Ministry of Oceans and Fisheries

PM/BC Reduction by DPF and wet-ESP for marine ship engines:

Recent R&D in Korea

Sunho Park

Associate Professor
Department of Mechanical Engineering

Dankook University
Republic of Korea

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Outline

Ministry of Oceans and Fisheries

1. Background
2. R&D Overview
3. DPF for 400kW Ship Engine
4. Wet-ESP for 3MW Ship Engine
5. Summary and future plan

1. Background

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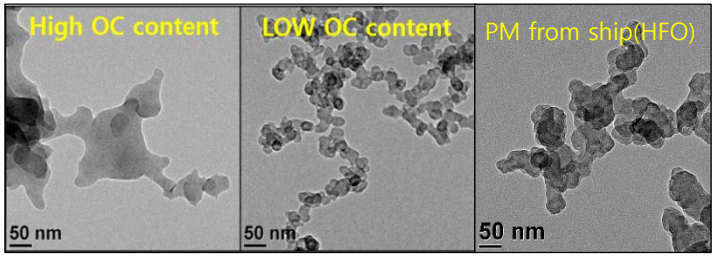
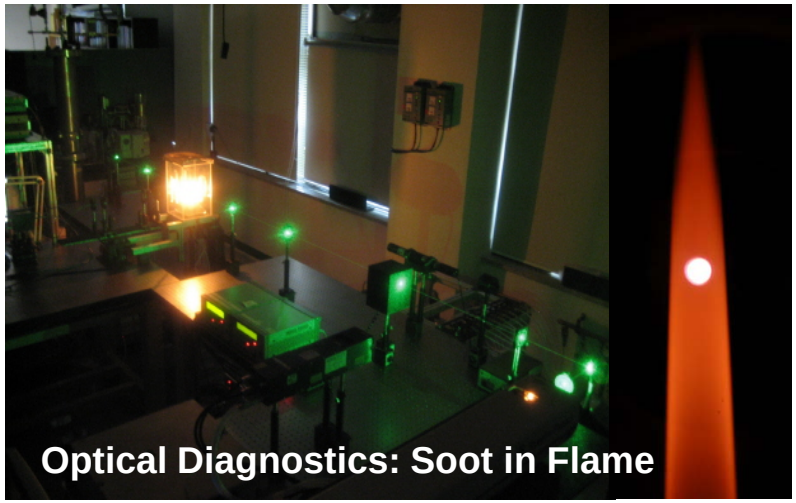
Speaker's research at Dankook University

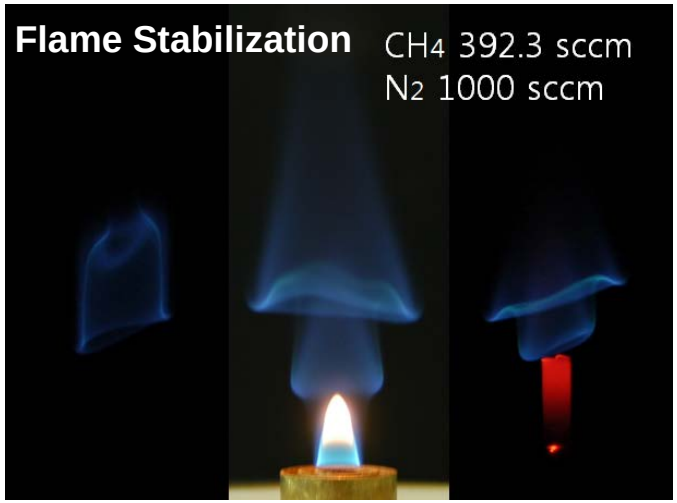
Synthesis and Characterization of PM



Animal Exposure

VOC Removal by Plasma





1. Background

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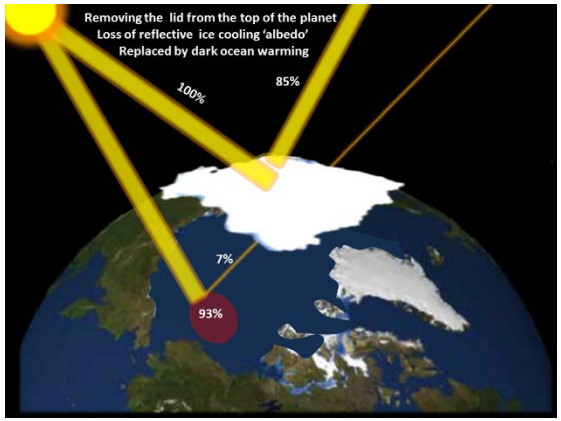
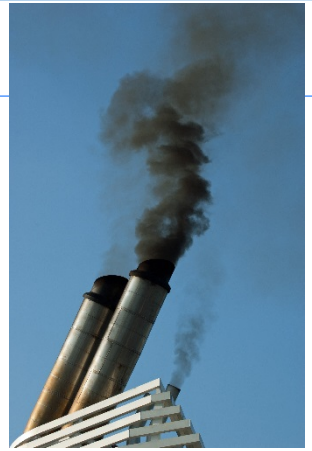
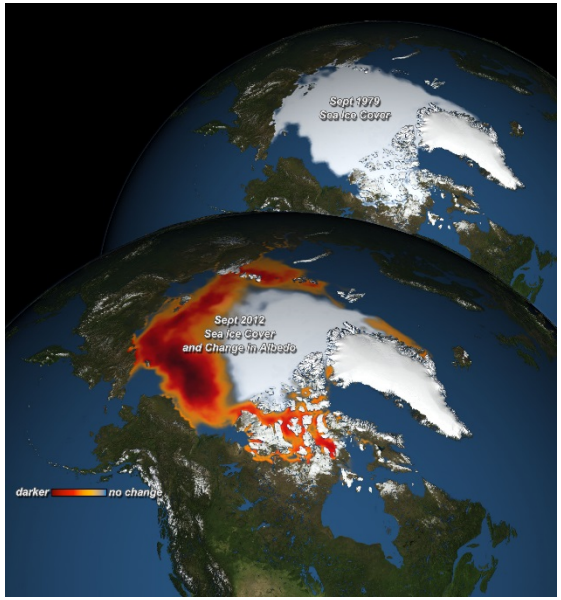
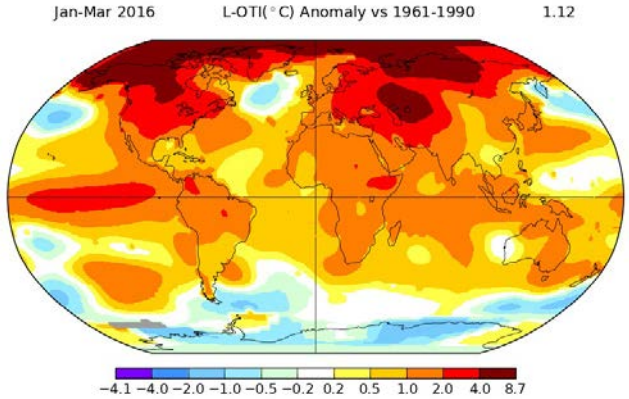
Air pollutants from ship and their climate effects









Source: Atmospheric Sciences

1. Background

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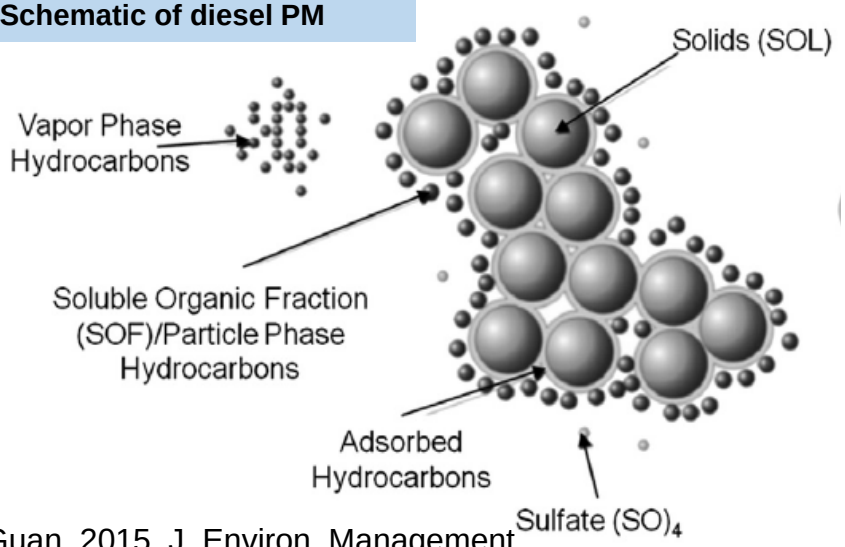
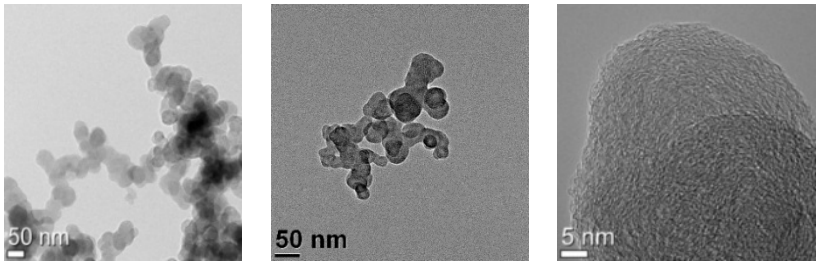
Particulate Matters

Schematic of diesel PM

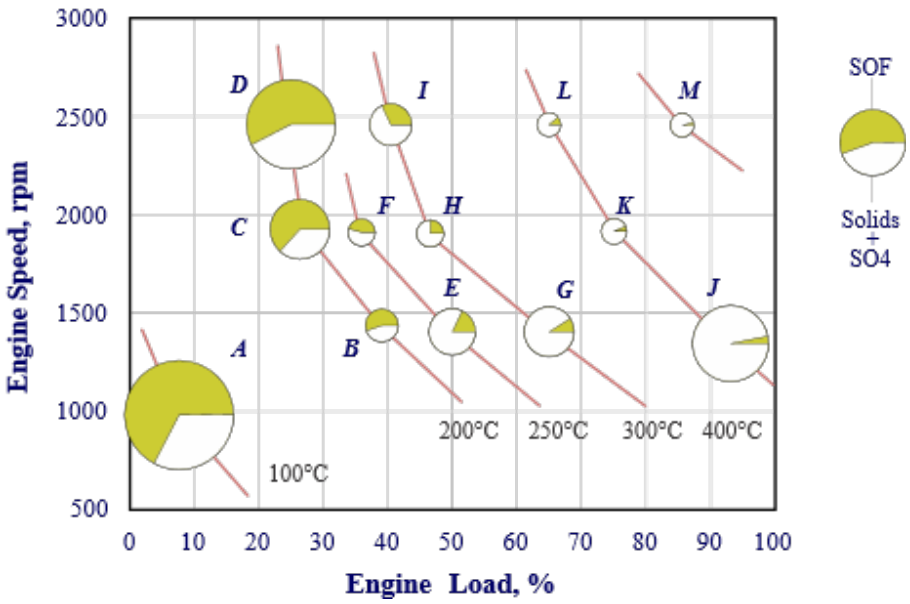


Guan, 2015, J. Environ. Management

Main fractions	Sub-category
Solid fraction (SOL)	- Elemental carbon - Ash
Soluble organic fraction (SOF)	- Organic material derived from L.O. - Organic material derived from Fuel
Sulfate particulates(SO_4)	- Sulfuric acid - Water
Total particulate matter(TPM) = SOL + SOF + SO_4	



[TEM image of particulate matters]



Source : Diesel particulate filter, www.dieselnet.com

1. Background

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IMO PPR Agenda

‘Consideration of the impact on the Arctic of emissions of Black Carbon from international shipping’

▶ We finalized the definition for Black Carbon,

▶ We have been identifying appropriate methods for measuring black carbon emissions, and

▶ We are considering possible control measures that reduce black carbon emissions from international shipping.

1. Background: Global Projects

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Cleanest ship project

Fuel

- Low sulfur fuel

Operation

- Advising speed control

After-treatment system

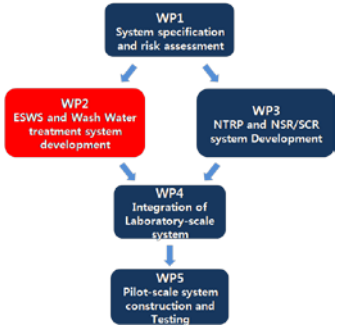
DPF + SCR

Contents	NOx	PM	SOx
Engine out emission	8	0.15	0.81
Emission with reduction tech.	0.2-2.2	0.004	0.004
Reduction rate(%)	72.5-90.0	97.3	99.5

DEECON project

Innovative After Treatment System for Marine Diesel Engine Emission Control

Budget: 3.465 M€
Duration : 3 yr. (09/2011 ~ 08/2014)



Electrostatic Sea Water Scrubber(ESWS)

- SOx and PM removal

Non-thermal Plasma Reactor

- NOx and VOC abatement

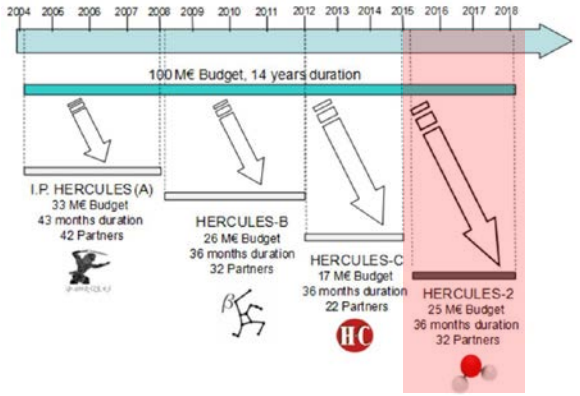
SCR

- Removal of any residual NOx

ESWS wash water treatment system

- Treatment of liquid by-products

HERCULES project



Budget: 86 M€ + 25 M€
Duration : 119 months + 36 months

The objectives of the HERCULES-2

- Fuel flexible engine
- New materials
- Adaptive power plant
- **Near-zero emissions engine**

Work package 8

- 80% PM reduction with after-treatment system
- Adaptation and integration of after-treatment system(SCR on DPF)

1. Background

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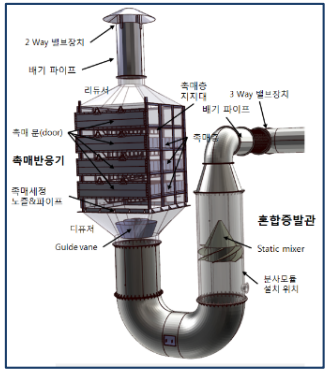
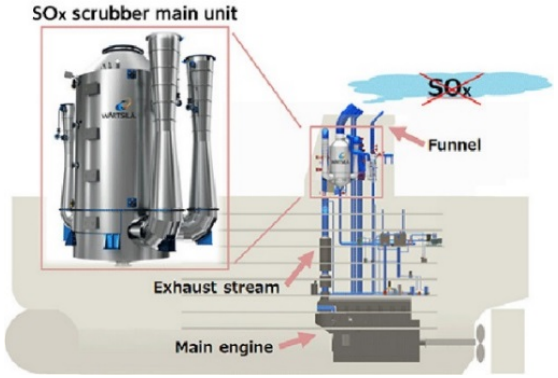
Recent government-supporting R&D in Korea

❖ **Development of NOx reduction unit for 10,000 ps-class ship engines (2011~2017, Ministry of Oceans and Fisheries)**



❖ **Installation and proof of SOx scrubber for ships toward IMO global sulfur cap (2018~2021, Ministry of Oceans and Fisheries)**



❖ **EGCS for Tier Ⅲ regulation and 0.1%-sulfur fuel (2012~2014, Ministry of Trade, Industry and Energy)**

2. R&D Overview

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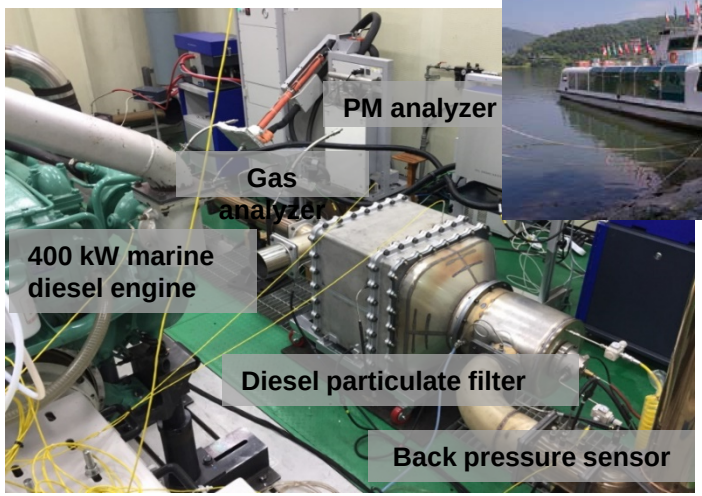
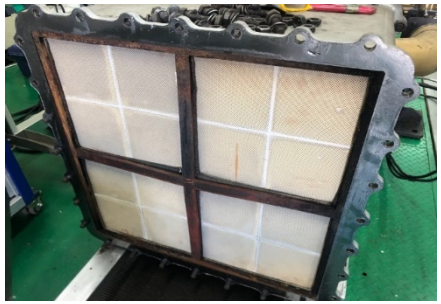
Development of DPF and wet-ESP for ships

- 2012-2018, Ministry of Oceans and Fisheries

DPF system for sub-MW engine

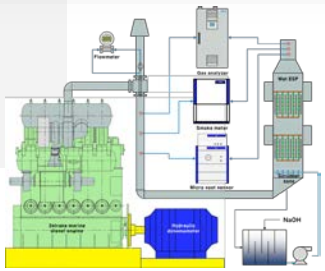




<**Inlet and outlet view in DPF system**>

Wet ESP system for MW engine

<2 st. diesel engine HHI-MAN B&W 6S46MC-c7>



2. R&D Overview

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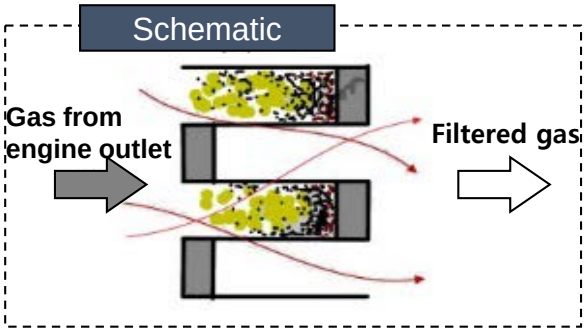
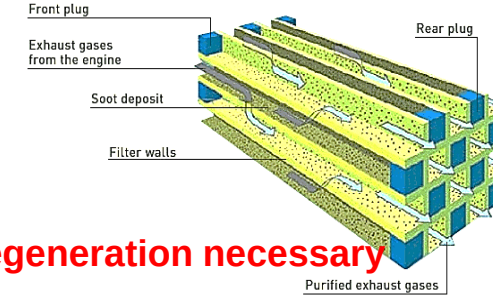
Basic Principles

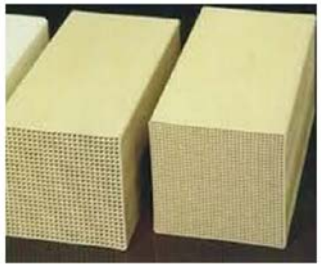
❖ Diesel Particulate Filter



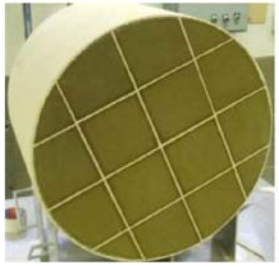


Regeneration necessary

13“ coated substrate

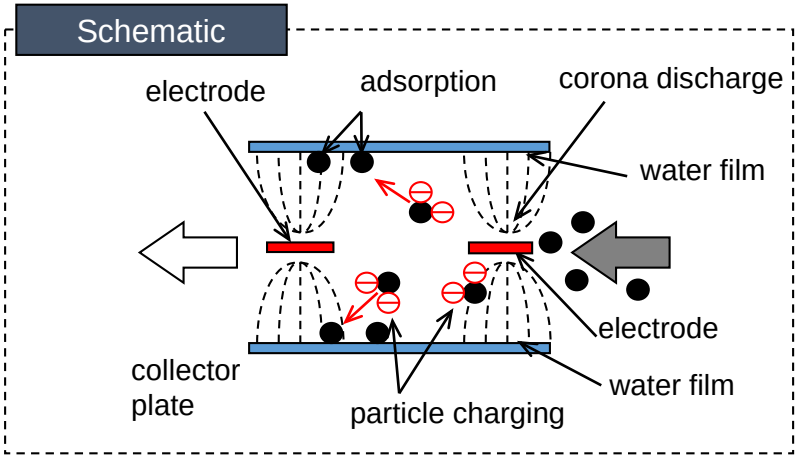


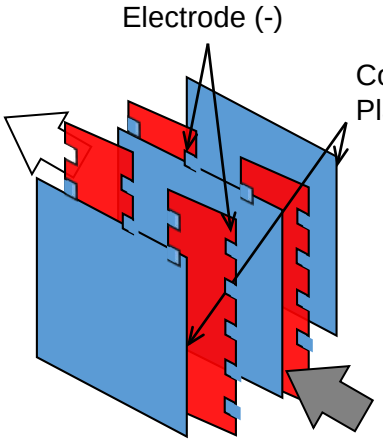
6“square substrates



24“ substrate

❖ Wet Electro-static Precipitator





Flushing of collector plate necessary

2. R&D Overview

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Ship application characteristics and the R&D objectives

▶ **Ship application characteristics**

- High sulfur content in fuel results in SO_2 in exhaust gas and a high sulfate fraction in PM
  : Sulfur poisoning of catalyst, Corrosion of ESP electrode, etc.
- PM contains more SOF (soluble organic fraction)
  : Controlling regeneration of PM in DPF is harder, DOC functionality issue
- Size of the after-treatment system is much greater than the system for land vehicles
- Allowable back pressure is lower
- Ship stability issue

⋮

▶ **Objectives: Not only deal with the issues in the above, but also satisfy the following conditions ;**

❖ **Diesel Particulate Filter**

400 kW engine DPF	
Back Pressure	< 100 mbar
PM/BC reduction	> 90 %

❖ **Wet Electro-static Precipitator**

3MW engine ESP	
Back Pressure	< 60 mbar
PM/BC reduction	> 90%

on par with existing systems

2. R&D Overview

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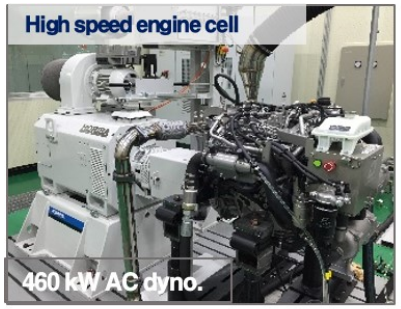
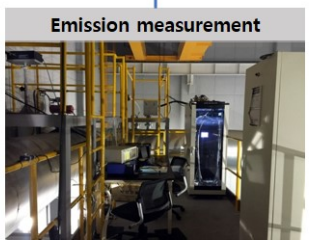
Test bench for marine engine emission and performance

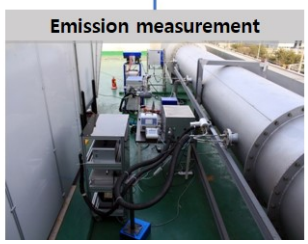
Low speed engine cell

Korean Register
Testing & Certification Center
Gunsan, Korea

High/midium speed engine cell







- Fuel : Bunker-A (0.29%S), high sulfur diesel(0.34, 0.05%S), ULSD(< 10 ppmS)
- Engine : HHI-MAN 6S46MC(2-str., 7.4 MW), Doosan Infracore 4V158TIH(4-str., 403 kW)
- Test cycle : E2, E3 cycle from ISO 8178

2. R&D Overview

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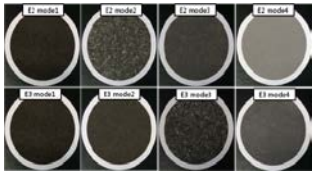
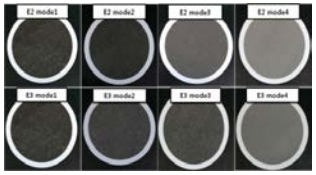
PM emission from the test engines

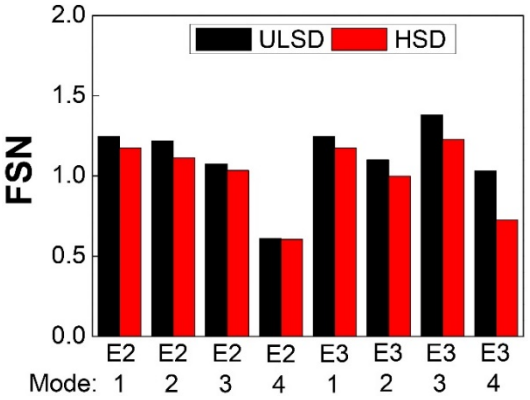
❖ **2-st 7.4 MW engine**

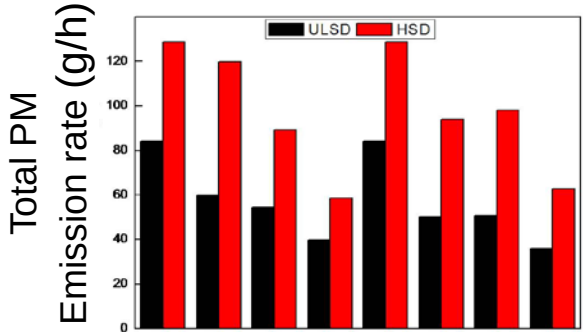
ULSD

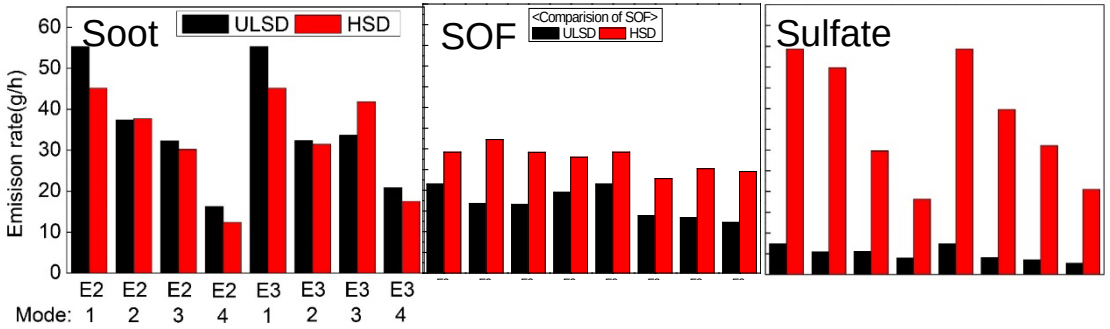




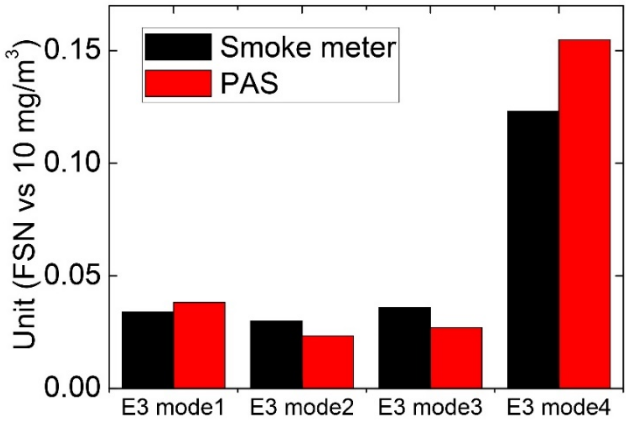
HSD

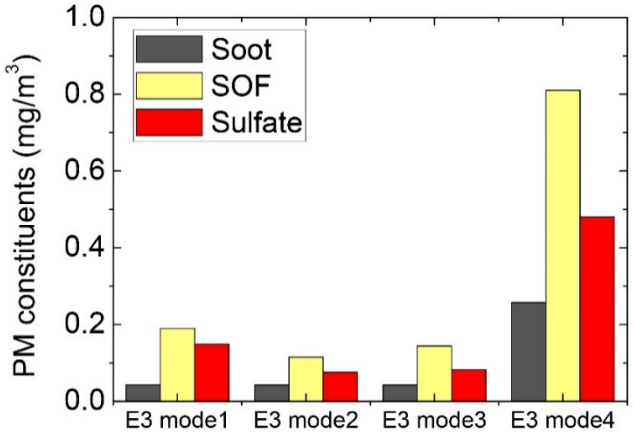






❖ **4-st 400 kW engine (ULSD)**





3. DPF for 400 kW ship engine

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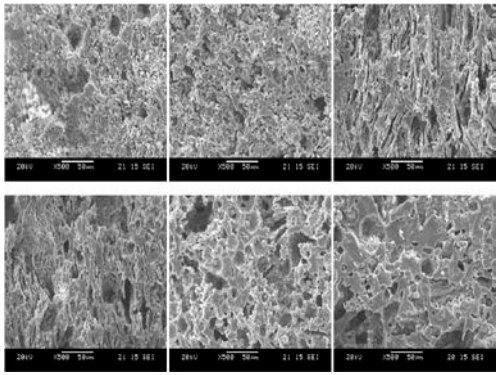
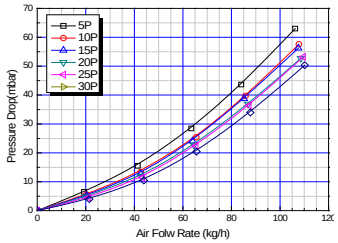
Part design and development

❖ Pore former and microstructure of the substrate

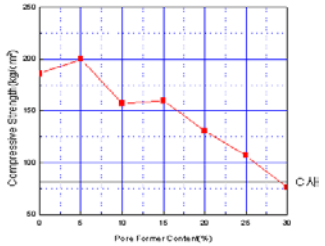


Parameter	Pore former					
	Graphite				PMMA	Walnut shell
	A	B	C	D		
Density [g/cm^3]	1.3	1.3	1.3	1.3	1.3	1.2
Porosity [%]	50.1	50.6	49.9	51.0	50.5	53.7
Ave. pore size [㎛]	6.7	6.7	6.8	7.7	8.0	10.7
Intrusion vol. [cc/g]	0.40	0.27	0.37	0.39	0.37	0.30

Air Flow Rate vs Back Pressure



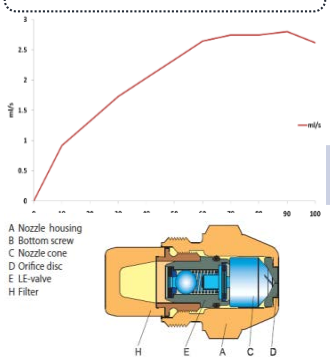
Compressive Strength vs Pore Former Cont.(%)



❖ Active regeneration burner

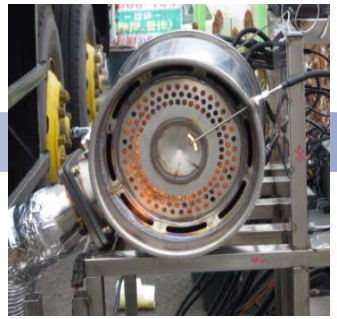
Air flow controller

Fuel injecting nozzle

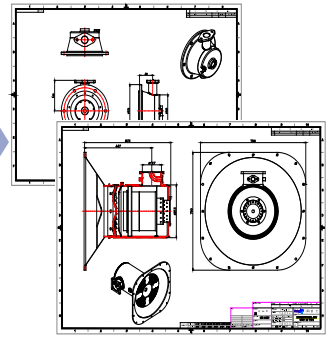


Flame control

Ignition test



Burner systemization



3. DPF for 400 kW ship engine

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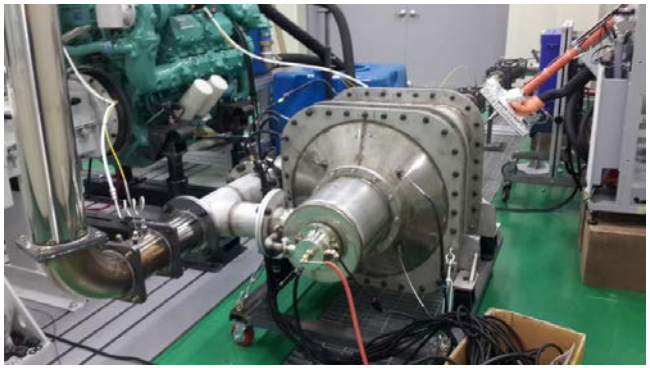
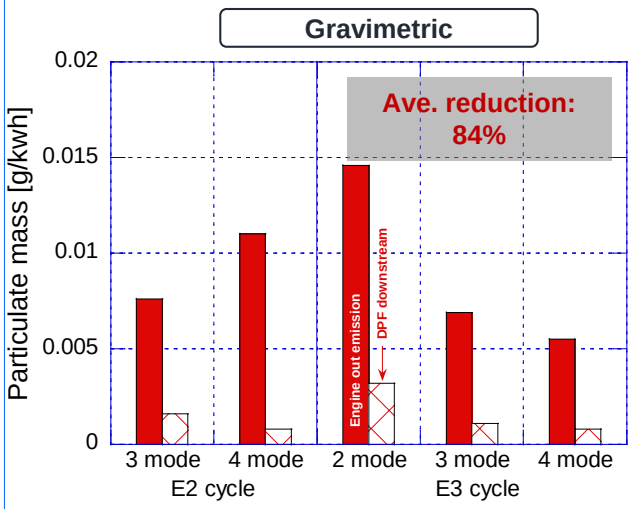
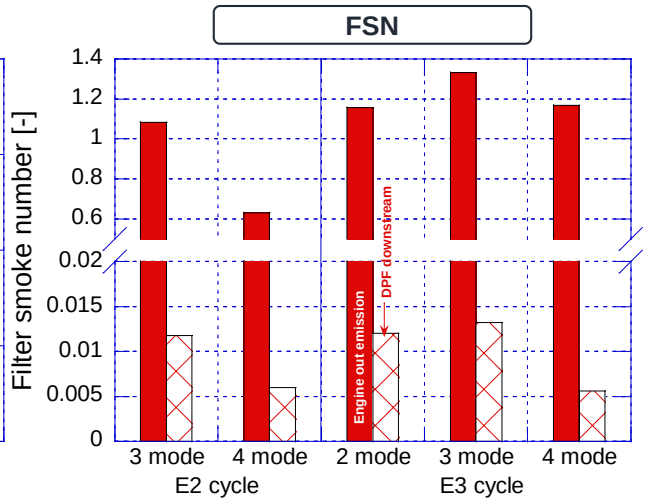
Test results

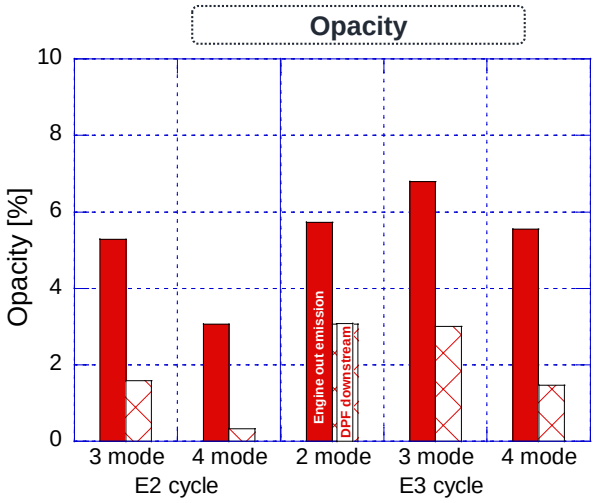
❖DPF system for 400 kW engine

Experimental conditions (E2 & E3 cycle)								
Cycle	E2 cycle				E3 cycle			
Power [kW]	403	302	202	101	403	302	202	101
Speed [rpm]	1,800				1,800	1,638	1,440	1,134
Torque [Nm]	2,139	1,604	1,069	535	2,139	1,763	1,337	849
Mode	1	2	3	4	1	2	3	4







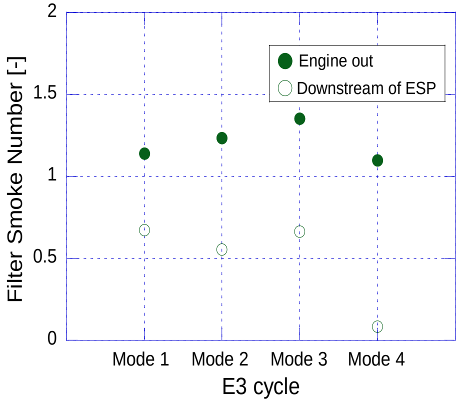


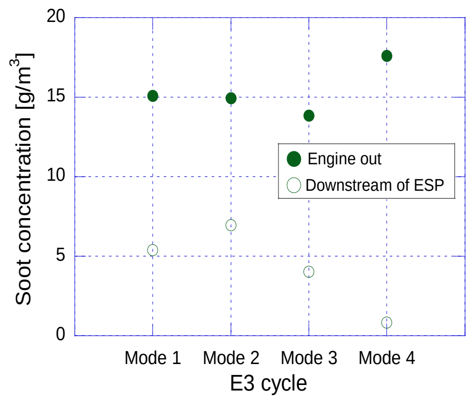
4. Wet-ESP for 3MW ship engine

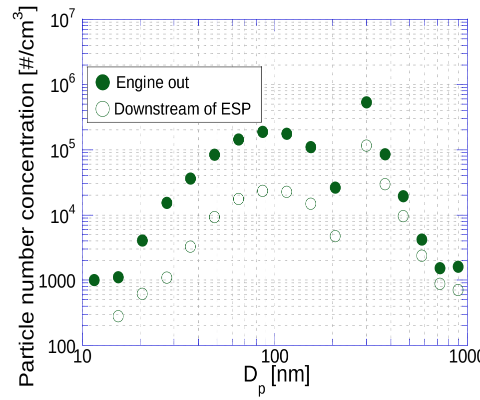
Ministry of Oceans and Fisheries

Background research

❖ Electro-static precipitator



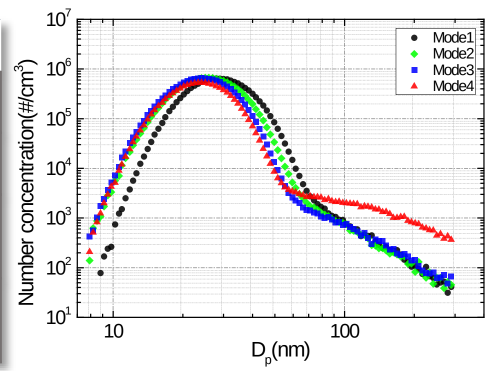


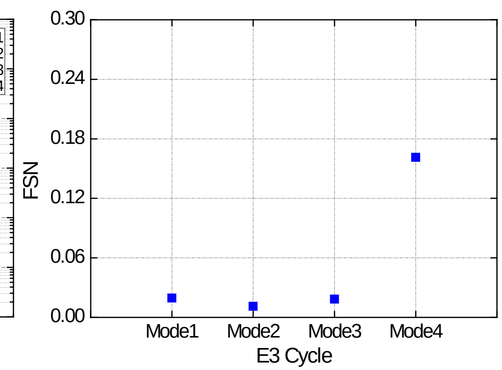


❖ 2-st 7.4 MW engine emission measurement

Experimental condition (E3 cycle)

Mode	1	2	3	4
Power [kW]	7,400	5,500	3,700	1,850
Speed [rpm]	129.0	117.2	102.4	81.3
Torque [Nm]	547.8	452.2	345.0	217.3

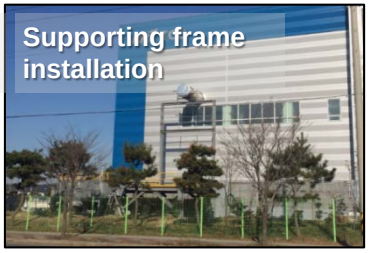




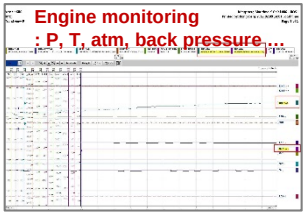
4. Wet-ESP for 3MW ship engine

Ministry of Oceans and Fisheries

Installation and test



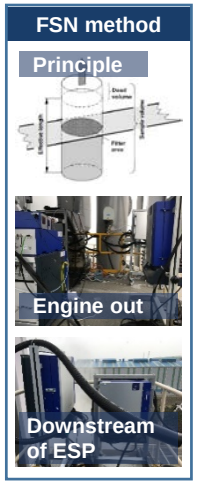
Engine Specifications	
Power [kW]	7,400 @ 129 rpm
Bore x Stroke	460 x 1,932
Cylinder number	6
Fuel cons. [kg/h]	1,393
Engine type	2 stroke

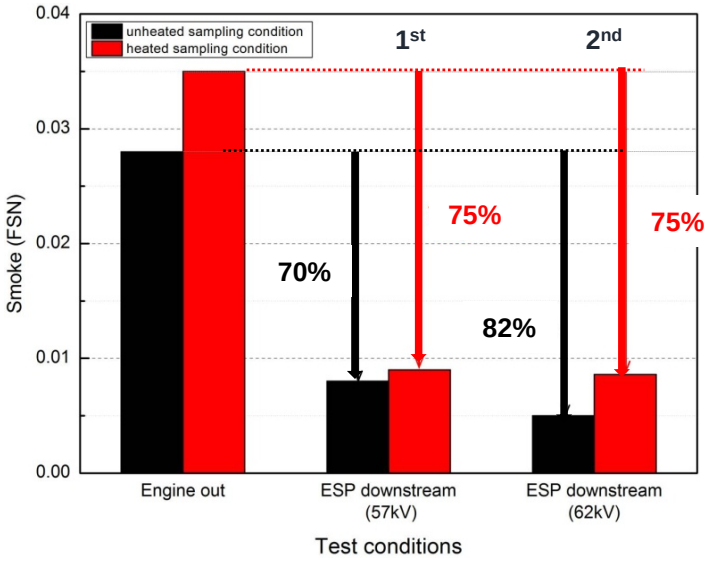


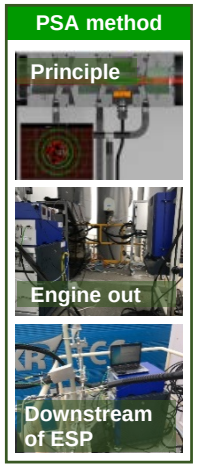
4. Wet-ESP for 3MW ship engine

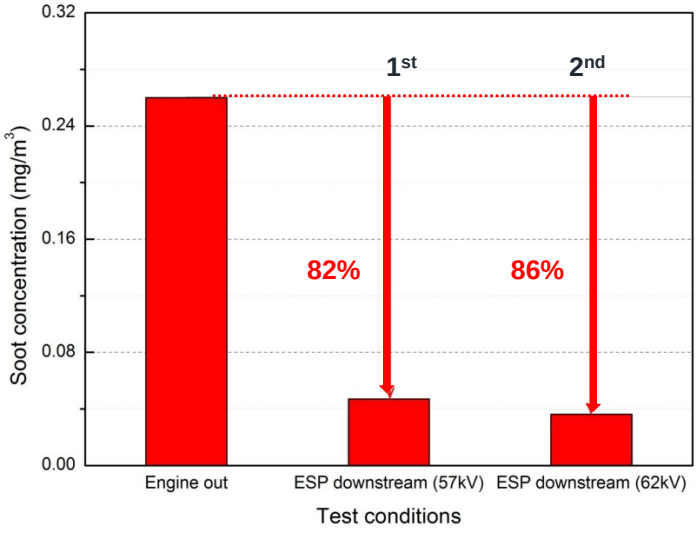
Ministry of Oceans and Fisheries

Test results









❖ PM/BC reduction

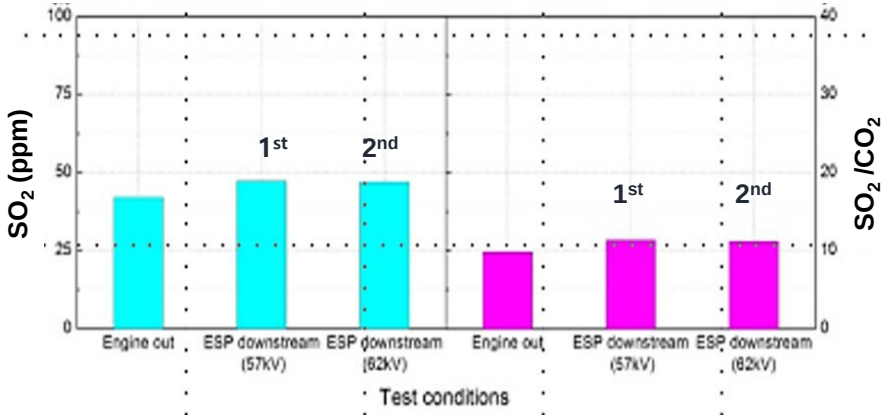
- FSN method: 75-82%
- PAS method: 82-86%

❖ Back Pressure

~ 38 mbar

❖ Gaseous emissions

rarely removed

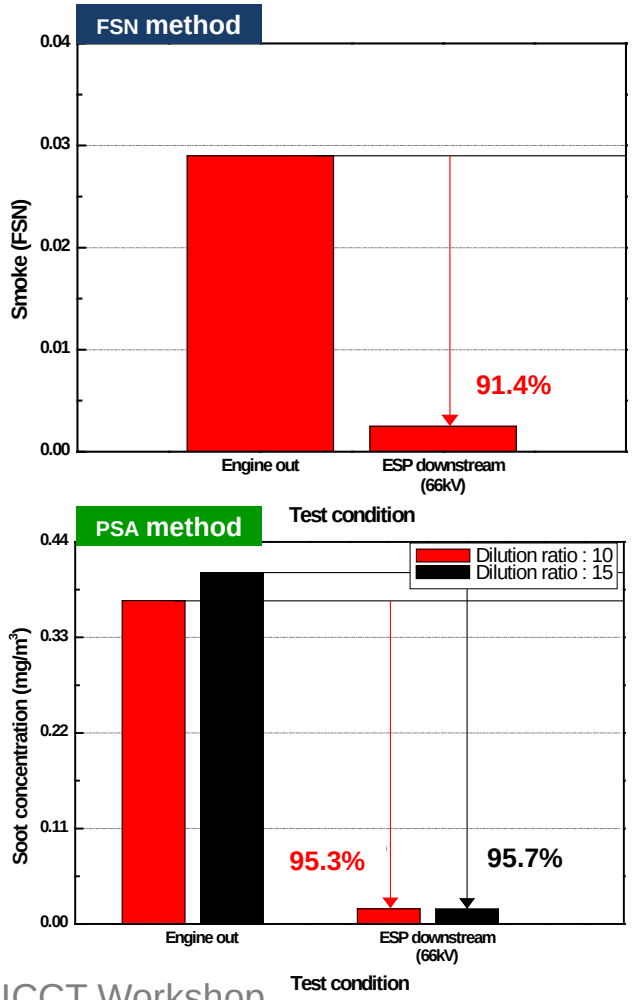


4. Wet-ESP for 3MW ship engine

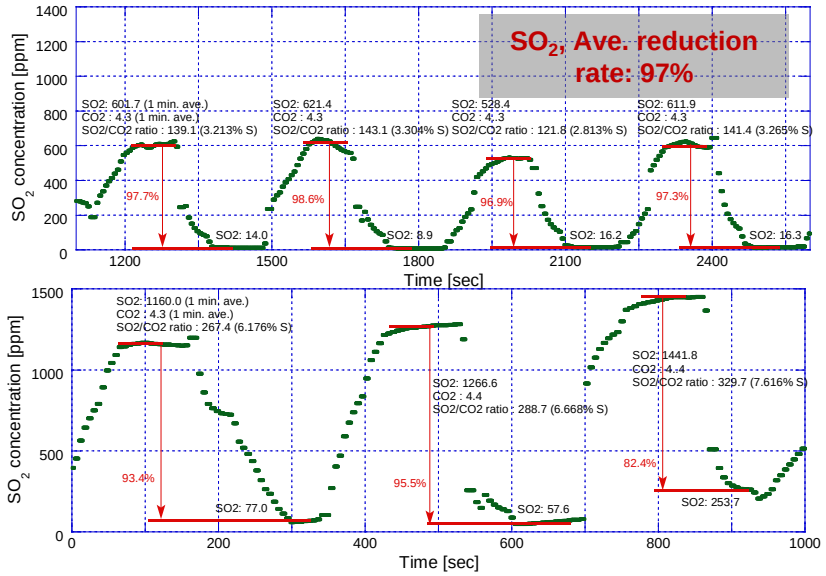
Ministry of Oceans and Fisheries

Test result of the final product

❖ PM/BC reduction



❖ SO_2 reduction



❖ Performance of the final product

- Back pressure: 31 mbar < 60 mbar
- SOx reduction: 97%
- PM/BC reduction: 91.4% > 90%

5. Summary and future plan

Ministry of Oceans and Fisheries

Summary and future plan

▶ DPF system for sub-MW class and wet-ESP for MW class marine engine developed in Korea

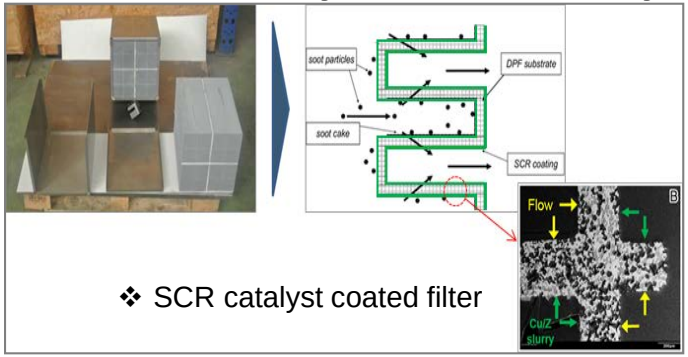
400 kW engine DPF	
Back Pressure	57 mbar
PM/BC reduction	96 %
Fuel Consumption increase & Power loss	0.9 %

3MW engine ESP	
Back Pressure	31 mbar
PM/BC reduction	91 %
SOx reduction	97 %

▶ Real ship installation and proof will be performed soon.

❖ **Real ship proof of the developed DPF system (2018-2021, Ministry of Oceans and Fisheries)**

❖ **Development of <u>SCR on DPF system</u> for 500 kW marine engines (2018-2021, Ministry of Trade, Industry and Energy)**



5. Summary and future plan

Ministry of Oceans and Fisheries

Control measures under consideration (IMO PPR CG)

- Fuel Type

  ⋮

- Fuel Treatment

  ⋮

- Exhaust gas treatment

Diesel Particulate Filters (DPF)

Electrostatic Precipitators (ESP)

Selective Catalytic Reduction (SCR) with Diesel Particulate Filter (DPF)

Covers both SCR combined with DPF in a serial connection, and SCR-F technology. The latter is a single device which has the functions of both SCR and DPF by coating SCR catalysts on a filter for DPF.

⋮

Ministry of Oceans and Fisheries

Thank you very much for your attention!

Sunho Park

Associate Professor of Mechanical Engineering
Dankook University
Republic of Korea

E-mail: sunhopark@dankook.ac.kr