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MariEMS Learning Material

This is the 19th compilation by Professor Dr Reza Ziarati on the work of the EU funded Erasmus + MariEMS' partners and material extracted from the IMO TTT Course. The material is composed from Chapter 19 of the learning material. Readers are also advised to refer to the papers on IdealPort and IdealShip projects led by C4FF and published by MariFuture.

19. Technologies for Port Air Quality and GHG Emissions Reduction

19.1 Introduction

Port operations involves not only ship operation but a lot of other activities such as cargo loading and unloading, ground-level port related transportations and activities of harbour crafts for provision of various services to ports or ships (e.g. dredging, tugs, bunkering, etc.). The main prime mover for most of these vessels, vehicles, cargo handling equipment are diesel engines although move to electrification and use of other technologies are underway. In this section, technological solutions for port area emissions reduction and GHG emissions reductions are discussed. A number of studies has been carried out in the past, the most prominent ones are those by ICCT20 and the IMO. These studies are used as the basis of material in this section and the main outcomes of these studies are highlighted.

19.2 ICCT Study on Port Air Quality

Most of the studies performed on port related emissions concentrate on port air quality and not energy efficiency. One of these is reported by ICCT (International Council on Clean Transportation) in December 2012. In this report, the ICCT highlights the technologies that could be used in diesel engines as the prime mover for ships and port-side trucks. The main focus is on pollutants including PM (Particulate Matters), carbon monoxide, SOx, NOx and VOC.

The types of technologies identified for reduction of emissions are:

- **Diesel oxidation catalysts:** This is a device installed at the back of the engine on the exhaust gases path to oxidize such pollutants as CO, PM and HC.
- **Diesel particulate filter:** This is the devise used at the back of diesel engines on the exhaust gases path to trap the particulates and prevent them from leaving the engines.
- **SCR (Selective Catalytic Reduction):** This is a very well know technology for significant reduction of NOx emissions. As the name implies, it work via use of agents at the presence of a catalyst to covert NOx beck to N_2 and O_2.
- **Exhaust Gas Scrubbers:** Again this is a very well-known technology for the back of engines on the exhaust gases path to capture the SOx and prevent them from leaving the engine exhaust.
- **Exhaust Gas Recirculation (EGR):** This is a well-known technology that aims to reduce the engine's combustion temperature and thus reduce NOx via circulating part of the exhaust gas back into cylinder.
- **Shore power:** This refers to ship connection to port electricity so that the ship-board engines could be completely switched off.

- **Clean fuels:** These include a variety of options such as ultra-low sulphur fuel, LNG, CNG, water-emulsified fuels, biofuels and so on. Most of these options not only reduce SOx but also NOx as well.

Figure 19.2.1 summarises various options, itemises potential applications for use at ports, provides estimates for the reduction potential for various pollutants and provides basic cost estimations of each option. This shows a significant potential for alleviating air quality issues from ports but they mostly are considered as options for CO_2 reduction directly. In fact, most of these options may lead to a small increase in overall fuel consumption as for example NOx control methods most of the time makes engines less efficient.

Type	Technology Name	Application	Potential Emissions Reduction	Cost (US$)
General Emissions Control Technologies	Diesel Oxidative Catalysts (DOC)		**PM** 20-30% **HC** 50-90% **CO** 70-90%	$1,000-2,000 (Truck, CHE) $3,000-4,000 (Marine) Variable Cost (Locomotive)
	Closed Crankcase Ventilation (CCV)		**PM** 15-20%	$700 ($48-50 filter replacement)
	Diesel Particulate Filters (DPF)		**PM** up to 90% **HC, CO** 60-90%	$6-18K (Truck) up to $40K (Marine, Locomotive)
	Selective Catalytic Reduction (SCR)		**NO_X** 70-90%	$36K (Truck & CHE) $60K-120K (Marine)
	Lean NO_X Catalyst (LNC)		Moderate **NO_X** Reductions	$14K (On-road) $40K (Off-road (limited))
	Exhaust Gas Scrubbers		**SO_X** 90-99% **PM** 60-80%	$5M (Marine)
	Shore Power		Net emissions reductions	$1-15M
On-Engine Modification	Exhaust Gas Recirculation (EGR)		**NO_X** 40-50% **PM** 70% (with DPF)	$12K (Truck) $10M (Marine)
	Engine Replacement, Repower, Rebuild, Refuel		**NO_X** up to 90% **PM** up to 90%	$0.5-1.5M
	Slide Valves		**PM** 10-50% **NO_X** 10-25%	$1.5-16K (Marine)
Alternative Fuels	Ultra Low Sulphur Diesel (ULSD)		**PM** 5-15% **SO_X** 99%	Surcharge: $0.05-0.15/gal
	Biodiesel Fuel (BXX)		**PM** 15-70% **HC** 10-40% **CO** 10-50%	Surcharge $0.25-0.40/gal
	Emulsified Diesel Fuel (EDF)		**NO_X** 10-20% **PM** 15-60%	Surcharge $0.25-0.40/gal
Operational Strategies	Vessel Speed Reduction (VSR)		Net reductions in **NO_X, PM,** and other air pollutants	Net negative cost over time (balance fuel savings and travel time increase)
	Landside Operational Improvements		Net emissions reductions	Multi-million/billion dollar improvements

Notes: = Trucks, = Cargo Handling Equipment, = Marine, and = Locomotive. 1 icon= Low or uncertain deployment, 2 icons= Emerging, 3 icons= More Widespread. The technology and operational emission reduction options are diverse, and the per cent emission reduction estimates represent the potential reduction from best practices in each area. The associated cost ranges are illustrative, based on the most common such alternatives; "K" = 1,000 USD, "M" = 1,000,000 USD. Cost estimates are based on Starcrest (2012) estimates from the *Developing Port Clean Air Programs*.

Figure 19.2.1 – Port air emissions reduction measures according to ICCT December 2012 report

19.3 IMO Ship-Port Interface Study

The MEPC 68/INF.16 document presents the results of an IMO commissioned study that deals with a broad range of topics on ship-port interface including a large number of existing and future innovative technologies that ship owners and operators, ports, and other stakeholders can consider and evaluate for reducing emissions in the port area. A number of technology classification has been done in this study including for example "existing technologies" that are considered to be readily implement-able to reduce emissions from various operational modes of ships associated with the port area. This IMO commissioned study's focus is ship-port interface thus is not dealing with portside measures.

19.3.1 Measures categories

Existing measures are grouped into three major categories:

- Equipment measures
- Energy measures
- Operational measures

Equipment measures:

Equipment measures consist of the following groups that are applicable mainly to diesel engines and boilers:

- Engine technologies
- Boiler technologies
- After-treatment technologies

Energy measures:

The "energy" measures relate to energy sources used by a ship, whether they are physically located on board or on land (e.g., shore power). Energy measures include the following groups:

- Alternative fuels
- Alternative power supply

Operational measures:

The operational measures refer to those that primarily affect and focus on the operation of the ship, terminal, or port and can be implemented for reduction of emissions of ships in the port area. This can take the form of operational efficiency improvement on board, at the terminal, and/or at the port. Operational measures include the following groups:

- Ship operational efficiencies
- Port/terminal operational efficiencies
- VOC working losses

19.3.2 Symbols used:

The IMO commissioned report then provides a brief description of each measure including summary information about the measure, followed by discussion on how these considerations relate directly to the port area. The report then, in systematic way, summaries the findings using the following symbols as shown in brackets below:

- Applicable emission sources – describes which emission sources can be affected by the "measure" and include:
  - Propulsion engines (P)
  - Auxiliary engines (A)
  - Auxiliary boilers (B)
  - Applicable to propulsion engines, auxiliary engines, and auxiliary boilers (all)
  - Working VOC cargo tanks (Tank).

- **Retrofit-able:** This provides information if the measure can be retrofitted on existing ships with three options; (Yes – Y) or limited to only new builds (No – N), and not applicable (na).
- **Terminal/vessel:** The port/terminal operational efficiencies measures are sub-categorised as below:
  - Terminal (T)
  - Vessel (V)

• **Applicable operational modes:** This specifies the ship operational mode category in which the measure is effective. This operational modes are sub-categorised as:
  - Open water or sea conditions (S)
  - Transition (T) o Manoeuvring (M)
  - At-berth (B) o At-anchorage (A)
  - All modes (all)

• **Emissions and energy efficiency:** This lists the pollutant specific emission changes anticipated by the measure and provides a relative potential reduction. The IMO commissioned report highlights that emission reduction impacts are based on public data and published values, which do not necessarily represent verification by appropriate authority. For case where information have been available, the following symbols on impact of measure on emissions are used:
  - ↑ for increases in emissions
  - ↓ for decreases in emissions
  - ↕ for either increase or decrease depending on various factors

If a percentage value is provided it represents the potential maximum value. If published levels or limited data are such that the reductions cannot be quantified at this time, then the symbol "to be determined" (TBD) denotes this case.
It should be noted that emission reduction levels are dependent on applicable modes, engine loads, ship power configuration, fuels, operational parameters, equipment parameters, and other factors. Typically, each application of a measure needs to be evaluated on a case-by-case (CBC) basis such that specific parameters and conditions are considered to determine the most appropriate reduction level. Energy consumption is included as an indicator for energy efficiency.
19.3.3 Study outcomes on existing technology measures:

For each category, the IMO commissioned study presents a summary table within which the list of measures (first column) is given together with the applicability, retrofit-ability, applicable modes, and emission reduction potential for NOx, PM, SOx and HC and last but not least the "energy consumption" that denotes energy efficiency of some form. IN the following, a brief description of findings on various categories and measures are given. Engine technologies Figure 19.3.1 shows the engine related technologies that are to a large extent comparable to items covered under ICCT report (Section Figure 19.2.1).

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Engine Technologies								
Repower	P/A	Y	All	≤80%↓	↓ cbc	–	–	↕ cbc
Remanufacture Kits	P/A	Y	All	↕ cbc	↓ cbc	–	↕ cbc	↕ cbc
Propulsion Engine Derating	P	Y	STM	↑ cbc	↕ cbc	–	tbd	↕ cbc
Common Rail	P/A	Y	All	≤25%↓	↓ cbc	–	–	≤5%
Exhaust Gas Recirculation	P/A	Y	All	≤60%↓	tbd	–	tbd	tbd
Rotating Fuel Injector Controls	P	N	STM	≤25%↓	≤40%↓	cbc	cbc	cbc
Electronically Controlled Lubrication Systems	P	Y	STM	–	≤30%↓	–	≤30%↓	–
Automated Engine Monitoring/Control Systems	P/A	N	ALL	≤20%↓	tbd	≤3%↓	–	≤5%↓
Valve, Nozzle, & Engine Timing NOx Optimization	P	Y	STM	↓ cbc	↕ cbc	–	↓ cbc	↑ cbc
Slide Valves	P	Y	STM	↓ cbc	↓ cbc	–	↓ cbc	↕ cbc
Continuous Water Injection	P/A	Y	All	≤30%↓	≤18%↓	–	–	–
Direct Water Injection	P/A	Y	All	≤60%↓	↕ cbc	–	↕ cbc	–
Scavenging Air Moistening/Humid Air Motor	P/A	Y	All	≤65%↓	↑ cbc	↑ cbc	–	↑ cbc
High Efficiency Turbochargers	P/A	Y	All	↓ cbc	↓ cbc	–	↕ cbc	↓ cbc
Two Stage Turbochargers	P/A	Y	All	≤40%↓	tbd	–	–	↓ cbc
Turbocharger Cut Off	P	Y	STM	≤40%↓	tbd	–	tbd	↓ cbc
Crank Case VOC Leakage	P	Y	STM	–	tbd	–	≤100%↓	–

Figure 19.3.1 – Summary of engine technologies [MEPC 68 INF.16]

As can be seen, many technologies are judged to be retrofit-able, they apply mostly to both propulsion and auxiliary engines, and their impacts on energy consumption and GHG emissions could not be quantified. Some of the measures could have negative impacts on energy efficiency.

After-treatment technologies

Figure 19.3.2 shows the after-treatment technologies that are mainly related to diesel engines exhaust gas after treatment systems. These technologies include scrubbers, SRC, etc. and the main aim for their use is to reduce exhaust pollutants rather than CO_2 emissions.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
After-Treatment Technologies								
Selective Catalytic Reduction (SCR)	All	Y	All	≤95%↓	–	–	–	↑ cbc
Exhaust Gas Scrubbers - Wet	All	Y	All	≤5%↓	≤80%↓	≤98%↓	–	↑ cbc
Exhaust Gas Scrubbers - Dry	All	Y	All	≤5%↓	≤80%↓	≤98%↓	–	↑ cbc
Barge-Based Systems	AB	na	B	≤95%↓	≤95%↓	≤95%↓	tbd	↑ cbc

Figure 19.3.2 – Summary of engine exhaust gas scrubbing systems [MEPC 68 INF.16]

As can be seen, many technologies are judged to be retrofit-able and they could significantly reduce ship exhaust pollutants. Unfortunately, these technologies will generally increase the ship's energy consumption, thus the level of GHG emissions. The level of increase of energy consumption could not be quantified and will also depend on case by case.

Alternative fuels options

Figure 19.3.3 shows the alternative fuels that includes a large list of options such as natural gas, low sulphur fuel, bio fuels, methanol and so on.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Fuels								
Low Sulfur Fuels	All	NA	All	↓ cbc	↓ cbc	↓ cbc	–	↓ cbc
Liquefied Natural Gas - gas only	All	N	All	≤88%↓	≤98%↓	100%↓	↑ cbc	↕ cbc
Liquefied Natural Gas - dual-fuel	All	Y	All	↕ cbc	≤78%↓	97%↓	↕ cbc	↕ cbc
Water in Fuel	All	Y	All	≤30%↓	–	–	–	–
Methanol	All	Y	All	↓ tbd	tbd	100%↓	tbd	↓ cbc
Biofuels	All	Y	All	↑	tbd	↓ cbc	tbd	tbd

Figure 19.3.3 – Summary of alternative fuel options [MEPC 68 INF.16]

As can be seen, many of alternative fuels are judged to be useable with current technologies (retrofit-able). Some demonstrates significantly reduction potential for exhaust gas pollutants. They may lead to reduced energy use or GHG emissions depending on a case by case analysis. The case for alternative fuel is well known to industry, regulations on ECA (Emissions Control Area) forces industry to use low sulphur fuel or other relevant alternatives in designated areas and the move to natural gas in the form of LNG is underway in some parts of the world.

Alternative power system technologies

Figure 19.3.4 shows the alternative power technology options where on-shore power, barge power supply and solar power systems are highlighted.

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Alternative Power Systems								
On-Shore Power Supply	A	Y	B	≤95%↓	≤95%↓	≤95%↓	≤95%↓	≤95%↓
Barge Power Supply	A	Y	B	↕ cbc	↓ cbc	↓ cbc	↑ cbc	↕ cbc
Solar Power	A	Y	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

Figure 19.3.4 – Summary of alternative power systems [MEPC 68 INF.16]

As can be seen, the on-shore power system is the most effective system for reducing ship air pollutants. On other technologies, the level of reductions is not clear and will be case by case dependent. Also, on energy consumption and GHG emissions, the impact is not clear cut and the number for on-shore power only refers to ship-board fuel consumption reduction since same amount of energy will be used but this time in the form of electricity from onshore.

19.3.4 Future innovative technologies, fuels and operation processes

The measures included are those innovative technologies, fuels and operation methods that:

- Possess a clear theoretical potential for emission reductions or efficiency improvements that is either not yet tested in real-world application or exists primarily in a prototype phase of development.
- Are available and ready to deployed and is in limited or niche use, but with a substantial potential for expansion if certain key barriers like cost can be overcome.
- Are being used at land-side facilities or in other applications from which it can be adapted and re-engineered for application in the maritime sector.

Figure 19.3.5 shows a large number of alternatives in this area, some relating to existing technologies but some are purely new measures.

	System Applicability	Retrofitable	Market Maturity	NOx	PM	Efficiency Improvement	Cost
Measures from Existing List							
Engine Optimization Technologies	P	Y	M/E	↓	↓	↑	↕
Engine Automation and Data Collection	P/A	Y	M/E	↓	↓	↑	↓
Turbocharger technologies	P	Y	M/E	↓	↕	↑	↕
Combustion Water Technologies	P	Y	M/E	↓	↕	↕	↑
Shore-based exhaust treatment systems	P/A	Y	L/E	↓	↓	↕	↑
Automated Berthing	O	Y	M	↓	↓	↑	↓
Alternative Fuels	P/A	Y	M/E	↕	↕	↕	↕
Solar Power	E	Y	M	↓	↓	↑	↓
"New" Measures							
Variable camshaft timing	P	Y	L/E	↓	↓	↕	↓
Selective non-catalytic reduction (SnCR)	P	Y	L/E	↓	↕	↕	↑
Low-Temperature SCR	P	Y	L/E	↓	↕	↕	↑
Low NOx Burners	B	Y	L/E	↓	↕	↕	↑
Eletrical System Improvements	E	Y	M	↓	↓	↑	↓
Low energy lighting	E	Y	M	↓	↓	↑	↓
Multi-mode propulsion	P	N	M/E	↓	↓	↑	↕
Battery Hybrids	P/E	Y	L/E	↓	↓	↑	↓
Fuel Cells	P/E	N	L/E	↓	↓	↑	↓
Vessel size increase	O	N	M	↓	↓	↑	↓
Megaboxes	O	N	T	↓	↓	↑	↓
Alternative cargo Loading	O	N	T	↓	↓	↑	↓
Mid-stream operations	O	Y	L/T	↓	↓	↑	↓
Virtual Arrival and Alternative Berth Policies	O	Y	M/E	↓	↓	↑	↓

Figure 19.3.5 – Summary of innovative and emerging technologies [MEPC 68 INF.16]

As can be seen, many of these measures are judged to reduce not only air pollutants (NOx and PM) but also improve (increase) the energy efficiency of the ship and reduce costs.

19.3.6 Study key findings

From the above technical and operational measures identified and studies, the following key findings relevant to this section are reported by the MEPC 68/INF16 report:

- Numerous technical measures are available to effectively reduce emissions and increase energy efficiency, and experience with some of the measures implemented in the port area goes back over ten years and is growing. The range of available technical measures is quite extensive including engine and boiler technologies, after treatment technologies, fuel options, alternative power systems, operational efficiencies, and cargo vapour recovery.

- There are no "one size fit all" technical measure solution for ships and ports. Due to numerous variables such as pollutant(s) targeted, port configuration, cargos handled, drivers, barriers, vessels servicing the port area, vessel configurations, operational conditions and the nature of technical measures, each measure needs to be analysed on a case-by-case basis in advance of implementation.

- Several emerging and innovative technologies and measures potentially could provide additional options to reduce emissions from ships in the port area. There are initiatives underway from various stakeholders that are focused on the demonstration of emerging technologies and measures, with the ultimate goal of bringing them to the market in an expedited fashion.

19.4 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. MEPC 68/INF.16, "Study of emission control and energy efficiency measures for ships in the port area", MEPC 68/INF.16, 4 March 2015, report prepared by Starcrest Consulting Group, LLC CE Delft and Civic Exchange. Viewed Nov 2016.

2. ICCT December 2012, "Workshop brief: Technologies and operational strategies for best practices in port clean air programs" A report prepared for the International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, December, 2012. Viewed Nov 2016.

3. ICCT June 2012, "Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor's Air Quality Toolbox", June 2012. Viewed Nov 2016.

4. IMO Train the Trainer (TTT) Course on Energy Efficient Ship Operation, developed by IMO and the World Maritime University (WMU) in 2013.

http://www.imo.org/en/ourwork/environment/pollutionprevention/airpollution/pages/imo-train-the-trainer-course.aspx
Viewed Nov 2016.