OPERATION OF SELECTIVE CATALYTIC REDUCTION (SCR) SYSTEM FOR COMPLIANCE WITH IMO NOX TIER III

Compliance Requirements Background:

IMO Marpol VI regulations on Nitrogen Oxides (NOx) Tier III

1) IMO MARPOL Annex VI Regulation 13 sets diesel engine NOx emissions controls based on engine power production and installation date. Marine diesel engines must be built to meet, or have equivalent means of complying with the folowing emission standards:

Tier	Ship construction date	Total Weighted Cycle Emission limit (g/*k*Wh) n = engine's rated speed (rpm)		
		n < 130	n= 130 - 1,999	n > or = 2,000
I	prior to 1 January 2011	17.0	$45 \times n^{-0.2}$ e.g., 720 rpm = 12.1	9.8
II	on or after 1 January 2011	14.4	$44 \times n^{-0.23}$ e.g., 720 rpm = 9.7	7.7
III	on or after 1 January 2016	3.4	$9 \times n^{-02}$ e.g., 720 rpm = 2.4	2.0

The above applies to engines with power >130 kW installed onboard or that undergoes a major conversion after 01 January 2000 and if not solely used for emergency purpoes

2) When Operating in a MARPOL Annex VI, Regulation 13 NOx ECA, Tier III NOx emissions standards apply for **ships with a keel laying date on or after entry into force of that ECA**.
These ships must either have Tier III engines or an equivalent / alternative means of compliance (e.g., Selective Catalytic Reduction / SCR) in operation while in a NOx ECA.

Note: MARPOL NOx ECA Entry into force dates:
- **North America and US Caribbean Sea- January 1, 2016**
- North and Baltic Sea- January 1, 2021

3) Ships with NOx certified engines:
   a) provided with Engine International Air Pollution Prevention Certificate (EIAAPC) for such engines
   b) have an approved technical file for engine and any other additional system (SCR)
   c) must maintain a history of replacements and changes to NOx critical components, settings and operating values in a Record Book of Engine Parameters or if approved the PMS

SCR System Description and Details:

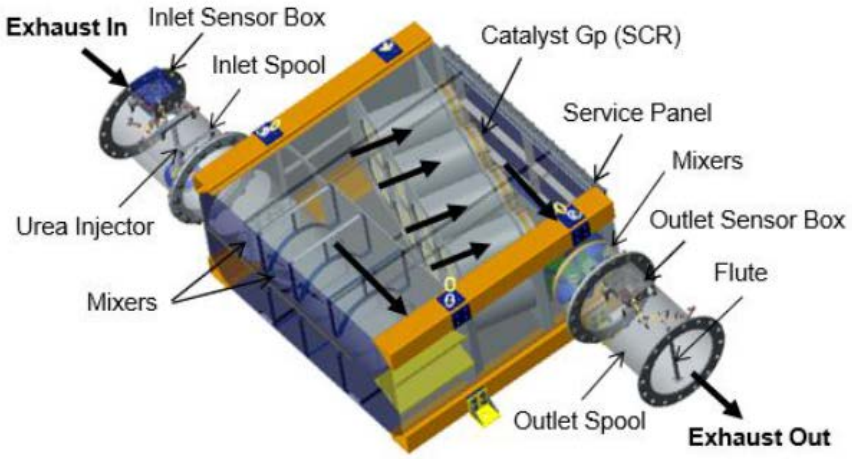
Selective Catalytic Reduction (SCR) System Components

1) The primary function of the SCR system is to reduce Nitrogen oxides (NOx), normal by-products of internal combustion engines, which are considered atmospheric pollutants. Through this process, **DEF = Diesel Exhaust Fluid** (an aqueous solution containing urea and deionized water) mixes with exhaust gases and the heat evaporates water from DEF, converting it to gaseous Ammonia (NH3). The Ammonia, exhaust gases, and the catalysts react with NOx and oxygen resulting in an output of nitrogen, water, and CO2.

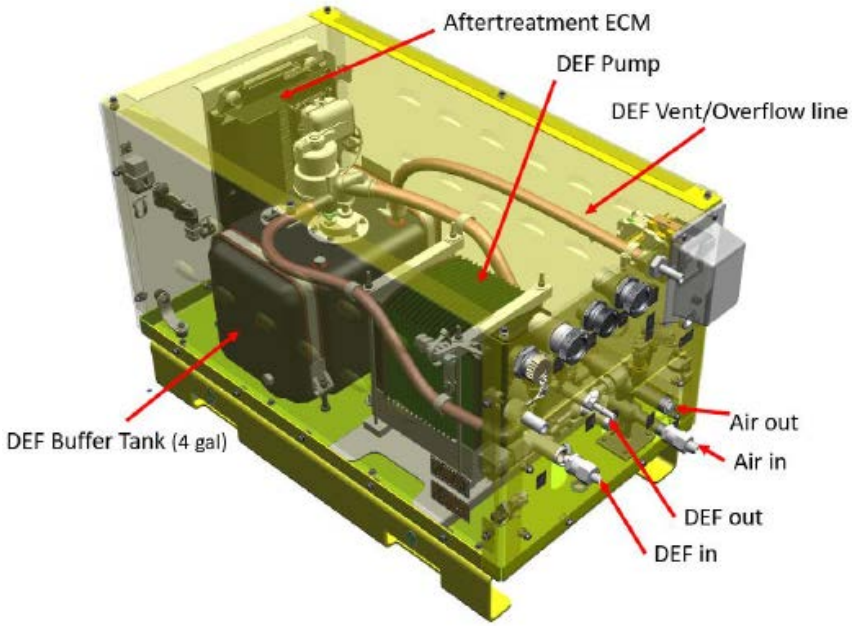
2) The **DEF** solution is approximately between 32.5% to 40% concentrations of urea and de-ionized water. The control system automatically adjusts to accommodate either option 32.5% or 40%. Load dependent mass flow of urea is continuously checked by the closed loop monitoring system to ensure compliance, and discrepancies are alarmed.

3) The two main components of the SCR system are:

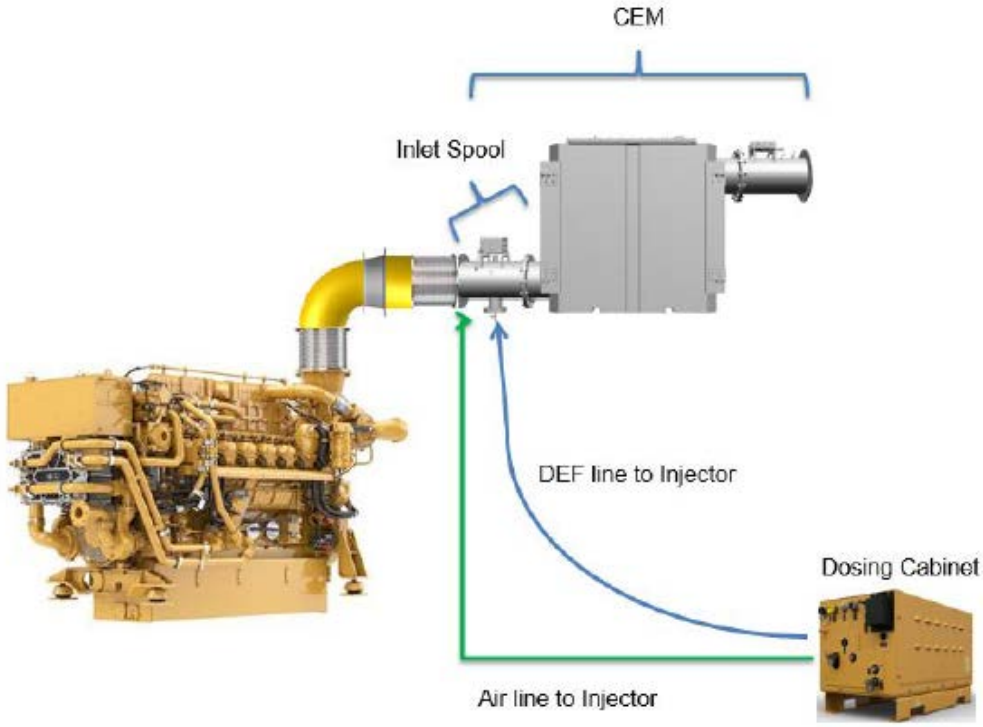
   a) **CEM (Clean Emissions Module)** - a stainless-steel reactor containing catalysts (commonly referred to as “bricks”). Exhaust gases from the engine enter the inlet spool of the CEM along with DEF and air, which are injected into the exhaust stream. The atomized DEF and exhaust gases then flow through a mixer plate. Water evaporates from DEF, creating gaseous ammonia NH3.



b) **Dosing Cabinet - a Pump Electronic Tank Unit (PETU) -** it contains a controller, DEF pump, and an air regulation system. It monitors engine and SCR parameters to determine dosing requirements, and provides the correct flow of DEF to the DEF injector which is located in the SCR Reactor. The air supply to the dosing cabinet must meet specific requirements for quality, temperature, flow and pressure

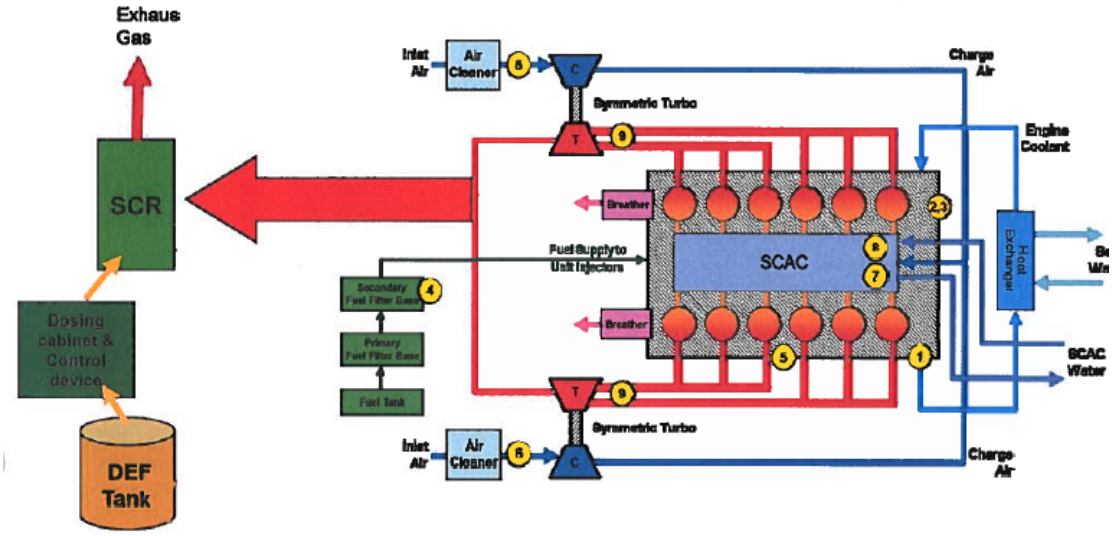


c) Each engine typically requires its own CEM and Dosing Cabined / PETU



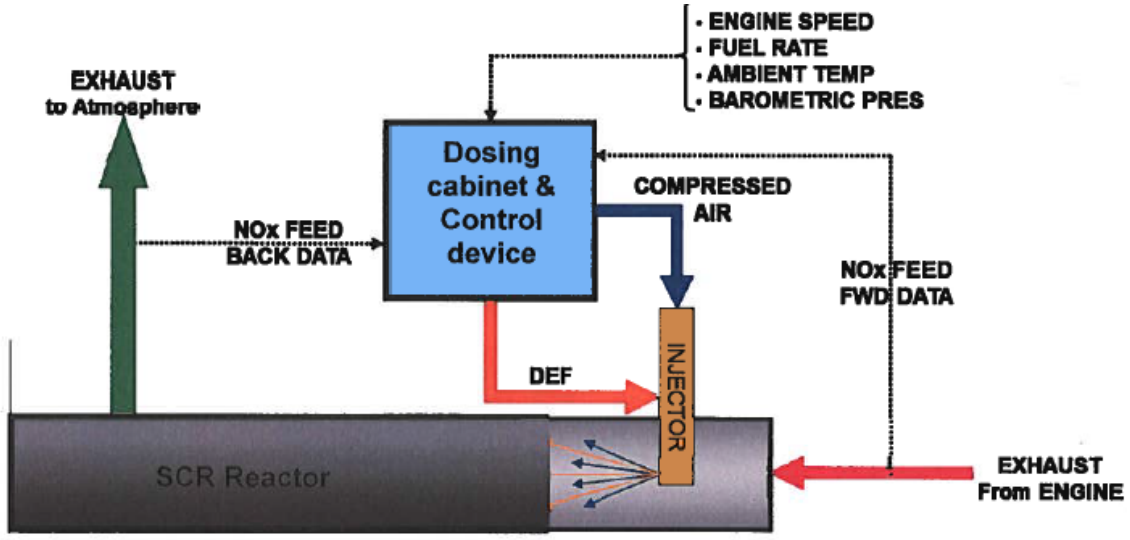
Principle of Operation of the SCR

1) The SCR is a combined engine and after-treatment system designed to meet IMO NOx Tier III end of the pipe emissions



2) During normal operation, the SCR aftertreatment controller determines the desired NOx conversion and then calculates the required DEF dosing. The system automatically adjusts dosing based on measured NOx conversion using the Engine Out (EO) and TailPipe (TP) NOx sensors. The controller then determines whether the required load dependent DEF flow is being achieved.

3) This aftertreatment system utilizes a closed-loop control strategy to regulate DEF injection into the exhaust to reduce NOx emissions based on both the EO and TP NOx sensors. The system compensates for different urea concentrations in the DEF (32.5-40%)



4) If a problem occurs with the aftertreatment system e.g. if the system cannot provide sufficient DEF flow to meet the required NOx conversion, or if the system is shut down in an emergency - an event for low or invalid aftertreetment with different severity (least / moderate) and erratic/intermittent or incorrect. The code is stored by the engine controller so that the occurrence can be reported as required for compliance.

PROCEDURES FOR DEF AND CEM

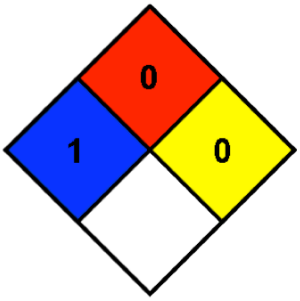
DEF = Diesel Exhaust Fluid / Urea solution - handling, storage, transfer and cleanliness

DEF / Urea solution - Safety measures

1) Use PPE such as gloves and goggles as is irritant to skin and eyes
2) Avoid breathing vapours- slight odour of ammonia may aggravate respiratory conditions
3) Avoid incompatible materials such as Nitric Acid, gallium, perchlorate, strong oxidizing agents, caustics and alkalis
4) Be aware of its caustic corrosive nature

Note: Any hoses or other non-metallic transfer equipment should be made from Nitrile Rubber (NBR), Fluoroelastomer (FKM), and/or Ethylene Propylene Diene Monomer (EPDM)

5) Keep away from heat:
   a) be aware of hazardous decomposition gases: Carbon Dioxide, and Ammonia (Ammonia oxidizes further to Nitric Oxide and Nitrogen Dioxide).
   b) will not burn
6) Be familiar with: its colourless, transparent, normally stable and non-explosive, not reactiveness with water nature; Ph range between 7.0-10.0; Health =1 rating



DEF /Urea solution - Maintaining concentration

1) Be aware of the following when ordering DEF / Urea solution onboard:
   a) The advantage of 32.5% concentration is that it provides the lowest possible freezing point, -11°C while 40% concentration freezes is at 0°C
   b) The 40% solution, having a higher concentration, has the advantage of using less DEF per the amount of fuel used
   c) The quality of DEF rapidly degrades when stored at high temperatures

Do not use agricultural grade urea due to the risk of contaminants that may damage the SCR system

2) Store DEF under the following temperature conditions as possible to ensure its required life:

Expected DEF Life	32.5 % DEF Storage Temperature	40% DEF Storage Temperature
Ideal Storage Temperature	-9°C to 25°C (15°F to 77°F)	2°C to 25°C (36°F to 77°F)
18 Months	Below 25°C (77°F)	Below 25°C (77°F)
12 Months	25°C to 30°C (77°F to 86°F)	25°C to 30°C (77°F to 86°F)
6 Months	30°C to 35°C (86°F to 95°F)	30°C to 35°C (86°F to 95°F)
1 Month – Test Before Use	Above 35°C (95°F)	Above 35°C (95°F)

3) Test before use DEF that has stored above 35°C for longer than one month **and/or** If DEF has been stored onboard for more than its expected life as above, as follows:
   a) Use refractometers for testing of % concentration
   b) Perform also a visual inspection as any changes in color and clarify indicate a quality issue

Note: DEF is typically colorless and clear

Changes in DEF % concentration can occur for a variety of reasons, including evaporation of water, degradation of urea, or contamination

4) Estimate needed DEF quantity:
   a) Use consumption based on 5-10% as related to fuel consumption
   b) Plan for a capacity safety margin of 5% of the total DEF tank volume to ensure adequate supply (2% of which is a margin for freeze protection)

DEF / Urea solution - transfer

1) Follow the safety measures above

2) Transfer DEF between the storage temperature recommendations shown in the table above

3) When dispensing DEF, use dedicated compatible filer, preferably a mesh-type of compatible metals, such as stainless steel

Do not use containers or funnels that have been used with other materials previously as this may cause contamination.

Note: Contaminants can degrade the quality and life of DEF

4) Maintain the installed strainers, screens and filters in the DEF system

5) Protect the DEF supply line from freezing and damage from foreign objects by regularly checking filters (or draining the supply line / filters if system is shut down in freezing conditions or put into storage

6) Protect the DEF tank from freezing by heater or other means

DEF / Urea solution – cleanliness, spills and leaks

1) Clean spills immediately, wipe surfaces, rinse with warm water

2) Contain spill as much as possible

Do not flush to sea

Dispose through a licensed waste disposal company, follow local regulations

3) Use caution when dispensing DEF near hot components (e.g. an engine that has recently been running)

Spilling DEF onto hot components will cause it to vapourize which can be harmful

4) Monitor condition of hoses and other non-metallic components for signs of degradation due to the corrosive nature of DEF

5) Check system and connections for leaks

Note: DEF leaks are easily recognizable by white urea crystals that accumulate at the site of the leak

Addressed leaks immediately as solid DEF is very corrosive to galvanized or unalloyed steel, aluminum, copper, and brass

CEM = Clean Emission Module – maintenance precautions

6) Welding

Welding of the CEM housing or mixing tube is strongly discouraged

Note: It is permissible to add exhaust lagging pins to the reactor housing for insulation purposes

7) Painting

Do not paint the CEM

Note: Skin temperatures of the CEM can reach as high as 525°C during operation and will cause charring and burning of the paint

■■ Completed ■■

SCR - OPERATIONAL PROCEDURES

1) Plan for use of the SCR system in advance before entry in a Marpol VI Tier III NOx ECA (North America and US Caribbean Sea) as part of the voyage planning process

2) Ensure the DEF concentration is within the required limits above

3) Operate the SCR with DEF injection always in a Tier III NOx ECA for emission compliance

4) Record in the Engine Logbook, together with the date, time and position of the ship:
   a) the tier and the on/off status of the marine diesel engines at the entry into and exit from the NOx ECA
   b) when the on/off status changes within such an ECA
   c) low or invalid aftertreetment events / alarms

   advise such inadequate aftertreatment events also shoreside to your Vessel Technical Group/Fleet Cell for ensuring reporting non-compliance (e.g. to US EPA)

   d) bunkering of DEF / Urea solution

5) Record in the Record Book of Engine Parameters (or PMS) all maintenance work

6) Maintain the SCR system as per manufacturer's recommendations including sensors calibration

Do not replace emission related components of the SCR system unless with such listed/approved in its Technical File or otherwise approved by the Administration

Replace such components with parts approved by the Manufacturer

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