Technologies for Reducing Black Carbon From Marine Engines

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- **3500 Series**
  - 8, 12, 16 cylinder
  - 526 – 2525 kW

- **C175 Series**
  - 16 cylinder
  - 2001 – 2168 kW

- **C32**
  - 12 cylinder
  - 492 – 1417 kW

- **C18**
  - 6 cylinder
  - 339 – 847 kW

- **C12**
  - 6 cylinder
  - 254 – 526 kW

- **C9**
  - 6 cylinder
  - 93 – 123 kW

- **C7.1**
  - 6 cylinder
  - 100 – 190 kW

- **C 4.4**
  - 4 cylinder
  - 93 – 123 kW

- **710 Series**
  - 8, 12, 16, 20 cylinder
  - 1400 – 4000 kW

- **M 20 C**
  - 6, 8, 9 cylinder
  - 1020 – 1710 kW

- **M 25 C**
  - 6, 8, 9 cylinder
  - 1900 – 3000 kW

- **M 32 C / E / DF**
  - 6, 8, 9 cylinder
  - 2880 – 5000 kW

- **VM 43 C**
  - 12, 16, 20 cylinder
  - 10800 – 18000 kW

- **M 43 C**
  - 6, 7, 8, 9 cylinder
  - 6000 – 9000 kW

- **VM 46 DF**
  - 12, 16, 20 cylinder
  - 5400 – 8100 kW

- **M 46 DF**
  - 6, 7, 8, 9 cylinder
  - 12000 – 16000 kW

- **VM 32 C**
  - 12, 16 cylinder
  - 6000 – 8000 kW

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  - 5400 – 8100 kW

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The following engine system technologies are available TODAY to reduce black carbon:

- FCT (flexible camshaft technology)
- Natural Gas Engines (& dual fuel engines)
- SCR (selective catalytic reduction)
Reducing PM also reduces black carbon

- In engine test cells, manufacturers measure PM (particulate matter) which includes both black carbon and non-black carbon components.
- The black carbon to non-black carbon ratio varies.
- Reducing PM with the technologies discussed in this presentation also reduces black carbon.
Flexible Camshaft Technology

• Normally, lower engine loads results in higher PM.
• FCT allows for PM reduction at low loads (e.g. operation under ice conditions in the Arctic) while maintaining optimum performance at high loads.
• At low loads, FCT retards intake valve timing while advancing start of injection (SOI) to reduce PM.
• Improves transient response at low engine loads (i.e. low vessel speeds).
• Valve and injection timing return to normal when operating at higher loads.
FCT major components

Valve drive
Cam shaft
Actuator
Controller

https://www.youtube.com/watch?v=iL1nVAJdijU
Example of FCT on a marine engine
Natural gas fuel can reduce black carbon

• Natural gas and dual fuel (NG w/ diesel ignition) engines can be designed to have low PM.
• Dual fuel engines can lower emissions on a per-unit energy basis when compared with diesel (including lower CO₂ emissions).
• Dual fuel engines are available as new.
• Existing engines can also be retrofitted.
MaK M 46 DF

- Dual fuel engine can reduce PM by 90%.

Source: Andreas Banck (MaK)

https://youtu.be/_Xjj6KJ_Qr4?list=UU7nWdc4LnuDTSp4j2Clyid
SCR systems lower both NO\textsubscript{x} and PM

- A study published by IMO in 2015 stated that “There is sparse evidence that BC reductions can occur with SCR (up to 35%)”
  - Study assumed SCR is retrofitted without any engine optimizations and does not account for in-cylinder PM reduction.
  - It is common for today’s SCR optimized engines to reduce PM by up to 80% over IMO II while improving fuel economy.

- SCR aftertreatment reduces NO\textsubscript{x} by +90%.
  - 15% BC reduction expected with Vanadia SCR.

- US EPA Tier 4 Marine and IMO Tier III engines utilizing SCR have significant reductions in PM.
Engine operation optimized for SCR

- Ideally, start with an engine designed for low-PM / BSFC.
- Calibrate engine for low PM emissions.

- This has the added benefit of reducing fuel consumption.
- SCR + urea is then used to reduce exhaust NOx down to a desired level.
Available Caterpillar / MaK SCR Systems

Key features:

- Complete marine certification society solution.
- Consists of SCR chamber, mixing tube, urea injection system and dosing cabinet.
- Urea transfer pump skid optional available.
- IMO Tier III certification.
- Optimized engine and SCR system.
- Application and installation support for every market segment and ship type.
- Available as a retrofit package.
Summary

• Good options exist today to reduce black carbon, for both new engines and as retrofits for existing engines.

• SCR with optimized engine is an attractive solution because it also improves fuel economy (lowers CO$_2$) while reducing black carbon.

• US EPA Tier 4 Marine and IMO Tier III engines utilizing SCR have significant reductions in black carbon.