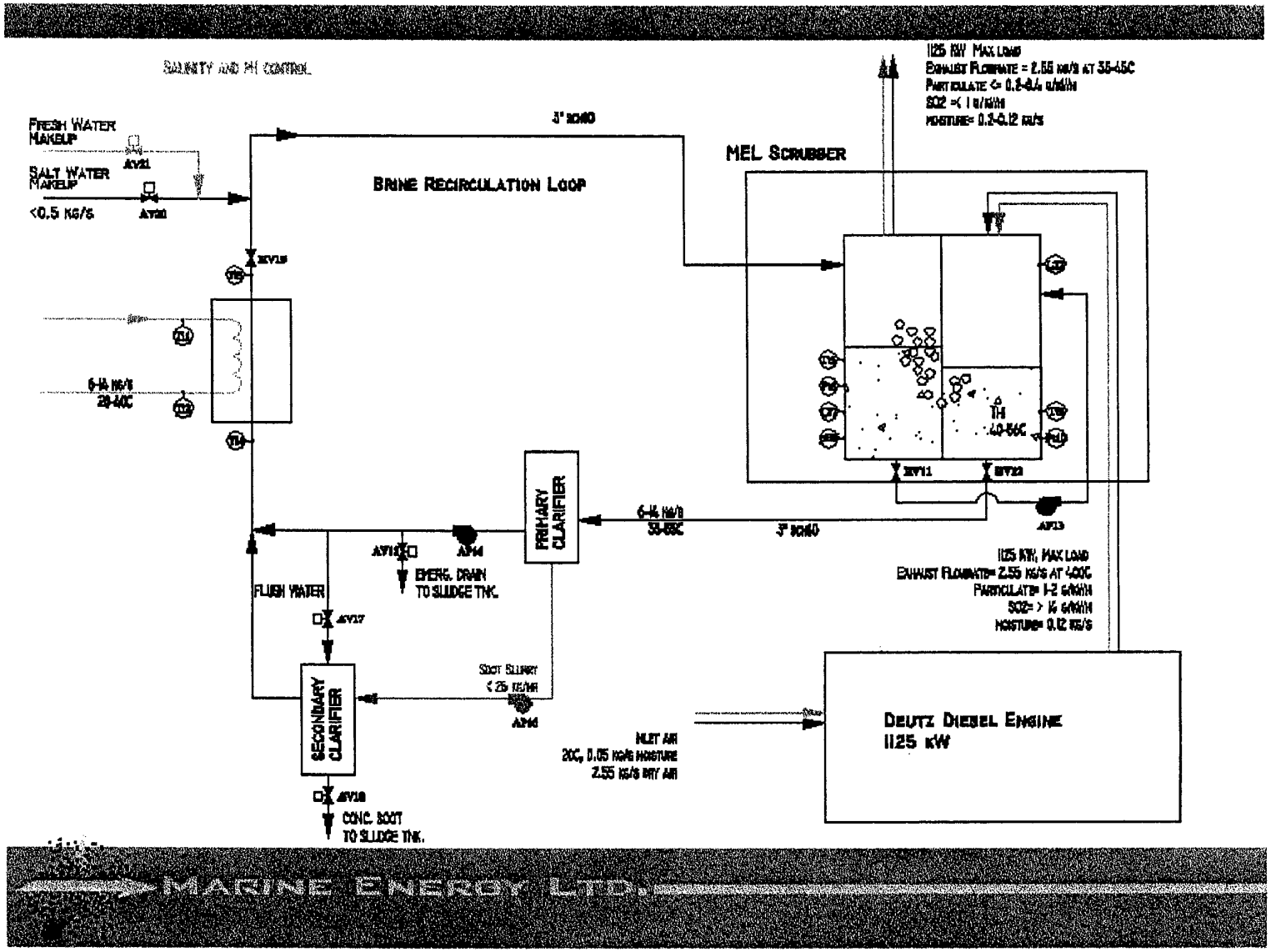
- Works by bringing exhaust gas in contact with water as fine scale bubbles, where surface area for contact is very high
- Requires modest supply of water as scrubbing agent, rather than purchased chemicals
- Can work at low back-pressure, compact, self-cleaning



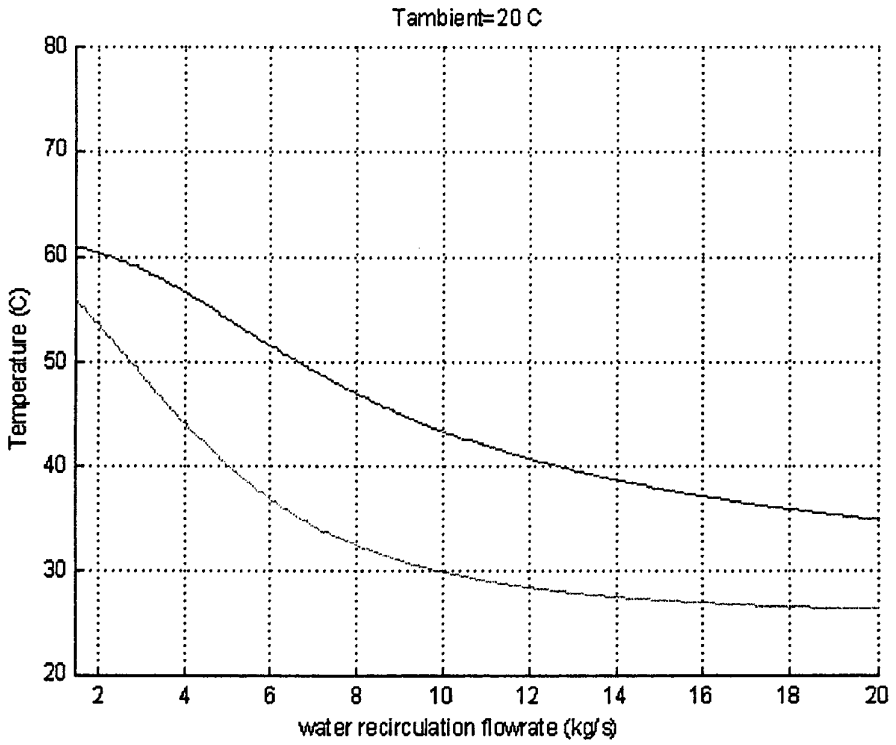
## Cutaway of MEL Scrubber



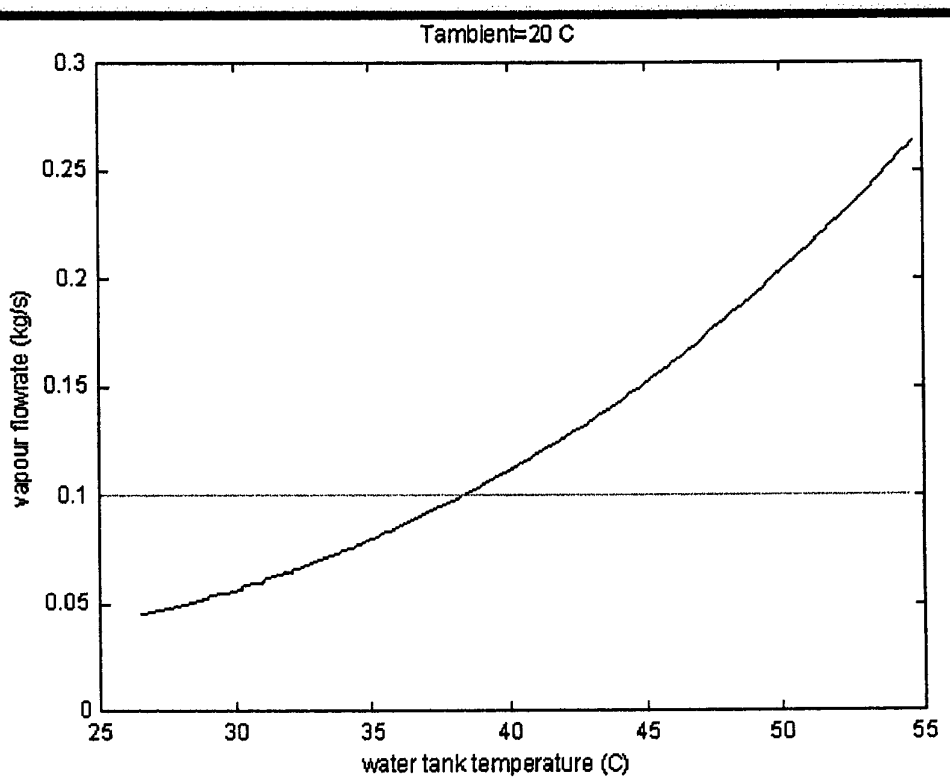

Water Conservation
▪ Excessive use of water in a wet scrubber can mean the difference between a practical installation and a non-practical one
▪ High water useage= Large piping, pumps, valves
▪ High water usage= handling of large volumes of wastewater
▪ By recirculating water through a heat exchanger, the moisture loss can be minimized, and the need to supply make-up water kept to manageable flows.
▪ Wastewater is minimized by separating particulate from the recirculated water.
MARINE ENERGY LTD.


SALINITY AND PH CONTROL
FRESH WATER MAKEUP
AV21
SALT WATER MAKEUP
<0.5 KG/S
AV20
3" SCH40
BRINE RECIRCULATION LOOP
MEL SCRUBBER
1125 KW MAX LOAD
EXHAUST FLOWRATE = 2.55 KG/S AT 35-45C
PARTICULATE <= 0.8-0.4 G/KG/H
SO2 =< 1 G/KG/H
MOISTURE= 0.1-0.12 KG/S
6-14 KG/S
28-40C
TH
40-55C
PRIMARY CLARIFIER
6-14 KG/S
35-55C
3" SCH40
AV18
AP14
EMERG. DRAIN TO SLUDGE TNK.
FLUSH WATER
AV17
SECONDARY CLARIFIER
SOOT SLURRY
< 25 KG/HR
AP16
AV19
CONC. SOOT TO SLUDGE TNK.
1125 KW, MAX LOAD
EXHAUST FLOWRATE= 2.55 KG/S AT 400C
PARTICULATE= 1-2 G/KG/H
SO2= > 1/2 G/KG/H
MOISTURE= 0.12 KG/S
INLET AIR
20C, 0.05 KG/S MOISTURE
2.55 KG/S DRY AIR
DEUTZ DIESEL ENGINE
1125 kW
MARINE ENERGY LTD.

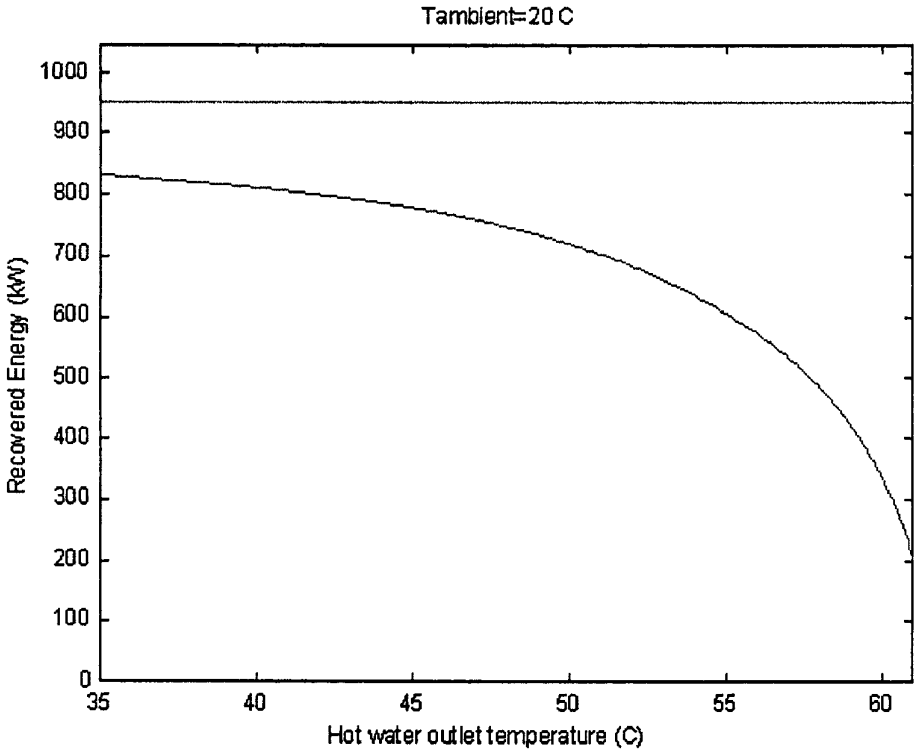
# Outlet Gas Temperature Versus Recirculation



# Moisture Balance Versus Gas Outlet Temperature



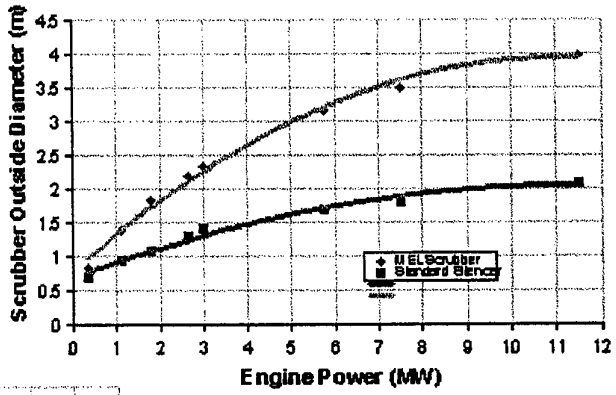
# Potential Heat Recovery



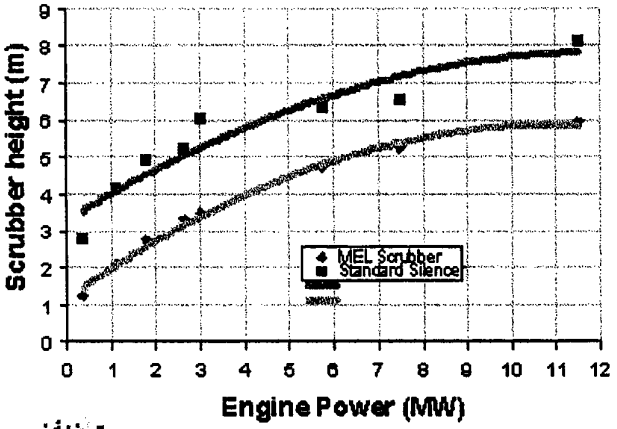


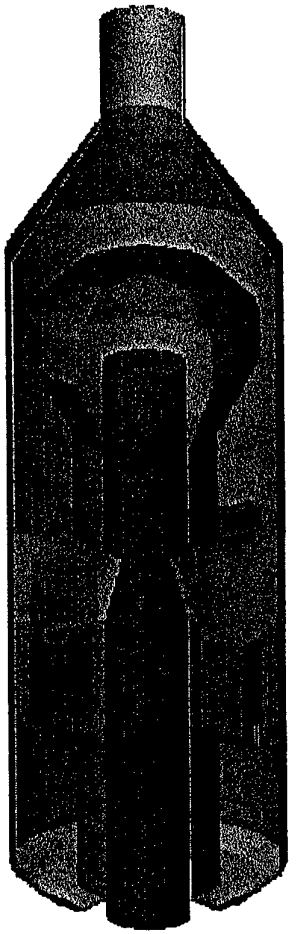

# Installation Sizes

Diameter

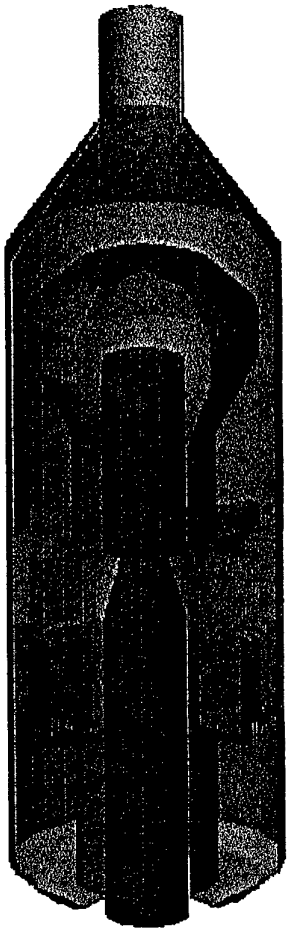



Height



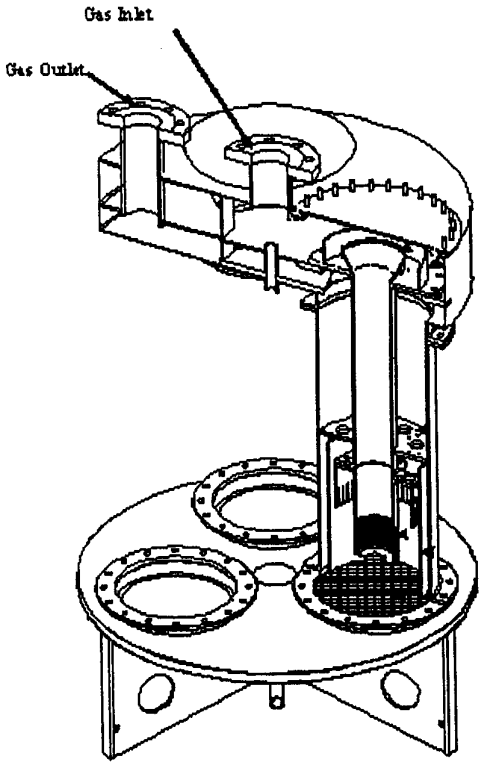



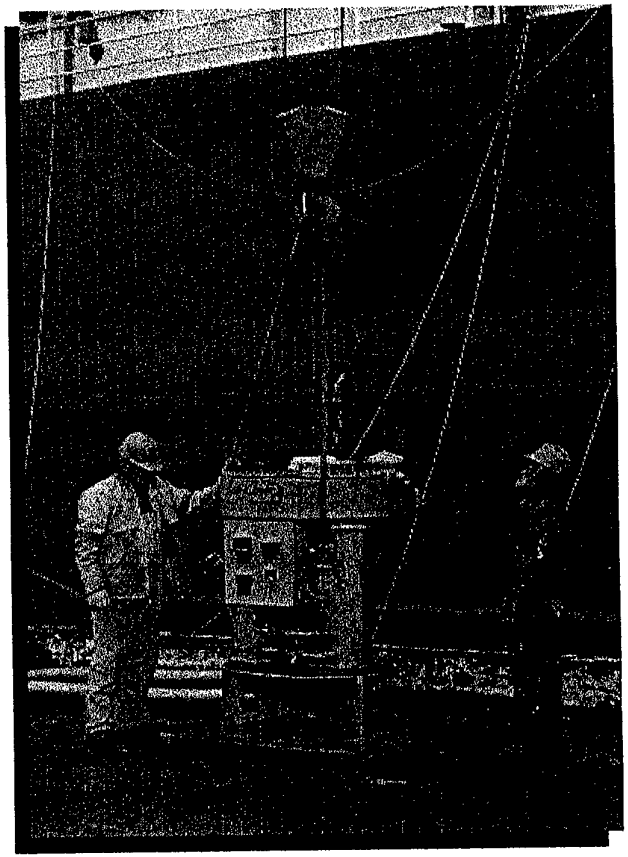
## MEL scrubber for 1100 kW Engine



- Diameter 1.1m
- Height 2.7m
- Built of Corrosion Resistent alloy
- Low back pressure
- Continuous flow-through system

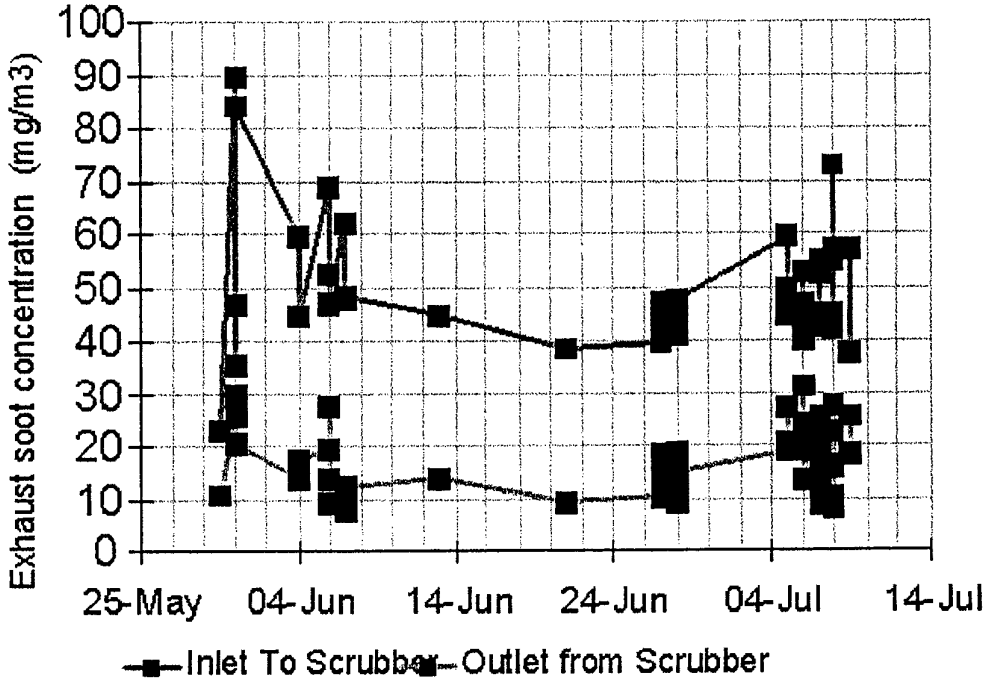
# Shipboard pilot plant of MEL scrubber



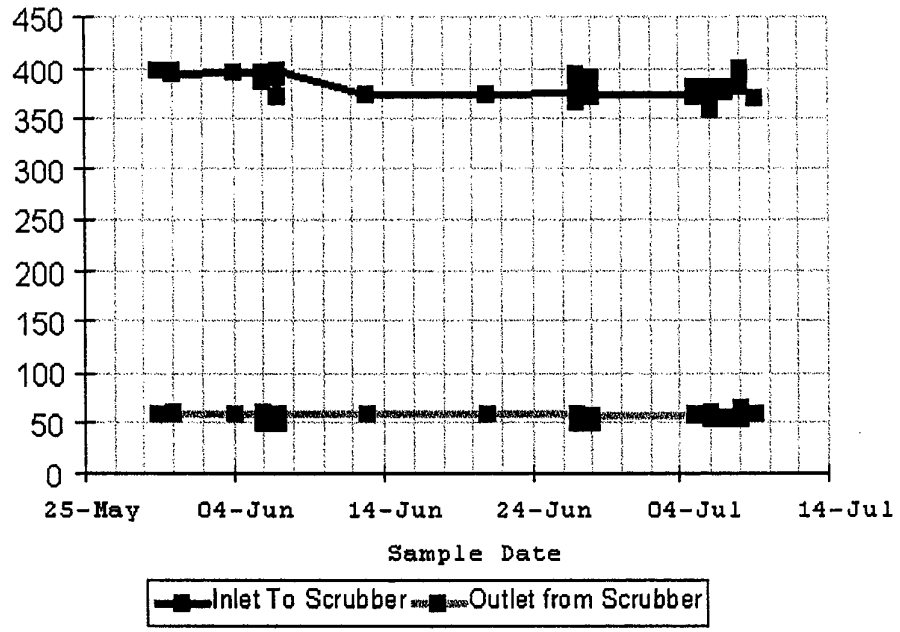



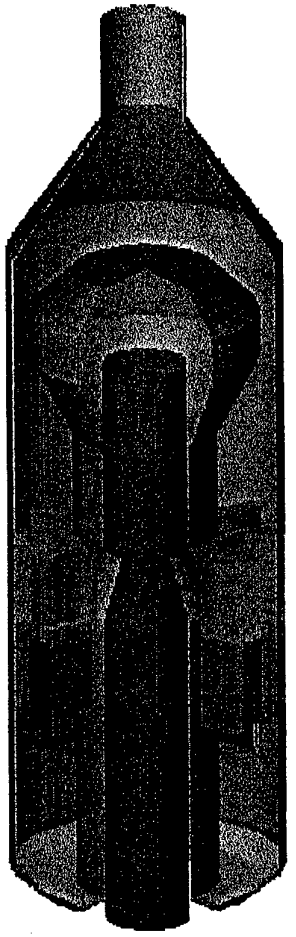
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# Time-series of Soot measurements

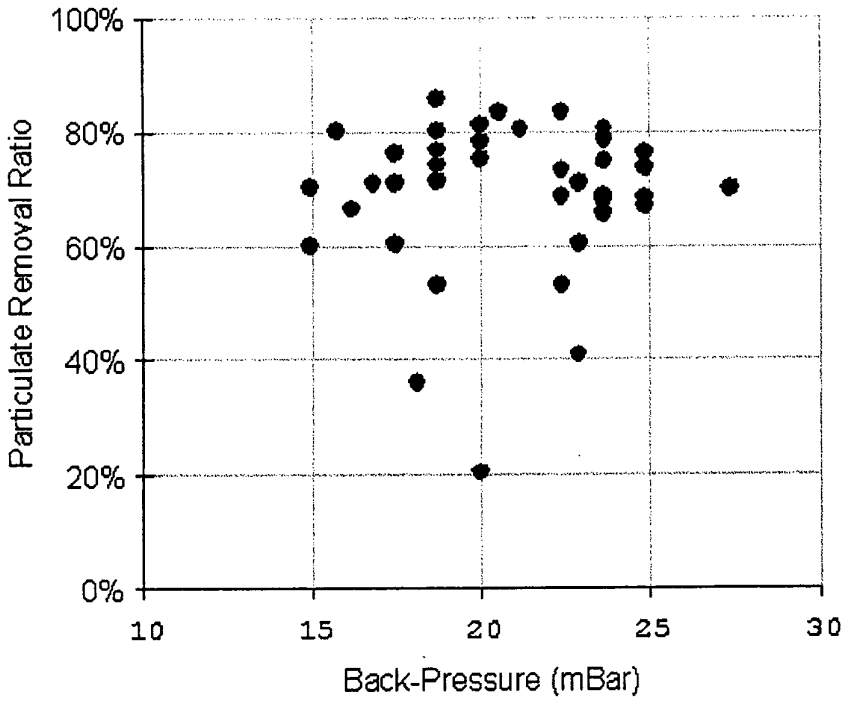


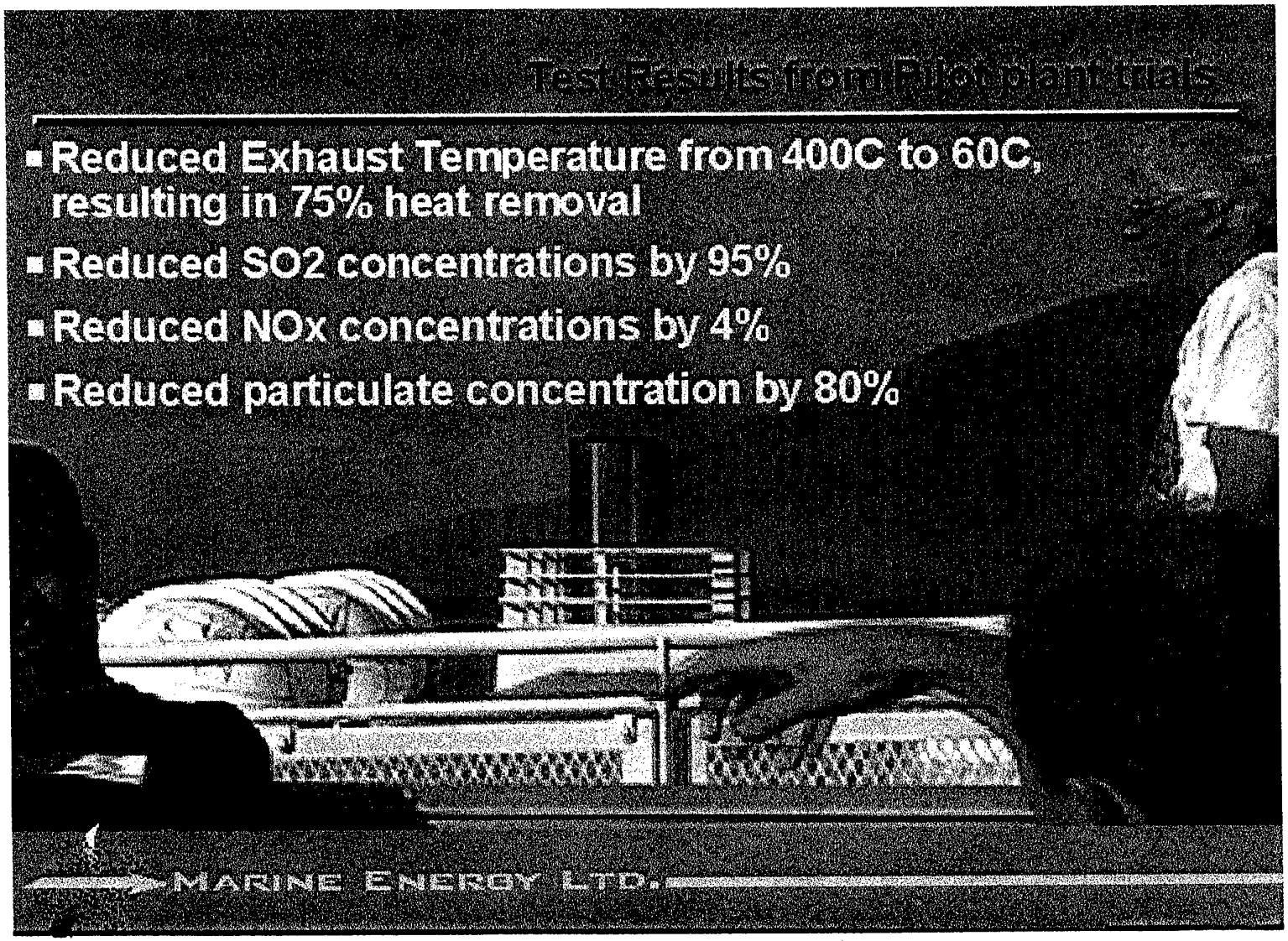
# Exhaust Temperatures



# Soot Removal versus Back Pressure




Test Results from Pilot plant trials
Reduced Exhaust Temperature from 400C to 60C, resulting in 75% heat removal
Reduced SO2 concentrations by 95%
Reduced NOx concentrations by 4%
Reduced particulate concentration by 80%
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## Summary

- Wet Scrubbers can provide a practical, cost-effective means to reduce $SO_2$ emissions and Diesel Particulate Matter
- Wet Scrubbers can be built with sufficiently low back-pressure for large marine diesels, and which do not require oceans of water supply



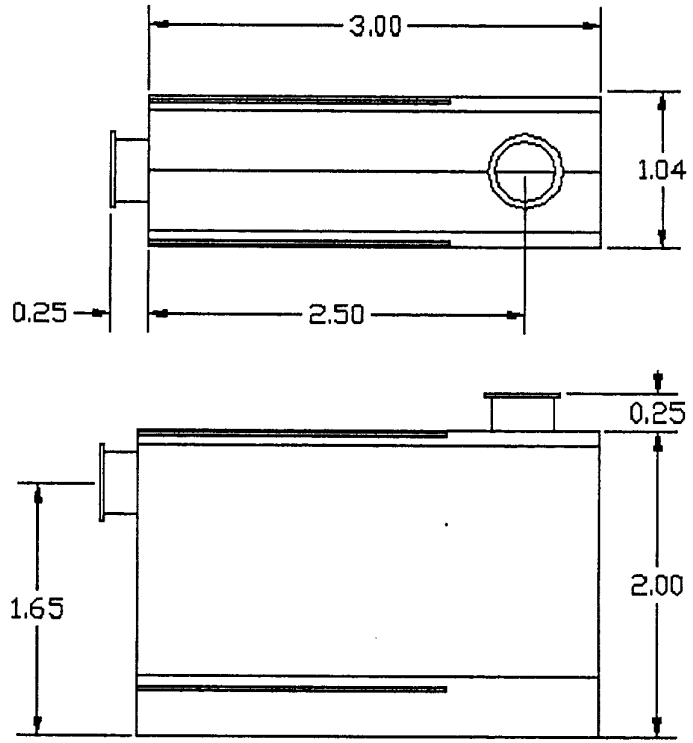
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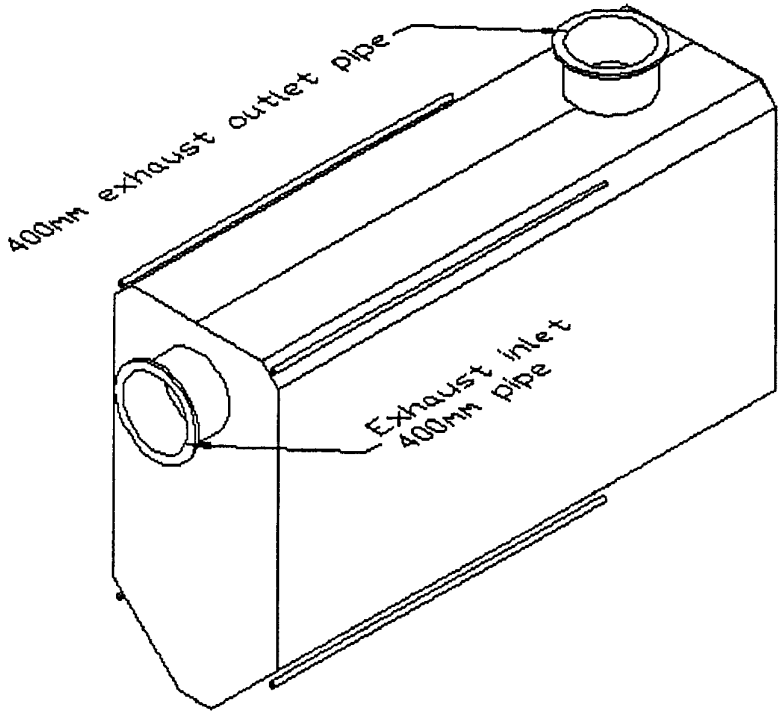
# The CCGS John P. Tully



- Oceanographic Research vessel
- Based Near Vancouver, BC
- Two geared 1125kW Deutz Diesel mains
- Three 470kW Gensets
- Launched 1985

# 1100 kW Horizontal-Format Scrubber




MARINE ENERGY LTD.

# Exhaust Gas Aftertreatment Systems Onboard Seagoing Vessels

**Dipl. Ing. Herbert Römich, Dr. Michael Joisten, Dipl. Ing. Sebastian Eidloth,**
**Siemens AG, GE**

## Abstract

The Selective Catalytic Reduction (SCR) has been a proven technology since many years in the field of the NOx reduction and it was originally developed due to the necessities of power plants to be retrofitted according to the emissions limits of the eighties laws. Since 1986 Siemens equipped more than 150 coal and oil fired boilers with its catalytic systems.

After good experiences with the integration of the SCR-technology, the Siemens' research has been continued to develop new application fields. In this way the new SINOx catalysts were installed in wood-fired boilers, incineration plants, stationary diesel engines, vessels and commercial vehicles, for industrial processes and in numerous others applications.

Since 1995 Siemens has been successfully operating in the marine sector, installing systems for seagoing vessels. Our references in this field include in the meantime more than 60 marine diesel engines with a total power of 200 MW approximately.

Due to the current legislation, the SCR application in the Baltic Area is at the moment quite limited. Nevertheless we are sure that in the future the requirements of exhaust gas treatments for marine propulsion will spread out enormously the SCR technology both in Europe and worldwide.

Session 4

Speaker Dr. Michael Joisten

MICHAEL JOISTEN is sales manager for catalytic NOx-abatement plants and catalysts.
Dr. Joisten studied chemistry at the RWTH Aachen. His PHD work was related to catalytic production of liquid fuels from synthesis gas. He joined the catalytic converter division of Siemens in 1991, starting with research and development of oxidation catalysts for the reduction of VOC emissions. At present Dr. Joisten's main task is the sale of SINOx plants especially for special applications like boilers or for the chemical industry. Furthermore, he is responsible for sales activities for VOC oxidation catalysts and dioxin abatement.

# "Exhaust Gas Aftertreatment Systems Onboard Seagoing Vessels"

## The Maritime Environment
## International Conference and Exhibition

**18th – 19th October 1999**
**Holiday Inn Brussels City Centre, Brussels, Belgium**

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2. SINOx System Operating Principle
3. SINOx Technology for Marine Applications
4. Sound Attenuation
5. References
6. Official Measurements
7. Summary



**Authors:**

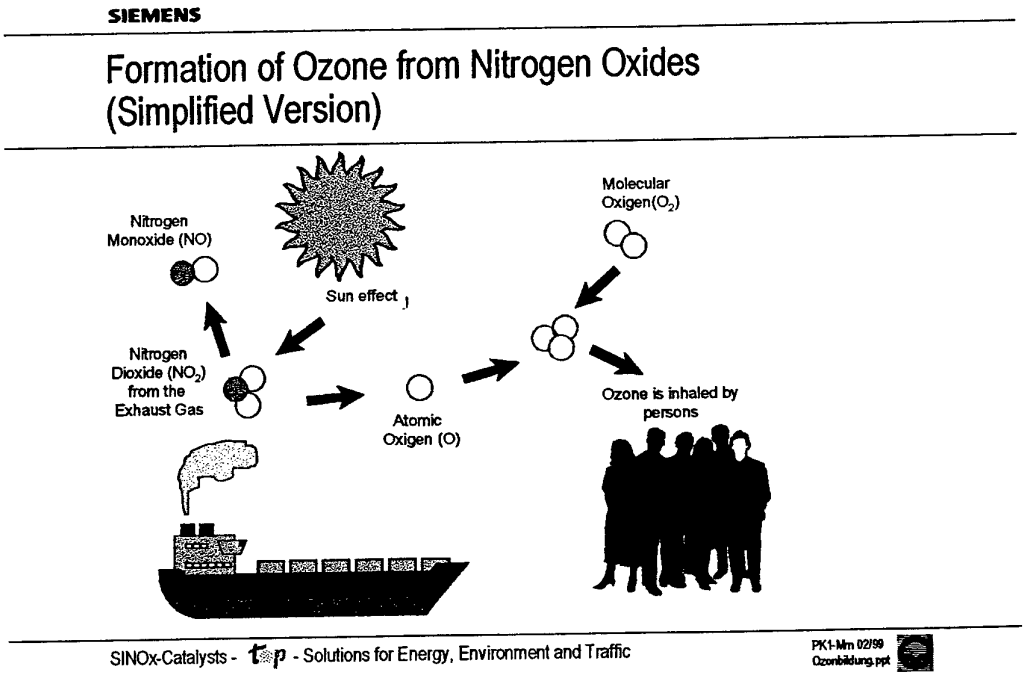
Dipl. Ing. Sebastian Eidloth
Dipl. Ing. Herbert Römich
Dr. Michael Joisten
Alessandra Silini

www.siemens-redwitz.de

## 1. Introduction

The problem of effective environmental solutions in the marine sector is gaining more and more importance in the last years, due to the high emissions coming from ships' stacks. Excepting a few cases, in which an exhaust gas aftertreatment is installed on board, all emissions produced by marine engines and incinerators flow directly in our atmosphere, without being cleaned before. However, the results and consequences for our environment appear some time later.

There are no official values at present, but it is assumed that the yearly consumption of fuel in the marine sector worldwide amounts to 110 up to 150 millions tons approximately. These values become plausible, if we consider that over 80.000 ships with more than 400 GRT are sailing through the world seas. In1996 just in the North and Baltic Sea, 790.000 tons of nitrogen oxides were emitted by ships into the atmosphere and finally, in form of rain, into the sea. This has caused, together with other influencing agents, a repeated prolification of algae as well as a lack of oxygen in the coastal regions and in the domestic seas during the summer months. In addition to this, ships emissions are also for a relevant part responsible for the phenomenon of acid rain and for the formation of ozone (Figure 1).




Compared to the country applications, the fuel used in the marine field has an extremely high sulphur content, which can amount up to 4.5% and more. Due to this fact, particularly in the North and Baltic Sea, 547,000 tons of sulphur dioxide ($SO_2$) have been emitted by ships into the atmosphere,

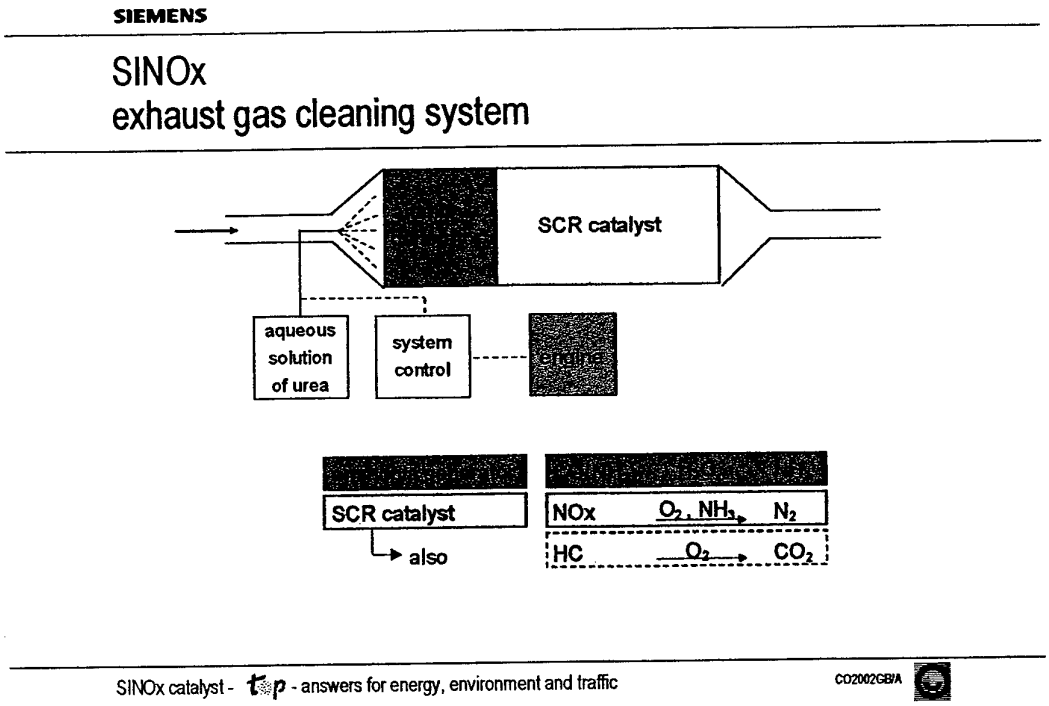
without having been filtered before. In the port areas the situation is even more drastic. According to the opinion of the environment authorities of Hamburg, ships are responsible for 80% of the $SO_2$ pollution produced by traffic means.

## 2. SINOx System Operating Principle

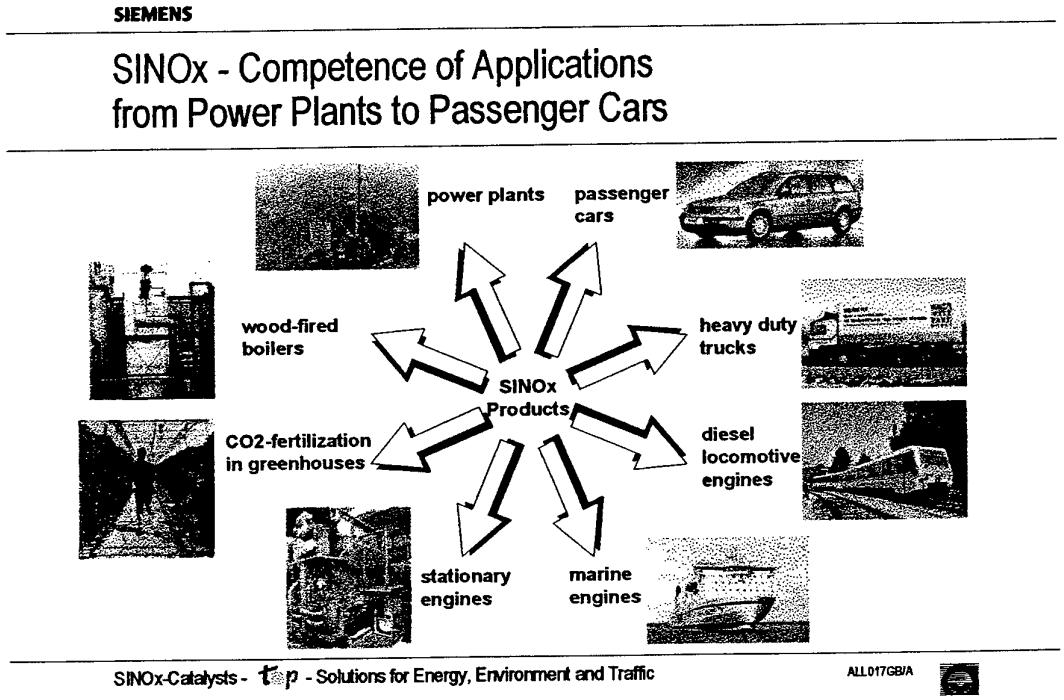
Different technologies are used to solve this problem, well known are the methods of water injection and the SCR technology. Using the water injection, it is possible to reduce NOx up to approx. 6 – 7 g/kWh, the SCR process, however, can reduce NOx to 2 g/kWh and lower. On the Birka Princess, for example, the NOx values measured after the SINOx system were 0.5 g/kWh. For this reason and considering further safety measures concerning the main engine, as well as the huge amount of fresh water which has to be daily produced, many ship owners have chosen to operate with the SCR technology.

The SINOx exhaust cleaning system consists primarily of the *catalytic converter*, the *control system* and the *dosing system* for the *reducing agent*. An aqueous solution of urea is added as the reducing agent instead of the ammonia which is used for example in coal-fired power plants. It is injected upstream the catalyst and it reacts with the nitrogen oxides reducing them to nitrogen and water. Urea offers the special feature of being completely trouble-free in handling, transportation and storage. Urea is also used as a fertilizer or as a feed supplement in agriculture. It is colorless, odorless, nonpoisonous and of no biological concern.

Important design factors are the exhaust gas temperature, amount and composition, and the required purity level of the cleaned gas. The control system ensures an optimum process control of the exhaust cleaning system and for a correct dosing of the reducing agent. A specially developed control algorithm enables completely automatic supply of the correct amount of aqueous urea solution in accordance with the current nitrogen oxide emission levels from the engine. Consumption of reducing agent is thus kept to a minimum and exhaust emissions are reliably reduced below the specified limits (Figure 2).

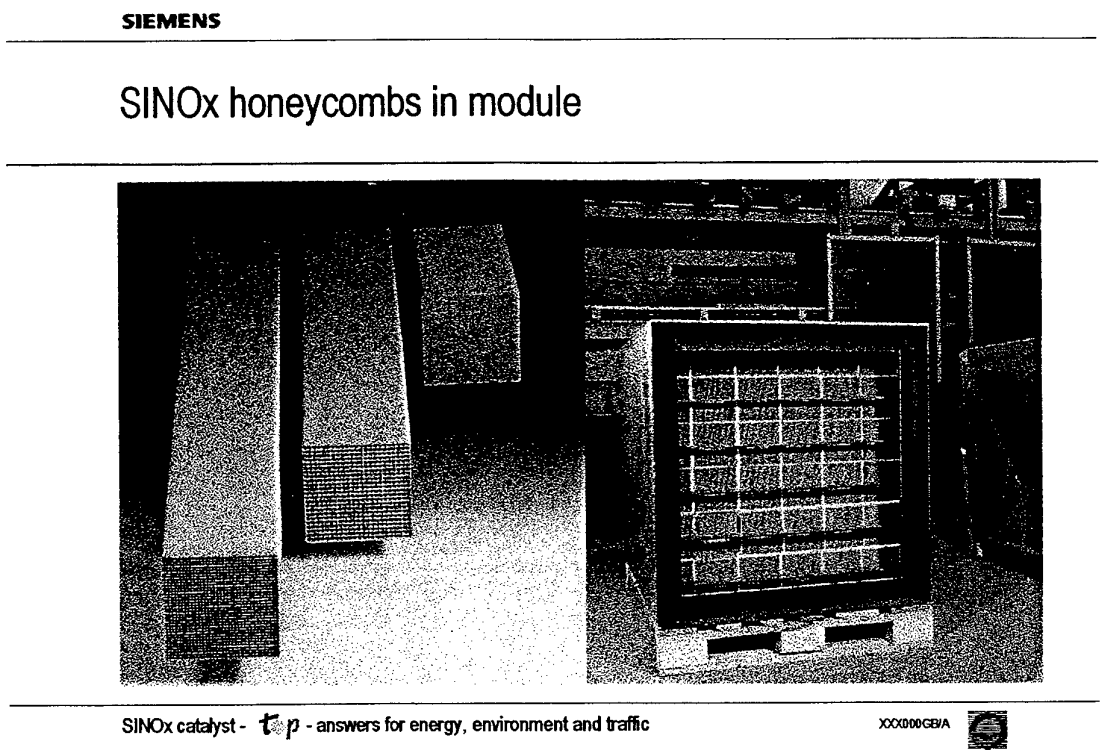



The catalytic converters are designed chemically and physically to suit the individual conditions in each application. SIEMENS' SINOx systems have been successfully applied in various fields, from big power plants to commercial vehicles. (Figure 3).



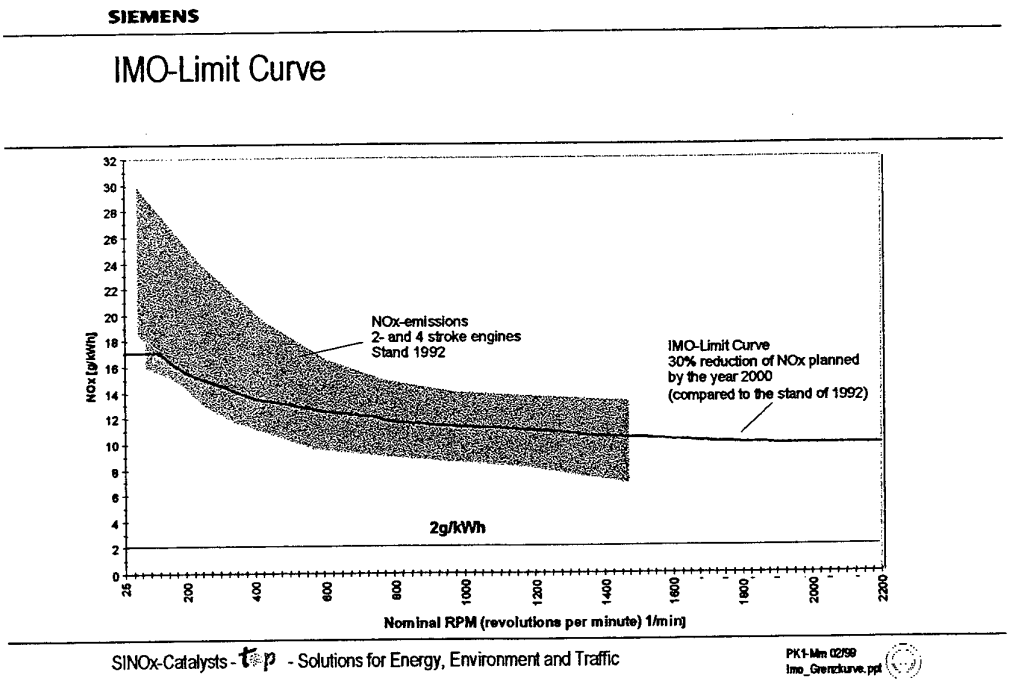

The central feature of the SINOx system is a fully ceramic, fine-celled honeycomb catalyst of titanium dioxide containing vanadium pentoxide as the active substance. The SINOx catalysts are

characterized by high catalytic activity, high selectivity and high resistance to erosion and to chemical elements like sulphur etc. They are also insensitive to particulate deposits as well as high mechanical and thermal loads. The honeycombs are packed in prefabricated modules made of steel and the single components can be replaced quickly and individually. (Fig. 4)




## 3. SINOx Technology for Marine Applications

While automobiles and power plants continue to become cleaner due to catalytic exhaust cleaning systems, ships have continued to date to emit uncleaned exhaust gas. The International Maritime Organization (IMO) has therefore set the goal of reducing nitrogen oxide emissions by 30%, based on 1992 values, by the year 2000. This project has received massive political support, especially in northern Europe. For example, ships with lower NOx emissions pay significantly lower port fees in Sweden. In fact, the Swedish Government imposed in 1998 requirements on the ferry traffic between the island of Gotland and the main land of Sweden demanding these operators to reduce the NOx emission from their ferries to a value of 2 g/kWh and lower. By this type of requirements and financial incentives in the shipping industry low emission will become a competitive factor in the future and will also face international regulations from IMO at the beginning of year 2000 (Fig. 5)




In 1995, foreign ship traffic in Sweden had increased to approximately 225,000 port entries and exits. There is a very heavy concentration in ferry traffic and in the ferry ports. In 1995, roughly 120 ferries in foreign traffic provided for approximately 170,000 movements of ships into and out of the ferry ports, approximately 75% of traffic. The dominating ferry ports are clearly Helsingborg, Malmö, Trellborg, Gothenberg and Stockholm. More than 80% of all ferries enter these five ports alone. Emissions are thus a local or regional problem. The situation can be compared to other European ferry ports, for example in Germany, Denmark, Norway and Finland.

Emissions are proportional to engine output and thus to the size of the ship. Large powerful night ferries with extensive hotel and restaurant activities cause significantly higher environmental impact than smaller day ferries.

A schematic picture of the traffic and environmental impact in the Swedish ports can thus be estimated. The result is that most of the environmental impact comes from traffic in the large ferry ports.

Shipping lane fees stipulated by Swedish parliament, adjusted to EU regulations and taking effect on January 1, 1998, are based on a two-part shipping fee system. The first part is based on the bulk carrying capacity of the ships (ship contribution) entering or departing Swedish ports to transport passengers or goods. The fees are levied on a maximum of twelve trips per calendar year for

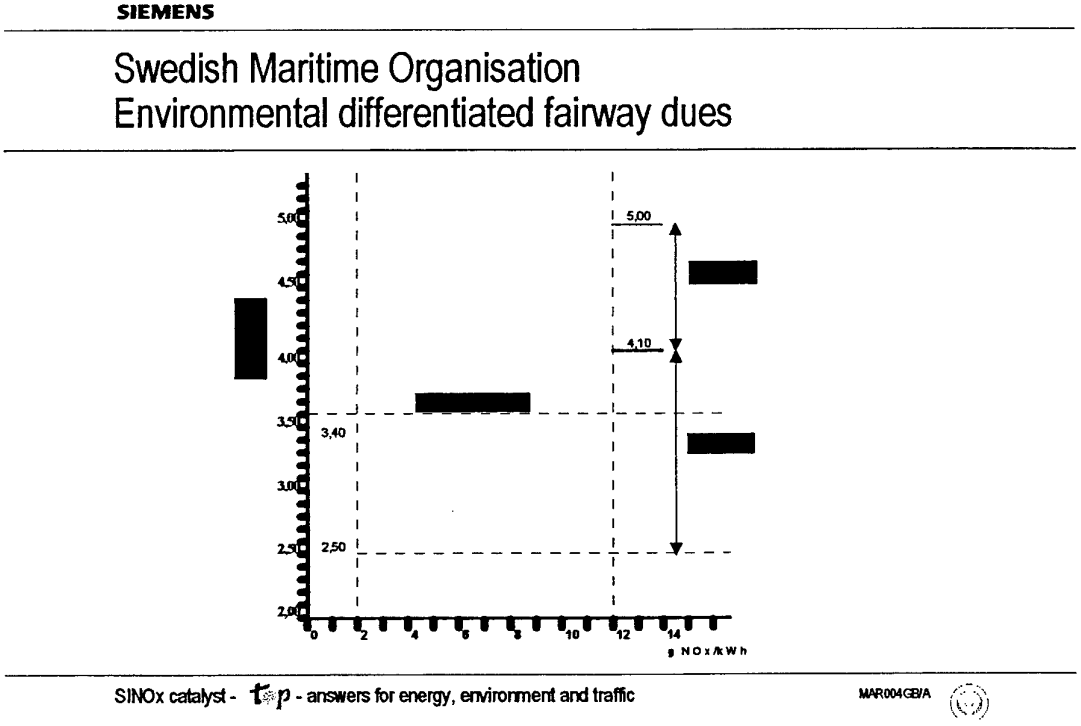
freighters. Passenger and rail ferries must pay the fee a maximum of eight times per calendar year. Some ships, including cruise ships, are exonerated from these fees under certain conditions.

The second part of the fee is based on the amount of nitrogen oxides emitted.

As can be seen in the schematic (Fig. 6), the regulation has two objectives:

1. Reduction of NOx from 12 g/kWh to 2 g/kWh, i.e. emissions are again significantly below the new IMO curve.

2. Reduction of $SO_2$ emissions.
   A level of < 1% sulfur in fuels for cargo vessels and < 0.5% for ferries is targeted.




After having explained the functions of our SINOx systems, we would like to give you further information concerning their performance, operation and running costs. These data have been calculated according to our experience of the systems working. For specific applications, however, the exact amounts have to be submitted in a quotation (Fig. 7)

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## SINOx SCR Figures

| | | |
|---|---|---|
| **Performance** | NOx Reduction | 90 - 99 % at MCR |
| | HC/CO Reduction | 80 - 90 % at MCR |
| | Soot Reduction | 30 - 40 % at MCR |
| | Noise Reduction | 30 - 35 dB(A) |
| **Operation** | Temperature Span | 250 - 530 C |
| | Fuel | MDO/HFO |
| **Consumables** | Urea Solution (40%) | 15 - 20 l/h (per MW) |
| | Catalyst Life Span | 5 - 7 years (depending on fuel quality) |
| **Cost for SINOx** | Investment Cost | 37 - 65 □/kW |
| | Operation Cost | 2,8 - 3,7 □/MWh |

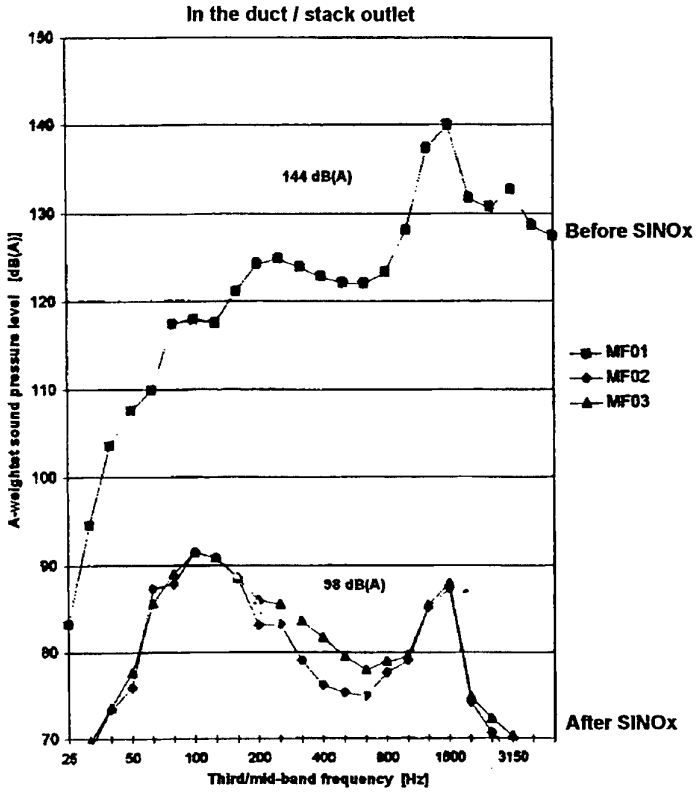
SINOx catalyst - top - answers for energy, environment and traffic MAR003GB/B

## 4. Sound Attenuation

Owing to their material composition, our catalysts have a particular suitability concerning the sound attenuation. According to the different frequency fields, they are able to reduce the sound up to 10 – 40 dB(A). In this way, the SINOx catalyst, installed with an engine specific silencer, guarantees a high sound attenuation. The following example shows the sound attenuation achieved at a high speed diesel engine (Fig. 8)

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# Sound Reduction

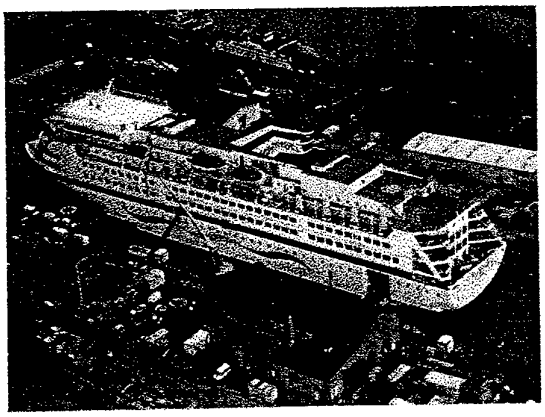



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## 5. References

Due to the Swedish government regulations in force, the demand of exhaust gas treatment systems has considerably increased, particularly for catalysts on vessels. Our reference list shows that the tendency of application of our SINOx catalysts is going to spread out in other ships categories as fast ferries and in the future also cruise ferries. In the following pictures are shown some of our references in the marine sector. (Fig. 9, 10,11,12)

# SINOx Marine System Birka Princess (S)
# SINOx for 4 x 4500 kW & 2 x 2250 kW Wärtsilä Engines



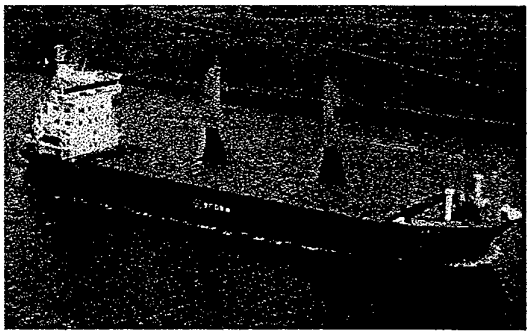
(all given data are typical per line)

| | |
|---|---|
| exhaust gas flow: | main engines 4 x 26000 Nm³/h |
| | aux. engines 2 x 14200 Nm³/h |
| temperature: | main engines 320°C |
| | aux. engines 305°C |
| NOx reduction: | < 2 g/kWh |
| urea consumption: | main engines 90 l/h |
| | aux. engines 53 l/h |
| catalysts: | main engines 3.09 m³ SW 35 |
| | aux. engines 1.89 m³ SW 35 |
| back pressure: | main engines 14 mbar |
| | aux. engines 15 mbar |
| fuel: | main engines HFO |
| | aux. engines MDO |

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# SINOx Marine System MS Cellus (S) for MaK 8M32 á 3840 kW and MAN 6L16/24 á 540 kW

(all given data are typical per line)



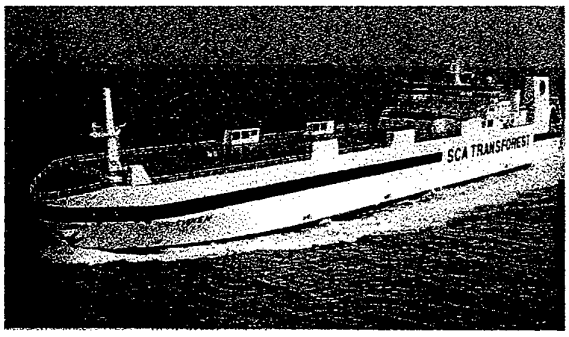
| | |
|---|---|
| exhaust gas flow: | main engine 21000 Nm³/h |
| | aux. engine 3000 Nm³/h |
| temperature: | main engine 300°C |
| | aux. engine 290°C |
| NOx reduction: | < 2 g/kWh |
| urea consumption: | main engine 66 l/h |
| | aux. engine 8 l/h |
| catalysts: | main engine 3 m³ SW 30 |
| | aux. engine 0.432 m³ SW 35 |
| back pressure: | 10 mbar |
| fuel: | main engine HFO 1%S |
| | aux. engine MDO |

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# SINOx Marine System MS Ortviken (S) SINOx for 2x MaK 6M552C á 4050 kW and 3x Mitsubishi S6R2 á 610 kW Engines

(all given data are typical per line)

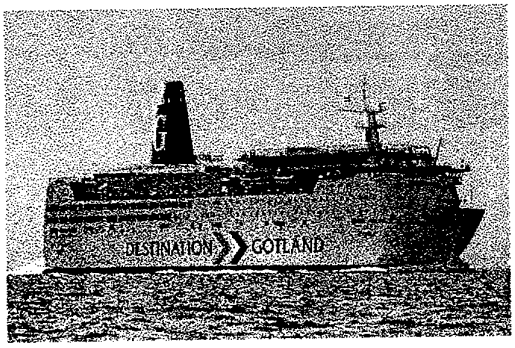



| | |
|---|---|
| exhaust gas flow: | main engines 2x 25500 Nm³/h |
| | aux. engines 3x 3200 Nm³/h |
| temperature: | main engines 340°C |
| | aux. engines 430°C |
| NOx reduction: | < 2 g/kWh |
| urea consumption: | main engines 85 l/h |
| | aux. engines 8 l/h |
| catalysts: | main engines 3.464 m³ SW 30 |
| | aux. engines 0.462 m³ SW 30 |
| back pressure: | 10 mbar |
| fuel: | main engines HFO |
| | aux. engines MDO |

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## SINOx Marine System Visby (S)
## for 4x B&W á 5200 kW and 3x WN 212V á 1435 kW




(all given data are typical per line)

| | |
|---|---|
| exhaust gas flow: | main engines 4x 37500 Nm³/h<br>aux. engines 3x 7500 Nm³/h |
| temperature: | main engines 363°C<br>aux. engines 350°C |
| NOx reduction: | < 2 g/kWh |
| urea consumption: | main engines 107 l/h<br>aux. engines 28 l/h |
| catalysts: | main engines 5.3 m³ SW 30<br>aux. engines 1 m³ SW 35 |
| back pressure: | main engines 17 mbar<br>aux. engines 13 mbar |
| fuel: | diesel/MDO |



## 6. Official Measurements

After each commissioning of a SINOx system, all NOx reduction results are registered in a specific report. In order to fulfil the requirements determined by the SMA (Swedish Marine Organisation), these values have to be measured by an official and independent institute as the GL, IVL or MTC. Two examples are shown in the following pictures:

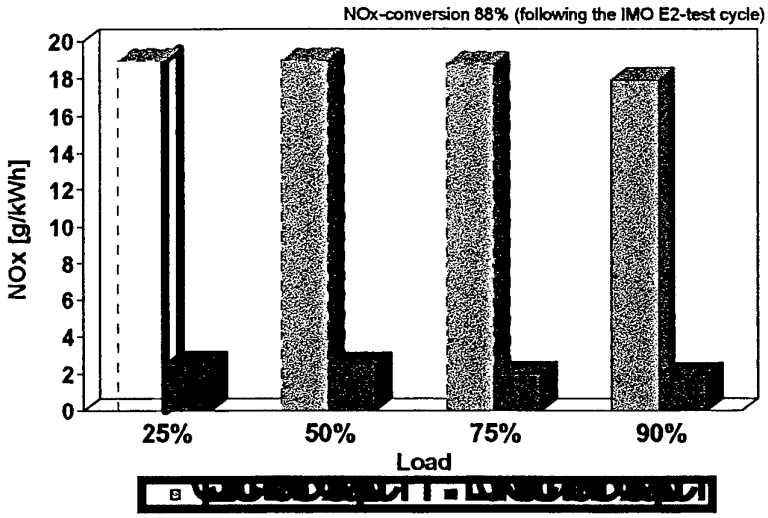
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### GL Official Measurements
### MS Cellus

| engine plant | make type | rated power [kW] | NOx at 75%load [g/kWh] |
|---|---|---|---|
| Main engine with SCR catalyst | MaK 8M32 Siemens SINOx | 3840 | 0.6 |
| Auxiliary engine with SCR catalyst | MAN B&W 6L16/24 Siemens SINOx | 540 | 0.2 |

**The ship´s weighted overall emission value for nitrogen oxides is 1.3 g/kWh NOx.**

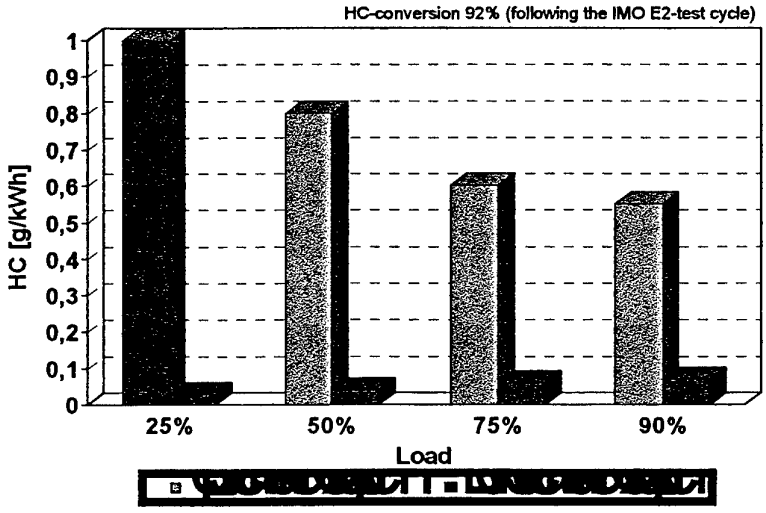
# NOx-Conversion as a Function of Load on Ship Engines MF Nils Dacke








# HC-Conversion as a Function of Load on Ship Engines MF Nils Dacke



## 7. Summary

? The installation of SINOx systems represents for shipping companies a solution of the diesel dilemma and guarantees to reach the emission limits fixed by the environmental authorities. In this way the ship owners can take advantages of the reduced harbour fees for "clean vessels".

? The SINOx systems are based on the SCR technology, which has been developed for power plants 20 years ago, and their application is now spreading out to different fields, particularly in the marine exhaust gas cleaning.

? A relevant advantage of the SINOx systems is their versatility: they are able to reduce different pollutants as NOx, hydrocarbons, soot and have also a sound attenuation effect. (Figure 16)

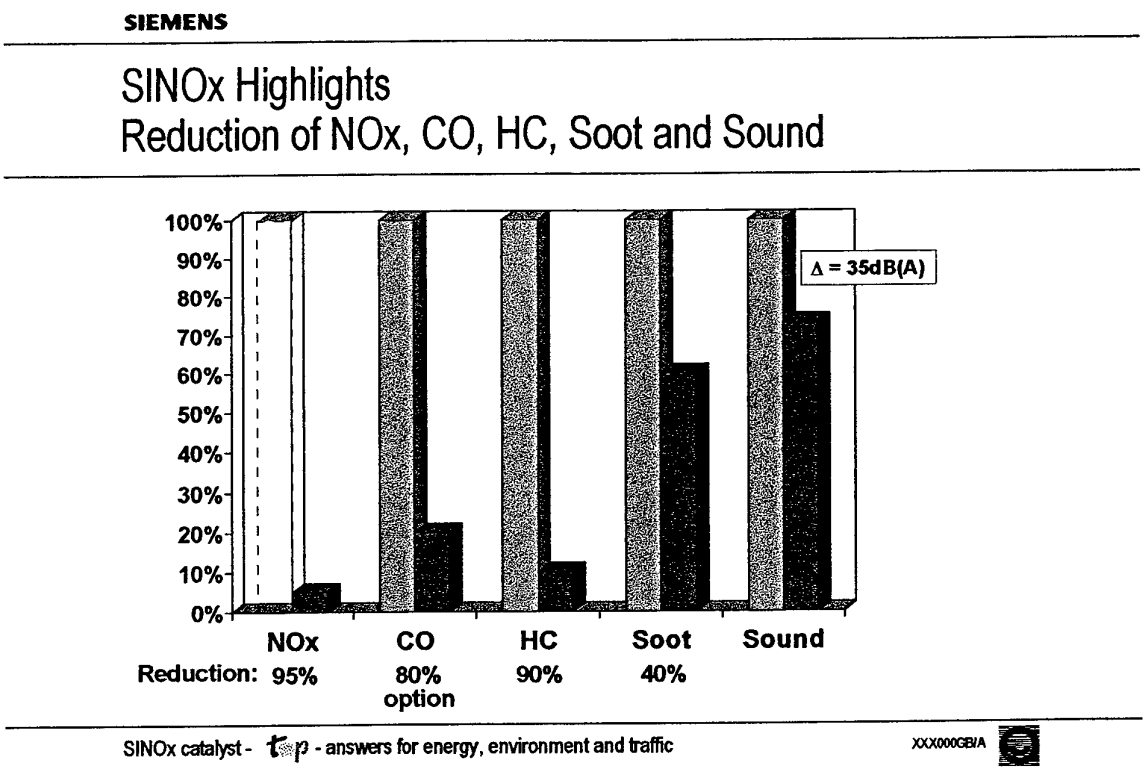



Figure 16

With a total SCR capacity of approximately 170 MW in the marine field, SIEMENS brings an effective and concrete contribute for our environment. At the moment, the already installed SINOx systems are able to reduce nitrogen oxides up to 1.7 t/h.

For the future, the market requirements will grow and spread out from offshore installations to catamarans and even cruise ferries.

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Maritime Conferences

# • The Maritime Environment •

## "Treatment Technologies for Gaseous Emissions from Ships"

## Supplement

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Maritime Conferences

# ·The Maritime Environment·

## Welcome to the conference

# Treatment Technologies for Gaseous Emissions from Ships"

## Conference Schedule

## The Conference is sponsered by:




**18th – 19th October 1999**
**Holiday Inn Brussels City Centre, Brussels, Belgium**

## Monday, 18th October 1999

09.00 - 10.00 **Check in and Welcome Coffee**

10.00 Welcome by the Conference Organiser

10.10 Keynote Address **"Expert Networking in NATO"**
***Dr. Keith L. Gardner,***
Deputy Assistant Secretary General for Scientific and Environmental Affairs, NATO

**Session 1** **Requirements and Policies for the Reduction of Air Pollution from Ships**

10.30 - 11.10 **Air Pollution and the EROS demand for Shipping**
**"To be reduced and how to be reduced"**
**Global, EU wide, Regional, National and Local**
Session Chairman ***Capt. Cornelius De Keyzer,*** Rotterdam Port Management, NL

11.10 - 11.50 **IMO – Annex VI of Marpol**
***Klaas Jan Bolt,*** Ministry of Transport and Public Works, NL

11.50 - 12.30 **Certification of Marine Diesel Engines and Ships according to the new IMO-NOx-Requirements**
***Dr. Hans J. Gätjens,*** Germanischer Lloyd, GE

12.30 - 14.00 **Lunch**

14.00 - 14.30 **The View of the International Harbour Master's Association on Atmospheric Pollution caused by Ships related to Port Operations**
***Capt. Jaap Lems,*** Chairman IHMA's Environmental Working Group, NL

14.30 - 15.00 **Discussion Session 1**

**Session 2** **Emissions from Thermal Waste Treatment Processes**
**-Treatment Technologies and Alternatives-**

15.00 - 15.30 **Pulsed Corona Plasma Treatment of Gaseous Pollutants in the Flue-Gas from Waste Incinerators**
Session Chairwoman ***Dr. Fiona Winterbottom,*** AEA Technology, UK

15.30 - 16.00 **Non-Thermal Plasma for Marine Diesels**
***Lt Cdr. Glenn E. Walters,*** Ship Support Agency, MOD, UK

16.00 - 16.30 **Coffee break**

16.30 - 17.10 **Treatment of Off-Gas, VOC and Odor Emissions from Ships and other Point Sources Using Biotreatment Systems**
***William J. Guarini,*** Envirogen Inc., US

17.10 - 17.30 **Discussion Session 2**

17.30 - 19.00 **Reception**

## Tuesday, 19th October 1999

**Session 3** **Reducing Ozone Depleting Substances and other Greenhouse Gases -Impact of the Implementation of the Montreal Protocol and the Kyoto Protocol on the Maritime Industry-**

09.00 - 09.30 **Development of Refrigeration Agents from R12 to Halogen Free Substances**
Session Chairman ***Dipl.-Ing. Volker Behrens,*** NOSKE-KAESER GmbH, GE

09.30 - 10.00 **Navy Ozone Depleting Substances (ODS) Policy**
***Joel Krinsky,*** NAVSEA, USN

10.00 - 10.20 **Discussion Session 3**

10.20 - 10.40 **Coffee break**

**Session 4** **Exhaust Gases from Engines and Power Generators -Treatment Technologies and Alternatives-**

10.40 - 11.20 **Environmentally Friendly Propulsion Systems**
Session Chairman ***Peter Sunn Pedersen,*** MAN B&W Diesel A/S, SE
*Ola Ruch,* Statoil, NO

11.20 - 12.10 **Development of Future Emission Reduction Technologies**
***Dipl.-Ing. Bert Buchholz,*** MET GmbH, GE

12.10 - 13.10 **Lunch**

13.10 - 13.45 **The H.A.M. Concept (Humid Air Motor)**
**- A Novel Way to Reduce NOx**
***Jan Wettergård/***
***Lars-O. Olsson,*** Munters Euroform GmbH, SE

13.45 - 14.10 **The H.A.M. Concept (Humid Air Motor)**
**-Experience from Field Tests on a 6 MW Pielstick Engine**
***Emmanuel Riom,*** S.E.M.T. Pielstick, FR

14.10 - 14.45 **Design and Testing of a Bubble-Scrubber for SOx and Particulate from Marine Engines and Incinerators**
***Dr. Andrew Trivett,*** Marine Energy Ltd., CA

14.45 - 15.20 **Exhaust Gas After-treatment Systems Onboard Seagoing Vessels**
***Dr. Michael Joisten,*** Siemens AG, GE

15.20 - 15.40 **Discussion Session 4**

15.40 **Summary and Conclusions**

SCHEDULE.DOC

# *Participants in the Conference "Treatment Technologies for Gaseous Emissions from Ships"*

***October, 18th - 19th 1999, Brussels / Belgium***

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# Future Conference Programme

**15th – 17th March 2000** **Fresh Water Production and Waste Water Treatment Technologies for Ships and Islands**
*Genoa, IT*

The conference shall provide a forum for discussion and exchange of information on the latest technologies and equipment for the production of fresh water, purification of potable water and the treatment of polluted water for reuse or discharge into the sea aboard ships and on islands without natural fresh water resources.

**28th – 30th June 2000** **Ships Waste – Management and Treatment in Ports and Shipyards**
*Bremerhaven, GE*

The conference shall provide a forum for discussion and exchange of information on the regulations, technologies and equipment pertaining to the environmentally compliant handling and treatment of ships and cargo waste in ports and shipyards.

**12th - 13th September 2000** **Hazardous Waste on Ships – Reduction, Control, Treatment and Replacement of Hazardous Substances**
*Southampton, UK*

The conference shall provide a forum for discussion and exchange of information on policies, regulations, technologies and equipment for the reduction, control, treatment and replacement of hazardous substances aboard ships.

**March 2001** **Environmentally Sound Ship Design for Navies, Coast Guards and Government Vessels**

The conference shall provide a forum for discussion and exchange of information on ship design principles, technologies and equipment for Navies, Coast Guards and Government Vessels in order to be compliant with international regulations for the protection of the maritime environment

**June 2001** **Thermal Waste Treatment Technologies for Shipboard Use**

The conference shall provide a forum for discussion and exchange of information on advanced incineration technologies, plasma treatment, and other oxidation technologies, and future research and industrial goals for the development of thermal waste treatment equipment for shipboard applications.

**September 2001** **Dredging of Ports – Environmental Treatment of Dredge Material for Discharge**

The conference shall provide a forum for discussion and exchange of information on regulations, mechanical, biological and chemical processes, technologies and systems for the environmentally compliant dredging of polluted ports and river beds and the environmentally sound transportation, preparation and treatment of the dredge material for discharge

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