INTERNATIONAL MARITIME ORGANIZATION

IMO

E

MARINE ENVIRONMENT PROTECTION COMMITTEE
53rd session
Agenda item 4

MEPC 53/4/4
15 April 2005
Original: ENGLISH

# PREVENTION OF AIR POLLUTION FROM SHIPS

## MARPOL Annex VI - Proposal to initiate a revision process

**Submitted by Finland, Germany, Italy, the Netherlands, Norway, Sweden and the United Kingdom**

| SUMMARY | |
|---|---|
| ***Executive summary:*** | This document calls upon the Committee to initiate a process to explore what amendments to MARPOL Annex VI may be appropriate to further reduce the adverse impact of diesel engine emissions on human health and environment. The annex to this document presents information on estimates of emissions from ships, their effects on human health and the environment, and technologies for control of emissions. |
| ***Action to be taken:*** | Paragraph 13 |
| ***Related documents:*** | MP/CONF.3/35, MEPC 44/11/7 |

**Background**

1 On 26 September 1997, the Parties to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78) adopted a new Annex VI to the Convention, Regulations for the Prevention of Air Pollution from Ships (1997 Protocol). Annex VI contains several important provisions to address air emissions from ships and provides an important tool to help reduce the adverse impacts of international shipping transportation on the global and local environments.

2 Regulation 13 of the 1997 Protocol contains limits for emissions of nitrogen oxides ($NO_x$) from marine diesel engines. According to Regulation 13, the $NO_x$ emissions of any diesel engine with a power output of more than 130 kW installed on a ship constructed on or after 1 January 2000, or that undergoes a major conversion on or after that date, shall not exceed the following limits:

| | | |
|---|---|---|
| (i) | 17 g/kW-hr | when *n* is less than 130 rpm |
| (ii) | $45.0*n^{(-0.2)}$ g/kW-hr | when *n* is 130 or more but less than 2,000 rpm |
| (iii) | 9.8 g/kW-hr | when *n* is 2,000 rpm or more |

where *n* is rated engine speed (crankshaft revolutions per minute).

3 Annex VI also contains limits for the sulphur content of marine fuel oil. According to Regulation 14, the sulphur content of any fuel oil used on board ships shall not exceed 4.5% m/m. For $SO_x$ Emission Control Areas (SECAs), this limit is reduced to 1.5% m/m.

4 The 1997 Air Pollution Conference was a historical response by the IMO to address air emissions from ships and their contribution to air pollution and other environmental problems. Especially the control of emissions of nitrogen oxides ($NO_x$) and sulphur oxides ($SO_x$) were subject of extensive discussion at the IMO prior to and during the Air Pollution Conference. At the 1997 Conference many delegations already recognized that the $NO_x$ emission limits established in Regulation 13 were very modest when compared with current technology developments. As a result, the Diplomatic Conference invited the Committee to review the $NO_x$ emission limits at a minimum of five-year intervals after entry into force of the 1997 Protocol and, if appropriate, amend the $NO_x$ limits to reflect more stringent controls. It is also observed that some air emissions from shipping, such as particulate matters (PM), are not addressed in the annex.

**Developments since 1997**

5 The contribution of ship emissions to air quality problems in many areas of the world is growing, and numerous governments are now considering how to better address ship and other port emissions at the local, national, and international level. Since 1997 many governments have further tightened standards applicable to on-road and off-road engines as well as fuel quality standards. In addition, particulate matter (PM) generated by diesel engines is an area of increasing concern as it impacts human health. The annex to this document presents information on the human health and environmental effects caused by emissions from marine diesel engines. Furthermore, information on the contribution of marine diesel engines to global pollutant inventories is presented.

6 Even though the entry into force date of Annex VI is 19 May 2005, engine manufacturers have been complying with the Regulation 13 $NO_x$ standards since January 2000 by producing marine engines that meet the standards adopted in 1997. To demonstrate compliance, Member States are issuing Statements of Compliance, as recommended by MEPC in MEPC/Circ.334 (19 November 1998), Interim Guidelines for the Application of the $NO_x$ Technical Code. These Statements are issued based on the same certification procedure that will be used after the annex goes into force in May 2005. Most, if not all, vessels built since 1 January 2000 have compliant engines.

7 It is widely acknowledged by marine engine manufacturers that different technology improvements now exist that will enable significant improvement over the existing standards found in Annex VI. Leading manufacturers have also revealed that significant emission improvements can be achieved in engines made before the year 2000 through valve upgrades and other procedures that are feasible through routine maintenance of the engines.

8 Encouraged by these developments and taking into account the adverse effect of marine diesel engine emissions, the submitting Member States recommend that the Committee initiate discussions at exploring what reductions may be feasible in light of developments since 1997. While Resolution 3 invites the Committee to review the limits five years after the entry into force of the annex, it is critical for discussions to begin now at the IMO if we want emission standards to be developed at the global level. Discussions are taking place within some governments to further reduce air emissions from ships. However, it is widely recognized that further discussion and action at the IMO is the most desirable and efficient mechanism for achieving further reductions that are harmonized at the global level.

9 The long lives of vessels with marine diesel engines means that the emission benefits associated with new standards take a long time to achieve their full effect. Because fleet turnover is so slow, it is important to consider more stringent emission limits for new engines as soon as possible. Five years have now passed since 1 January 2000 when new marine engines began compliance with the Annex VI standards. Moreover, progress in the development of emission control technologies, e.g. as presented in the annex to this document, suggests that it is appropriate for the Committee to investigate future emission control options.

**Conclusions**

10 It is the opinion of the Sponsors of this document that the most appropriate vehicle for addressing further improvements in air emissions from ships is through further action at the IMO. MARPOL Annex VI is the only global regime that directly addresses air emissions from ships. Numerous countries have now ratified the Annex or adopted national standards that parallel those in Annex VI. Many other governments are likely to soon ratify Annex VI and it is important that the IMO continues to move forward to explore possible amendments to the Annex since there is a major gap between the known human health and environmental effects of emissions from marine diesel engines, the corresponding regulations in Annex VI, and technologies now available to combat emissions.

11 In light of the observations noted above as well as the information in the annex to this document, the sponsors of this document recommend that the Committee begins a process to investigate how Annex VI could be updated to better respond to the present and future environmental challenges and technology developments. Specifically, the Committee should consider terms of reference for the current working group on air emissions to ships. The terms of reference may include consideration of what actions may be appropriate in addressing $NO_x$, improved fuel quality, $SO_x$ and particulate matter.

12 Members of the Committee should also be encouraged to draw attention to any issues that have arisen in recent efforts to prepare for implementation of the annex. The terms of reference should also include consideration of issues related to implementation of the annex that may require further clarification.

**Action requested of the Committee**

13 The Committee is invited to consider the above views and decide as appropriate.

***

# ANNEX

1 Although the shipping industry is considered to be environmentally friendly compared to other modes of transport, the information below shows why it is indicated that the shipping sector nevertheless should keep on taking the responsibility for its share of air pollution.

**Health and environmental effects associated with marine diesel engines: $NO_x$ and $SO_2$ emissions**

2 $NO_x$ emissions from marine diesel engines are of concern to the international community because these emissions contribute to ground level ozone and particulate matter as well as other environmental effects such as eutrofication, acid deposition, and nitrification. In addition, $NO_x$ and $SO_2$ react (with water, oxygen and oxidants) in the atmosphere to form acid rain. Furthermore, as pointed out in the IMO study of Greenhouse Gas Emissions from ships (pages 53-68), the indirect effect of $NO_x$ emissions to global warming should be noted.

**Acid Deposition**

3 Acid deposition, or acid rain as it is commonly known, occurs when $SO_2$ and $NO_x$ react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds that later fall to earth in the form of precipitation or dry deposition of acidic particles. It contributes to damage of trees at high elevations and in some regions lakes and streams may become so acidic that they cannot support aquatic life. In addition, acid deposition accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our collective cultural heritage.

4 Acid deposition primarily affects bodies of water where the soil has limited ability to neutralize acidic compounds. In the United States, for example, the National Surface Water Survey (NSWS) investigated the effects of acidic deposition in over 1,000 lakes larger than 10 acres and in thousands of miles of streams. It found that acid deposition was the primary cause of acidity in 75 per cent of the acidic lakes and about 50 per cent of the acidic streams. Hundreds of lakes have acidity levels incompatible with the survival of sensitive fish species. Acid deposition also has been implicated in contributing to degradation of high-elevation spruce forests.

**Eutrofication and Nitrification**

5 Deposition of nitrogen from marine diesel engines contributes to elevated nitrogen levels in water bodies. Increased nitrogen loading in water bodies, particularly coastal estuaries, upsets the chemical balance of nutrients used by aquatic plants and animals. Additional nitrogen accelerates "eutrophication," which is the accelerated production of organic matter, particularly algae, in a water body. This increased growth can cause numerous adverse ecological effects and economic impacts, including nuisance algal blooms, dieback of underwater plants due to reduced light penetration, and toxic plankton blooms. Algal and plankton blooms can also reduce the level of dissolved oxygen, which can reduce fish and shellfish populations. Eutrophication is of particular concern in coastal areas with poor or stratified circulation patterns. In such areas, the "overproduced" algae tends to sink to the bottom and decay, using all or most of the available oxygen and thereby reducing or eliminating populations of bottom-feeder fish and shellfish, distorting the normal population balance between different aquatic organisms, and in extreme cases causing dramatic fish kills.

6 Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation's fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation.

**Ozone**

7 Ground level ozone is formed when hydrocarbons and oxides of nitrogen ($NO_x$) react in the presence of sunlight. Exposure to ambient ozone contributes to a wide range of adverse health effects. Effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased medication usage, inflammation of the lungs, as well as a variety of other respiratory effects. People who are particularly at risk for high ozone exposures include healthy children and adults who are active outdoors. People with higher risks include children, people with respiratory disease, such as asthma, and people with unusual sensitivity to ozone. The effects of ground level ozone was experienced during the European heat wave in 2003, and the consequences were severe.

8 Based on a large number of scientific studies, the scientific community has identified several key health effects caused when people are exposed to levels of ozone found today in many areas of the world. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to higher ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate pre-existing respiratory diseases, such as asthma. It also can cause inflammation of the lung, impairment of lung defence mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses, such as emphysema and chronic bronchitis.

9 Beyond its human health effects, ozone has been shown to injure plants, which has the effect of reducing crop yields and productivity in forests, as well as damaging ecosystems. In addition it leads to ageing of different types of paints, plastic, natural and synthetic rubber, tyres etc.

**Global warming**

10 The IMO Study of Greenhouse Gas Emissions from ships describes the indirect effect of $NO_x$ emissions to global warming. The study states that in addition to $CO_2$, ozone is considered an important greenhouse gas. Ships do not directly produce ozone during engine combustion, but they do emit ozone precursors, $NO_x$ and VOCs. Ozone's global warming potential occurs because it absorbs both incoming solar radiation in the ultraviolet and visible regions and terrestrially emitted infrared radiation in certain wavelengths. Stratospheric ozone absorbs more energy than it re-radiates, acting as a net source of warming, although it exerts both heating and cooling influences. For ozone in the troposphere, however, both direct solar absorption and infrared trapping warm the surface-troposphere system. Ozone resulting from ship emissions – as the $NO_x$ from ships reacts with ship-based and biogenic ocean/coastal VOCs, or mix with land-based emissions and react – would contribute directly to the warming in the surface-troposphere system. Further research on the potential of the indirect contribution to global warming from ships' $NO_x$ emissions is needed, but it is estimated to in the magnitude to that of the total GHG emissions from shipping.

**Health and environmental effects associated with marine diesel engines: particulate matter emissions and diesel engine exhaust**

11 Marine diesel engines contribute to ambient levels of particulate matter through direct emissions of particulate matter. These engines currently emit high levels of $NO_x$ and $SO_2$ which react in the atmosphere to form fine particles secondarily (namely ammonium nitrate and sulphates). In addition to its contribution to ambient PM, diesel exhaust is of specific concern because it has been judged to pose a lung cancer hazard for humans as well as elevating the risk of non-cancer respiratory ailments. The adverse health effects in humans together with the potential for significant environmental risks suggest that emissions from marine diesel engines should be further reduced to protect human health and the environment.

**Particulate Matter**

12 Particulate matter represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. $PM_{10}$ refers to particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers. Larger particles (>10 microns) tend to be removed by the respiratory clearance mechanisms whereas smaller particles ($PM_{10}$) are deposited deeper in the lungs. Fine particles can be generally defined as those particles with an aerodynamic diameter of 2.5 microns or less (also known as $PM_{2.5}$), and coarse fraction particles are those particles with an aerodynamic diameter greater than 2.5 microns, but equal to or less than a nominal 10 microns. Diesel particles are principally in the fine fraction.

13 Particulate matter has been linked to a range of serious respiratory and cardiac health problems. Scientific studies suggest a likely causal role of ambient particulate matter in contributing to a series of health effects. The key health effects categories associated with ambient particulate matter include premature mortality, aggravation of respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits, school absences, work loss days, and restricted activity days), aggravated asthma, acute respiratory symptoms, including aggravated coughing and difficult or painful breathing, chronic bronchitis, and decreased lung function that can be experienced as shortness of breath. Observable health effects associated with exposure to diesel PM include laboured breathing, chest tightness, and chronic respiratory disease (cough, phlegm, chronic bronchitis and suggestive evidence for decreases in pulmonary function). Symptoms of immunological effects such as wheezing and increased allergenicity are also seen. Exposure to fine particles is closely associated with premature mortality and hospital admissions for cardiopulmonary disease.

14 PM also causes adverse impacts to the environment. Fine PM is the major cause of reduced visibility. Other environmental impacts occur when particles deposit onto soils, plants, water or materials. For example, particles containing nitrogen and sulphur that deposit on to land or water bodies may change the nutrient balance and acidity of those environments. Finally, PM causes soiling and erosion damage to materials, including culturally important objects such as carved monuments and statues. It promotes and accelerates the corrosion of metals, degrades paints, and deteriorates building materials such as concrete and limestone.

15 The introduction of the EU directive on air quality limit values has led to an increased public and political awareness of the impact of emissions of mobile sources and diesel engines on human health. In those EU-member states that exceed local air quality standards, this also has brought increased attention and an increased pressure to develop additional and new $NO_x$ and

PM10 emissions reduction options for mobile sources, including ships. These emissions of ships significantly contribute to an increased local $NO_x$ and PM10 concentration in ports and port areas. Ship emissions also contribute to an increase of continental background concentration. Non-compliance to local air quality standards may hamper future goals or wishes for port infrastructure expansion.

**Diesel Engine Exhaust**

16 Diesel engine exhaust emissions are of concern beyond their contribution to ambient PM. There have been health studies specific to diesel exhaust emissions indicating that potential hazards to human health are specific to this emission source. For chronic exposure, these hazards included respiratory system toxicity and carcinogenicity. Acute exposure also causes transient effects (a wide range of physiological symptoms stemming from irritation and inflammation mostly in the respiratory system) in humans though they are highly variable depending on individual human susceptibility. The chemical composition of diesel exhaust includes several hazardous air pollutants, or air toxics.

17 Numerous governments and research institutions have concluded that diesel exhaust is likely to be carcinogenic to humans.

**Inventory contribution of marine diesel engines**

18 At the time the Regulation 13 emission limits were adopted, there was only limited information available about the contribution of marine diesel engines to the global and local environments. Since that time, more engine emission data has become available, and several inventory studies have been conducted to estimate the contribution of these engines to ambient ozone, PM, $NO_x$ and $SO_2$ levels.

19 The contribution of marine diesel engines to global pollutant inventories is considerable. Early studies estimated the total contribution of these engines to global $NO_x$ inventories at about 4 per cent. A 1997 study by Corbett and Fischbeck estimates that these engines may contribute as much as 10 million tons of $NO_x$ and 8.5 million tons of $SO_x$ annually, which is about 14 per cent of world-wide nitrogen emissions and 6.5 per cent of all sulphur emitted by all fuel combustion sources including coal.[1] That study uses a top-down methodology and estimates emissions based on global marine fuel consumption. A 2003 study by Enderson et al. finds similar results (see below).[2] A 2000 study performed for the European Commission by BMT uses a similar methodology to determine world-wide $NO_x$ and $SO_x$ emissions from ships.[3] Table 1 presents the BMT estimates of world-wide $NO_x$ and $SO_x$ emissions from ships in 2001 by vessel category.[4] As illustrated in Table 1 below, the majority of these emissions are from tankers and dry bulk ships.

[1] J.J. Corbett and P. Fischbeck, "Emissions from Ships," Science, Volume 278, pages 823-825 (1997).

[2] Enderson, Ø., et. al., "Emission from International Sea Transportation and Environmental Impact," Journal of Geophysical Research, Vol. 108, No. D17, September, 13, 2003.

[3] BMT Murray Fenton Edon Liddiard Vince Limited, "Study on the Economic, Legal, Environmental and Practical Implications of a European Union System to Reduce Ship Emissions of $SO_2$ and $NO_x$," Final Report for the European Commission, August 2000.

[4] PM inventory estimates are also included in Table 1 and are based on the activity factors in the BMT study combined with emission factors used by the United States Environmental Protection Agency. $NO_x$ and $SO_x$ emissions are distributed by vessel type using BMT activity and fuel consumption estimates.

**Table 1**
Global Shipping Emissions By Vessel Type (2001)

| Vessel Type | Number of Ships Globally | % of World Commercial Fleet Tonnage | $NO_x$ MT/yr | $SO_x$ MT/yr | PM MT/yr |
|---|---|---|---|---|---|
| Tankers >1000 GRT | 6,781 | 36% | 2.9 | 2.1 | 0.16 |
| Dry Bulk >1000 GRT | 5,726 | 31% | 2.6 | 1.8 | 0.14 |
| Container >1000 GRT | 2,382 | 11% | 2.6 | 1.8 | 0.14 |
| Ro-Ro >1000 GRT | 1,432 | 5% | 1.1 | 1.1 | 0.10 |
| Cruise/Passenger >1000 GRT | 283 | 4% | 0.3 | 0.3 | 0.02 |
| Other Cargo >1000 GRT | 11,224 | 13% | 2.8 | 3.0 | 0.26 |
| Ships 250-1000 GRT | 30,000 | 4% | 0.4 | 0.5 | 0.04 |
| TOTAL | 57,826 | 100% | 12.6 | 10.5 | 0.87 |

Sources: BMT, 2000, EPA 2003

20 Corbett recently completed a new study that suggests that global marine diesel engine emissions may be significantly higher than previously estimated.[5] The 2003 Corbett study uses a bottom-up approach that estimates emissions based on the number of ships in the global fleet and their operating characteristics. The results of this study are presented in Table 2.[6] The emissions inventory estimates from the 1997 Corbett and 2003 Enderson study are also included for comparison.

**Table 2**
Estimates for Global Shipping Emissions

| Study | $NO_x$ [Mt/yr] | $SO_x$ [Mt/yr] | PM [Mt/yr] | Year Modelled |
|---|---|---|---|---|
| Enderson et. al. [2003] | 14 | 8 | 1.1 | 2000 |
| Corbett and Koehler [2003] | 23 | 13 | 1.6 | 2001 |
| Corbett et.al. [1997] | 10 | 8 | -- | 1996 |

21 As countries take steps to reduce the land-based sources of these emissions and as global trade continues to increase, the significance of marine diesel emissions is growing steadily. The European Union estimates that $SO_x$ emissions from ships were about one-eighth the magnitude of land-based sources in the EU in 1990 and about half in 2000.[7] By 2010, $SO_x$ emissions from ships in this area are projected to approach the magnitude of land-based sources and may exceed

5 Corbet, J., Koehler, H., "Updated Emissions from Ocean Shipping," Journal of Geophysical Research, Vol. 108, No. D20, October 29, 2003.

6 Adjustments were made to the emission inventories presented in the paper to allow for a direct comparison. For instance, the tonnes of N presented in the 2003 study were converted to $NO_x$ using a molecular weight ratio of $NO_2$ to N. Also, the tonnes of emissions presented in the Enderson study are adjusted to account for all ships over 100 gross registered tons (rather than just cargo and passenger ships) by using fuel consumption estimates presented in the study.

7 Nicola Robinson, "EU Stakeholder Workshop on Low-Emission Shipping: Day 1: Research, Abatement Technologies & Best Practice," DG Environment, European Commission, September 4, 2003.

it soon after. This effect is due to growth in shipping and emission control programs for land-based sources. In the United States, marine diesel engines are estimated to account for about 4 per cent of total national $NO_x$ emissions; this is expected to increase to 6 per cent by 2020, even with the domestic Tier 2 standards. Other areas around the world will likely experience similar results.

22 It is important to note that a significant share of marine diesel engine emissions may occur along coastlines and in commercial ports, many of which are located in or near highly populated industrial settings and many of which are already experiencing serious air pollution. 90% of EU ship emissions are estimated to be within 90 km of land. Corbett 1997 estimates that approximately 70 per cent of these emissions occur within 400 kilometres from shore. It should be noted, however, the effects on land-side inventories depend on prevailing traffic, wind patterns, and other variables. Even so, these emissions can have important effects on land-side pollutant levels. For example, Santa Barbara County, California, estimates that engines on ocean-going marine vessels currently contribute about 37 per cent of total $NO_x$ in their area. These emissions are from ships that transit the area, as this area has no commercial port. By 2015 these emissions are expected to increase 67 per cent, contributing 61 per cent of Santa Barbara's total $NO_x$ emissions.

23 The long lives of vessels with marine diesel engines means that the emission benefits associated with new standards take a long time to achieve their full effect. Because fleet turnover is so slow, it is important to consider more stringent emission limits for new engines sooner rather than later.

**Advanced emission control technologies for reducing marine emissions**

24 The Regulation 13 $NO_x$ limits are based on the state of technology in 1992, and as average lead to a reduction of $NO_x$ emissions in the magnitude of 30%. From the present state of technology the solutions developed since then reflect relatively uncomplicated diesel engine emission control technologies that rely on in-cylinder changes. Since the time the Regulation 13 $NO_x$ emission limits were defined, in the early 1990s, the marine industry has been engaged in the development of more advanced emission control technologies for marine diesel engines. These engine manufacturers continue developing new marine-specific technologies.

25 In consideration of these new advances, the United States adopted Tier 2 marine diesel engine emission standards for engines below 30 litters per cylinder. These standards, adopted in 1999 and effective beginning 2004 through 2007, depending on engine size, reflect additional in-cylinder emission control technologies such as combustion optimization (timing regard, combustion chamber geometry, and swirl), advanced fuel injection control, improved charge air characteristics (jacket-water after cooling, raw water after cooling, separate-circuit after cooling) and electronic controls. The standards apply to PM as well as $NO_x$ emissions.

26 New information suggests that additional emission reductions beyond the United States Tier 2 marine diesel engine controls may be possible using advanced technologies for $NO_x$ and PM control. Technologies for reducing $NO_x$ include introducing water into the combustion process, $NO_x$ adsorbers, and selective catalytic reduction. PM control technologies include particulate traps and exhaust scrubbers.[8]

---

[8] More information about these diesel engine emission control technologies can be found in papers presented at the Ship Emissions Stakeholder Workshop (4&5 September 2003) sponsored by the European Commission (available at http://europa.eu.int/comm/environment/air/transport.htm, under Pollutant Emissions from Ships).

27 For onboard use these technologies should operate more than 8,000 h/a for more than 20 years without jeopardizing ship safety and consequently increasing the risk of accidental pollution. Also in the light of ongoing discussions about $CO_2$-indexing of ships fuel consumption and $CO_2$ emissions should not increase. Technologies should also be available for engines with a volume of up to 2,400 litres per cylinder. This will require additional development by engine manufacturers and suppliers of treatment systems. The following paragraphs give an overview about some present development tendencies without discussion of possible restrictions in applicability.

**$NO_x$ Reduction Technologies**

28 Significant $NO_x$ control can be achieved by introducing water into the combustion process in combination with appropriate in-cylinder controls. Water can be used in the combustion process to lower maximum combustion temperature, and therefore lower $NO_x$ formation, with an insignificant increase in fuel consumption. Data on these approaches show a 30-40 per cent reduction in $NO_x$ with water fuel ratios ranging from 0.3 to 0.4.

29 Catalytic emission control technologies can extend the reduction of $NO_x$ emissions by an additional 90 per cent or more over conventional "engine-out" control technologies alone. $NO_x$ adsorbers work to control $NO_x$ emissions by storing $NO_x$ on the surface of the catalyst during the lean engine operation typical of diesel engines. The adsorber then undergoes subsequent brief rich regeneration events where the $NO_x$ is released and reduced across precious metal catalysts. This method for $NO_x$ control has been shown to be highly effective when applied to diesel engines provided that low sulphur fuel is used.

30 Another $NO_x$ catalyst based emission control technology is selective catalytic reduction (SCR). SCR catalysts require a reductant, ammonia, to reduce $NO_x$ emissions. Because of the safety concerns with handling and storing ammonia, most SCR systems make ammonia within the catalyst system from urea. Urea is mixed into a water solution and injected into the exhaust where the heat decomposes the urea to produce ammonia and carbon dioxide which is channelled through a reactor where $NO_x$ emissions are reduced. With an appropriate control system to meter urea in proportion to engine-out $NO_x$ emissions, SCR catalysts can reduce $NO_x$ emissions by over 90 per cent for a significant fraction of the diesel engine operating range.

**PM Reduction Technologies**

31 A common form of exhaust after treatment for reducing diesel PM is the diesel particulate filter (DPF). DPFs control diesel PM by capturing the soot portion of PM in a filter media, typically a ceramic wall flow substrate, and then by oxidizing (burning) it in the oxygen-rich atmosphere of diesel exhaust. Filtering efficiencies for diesel soot can be 99 per cent with the appropriate filter design. However, the catalytic materials that most effectively promote soot and SOF oxidation are significantly impacted by sulphur in diesel fuel. Sulphur both degrades catalyst oxidation efficiency (i.e. poisons the catalyst) and forms sulphate PM.

32 It has been suggested that exhaust gas scrubbers (see below) have the potential to reduce PM emissions to a limited extent. This can result in some indirect PM emission reductions. However, such PM reductions are limited by the surface contact between the gas and the water. More PM reductions may be possible by using ultra fine water droplets in the exhaust.

**$SO_x$ Emission Control Technologies**

33 The primary technique for reducing $SO_x$ emissions is to reduce the sulphur content of fuel. This is because $SO_x$ emissions can be formed only if there is sulphur present in the exhaust stream. Another technology that is being investigated is exhaust gas scrubbing. This technique, which is allowed under Regulation 14 of Annex VI, is similar to scrubbers used on land-based power plans. In an exhaust gas scrubber, the exhaust is mixed with sea water which can adsorb about 80% of the $SO_x$ emissions in the exhaust. Because the sea water run through the system can contain high amounts of sulphur, it should be disposed of carefully. This technology is still experimental in marine applications. The effect of exhaust gas scrubbing are questioned for the reasoning that the exhaust gases when released to the atmosphere are water saturated and water vapour will be "sour water" and condensed when the exhaust gases leaves a ship's funnel in the same manner as occurs onboard a tanker in its inert gas deck system. Thus the mode and manner of the sulphur compound as an emission is changed from the gaseous sulphur dioxide to an aqueous based emission of sulphurous acid that will not be detected by the types of monitoring systems in place for verification of reduced sulphur forms of emissions. The Committee should look into these aspects of exhaust gas scrubbing.

___________