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Reduction of PM and BC Emissions from Marine Diesel Engines Using ESP-Cyclone System

Contents

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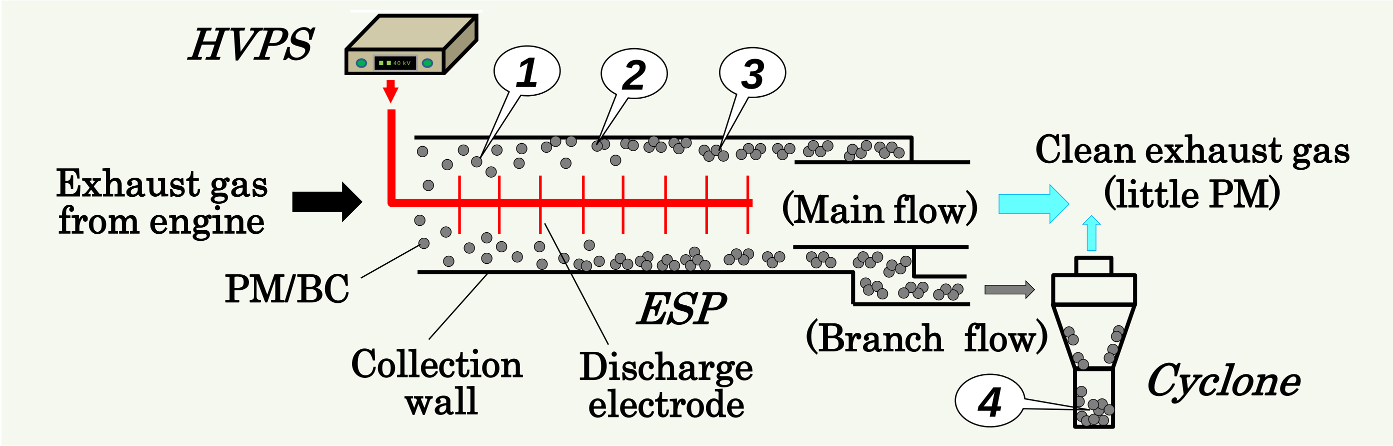
Outline of developed ESP-C system (1/2)

--- Mechanism of PM / BC collection by ESP-C (Figure 1)



(1) PM in exhaust gas: Charged by corona electrons.

(2) Charged PM: Collected on the collection wall and forms agglomerated PM.

(3) Agglomerated PM: Naturally peels off from the collection wall as large agglomerated PM and then flows to the downstream.

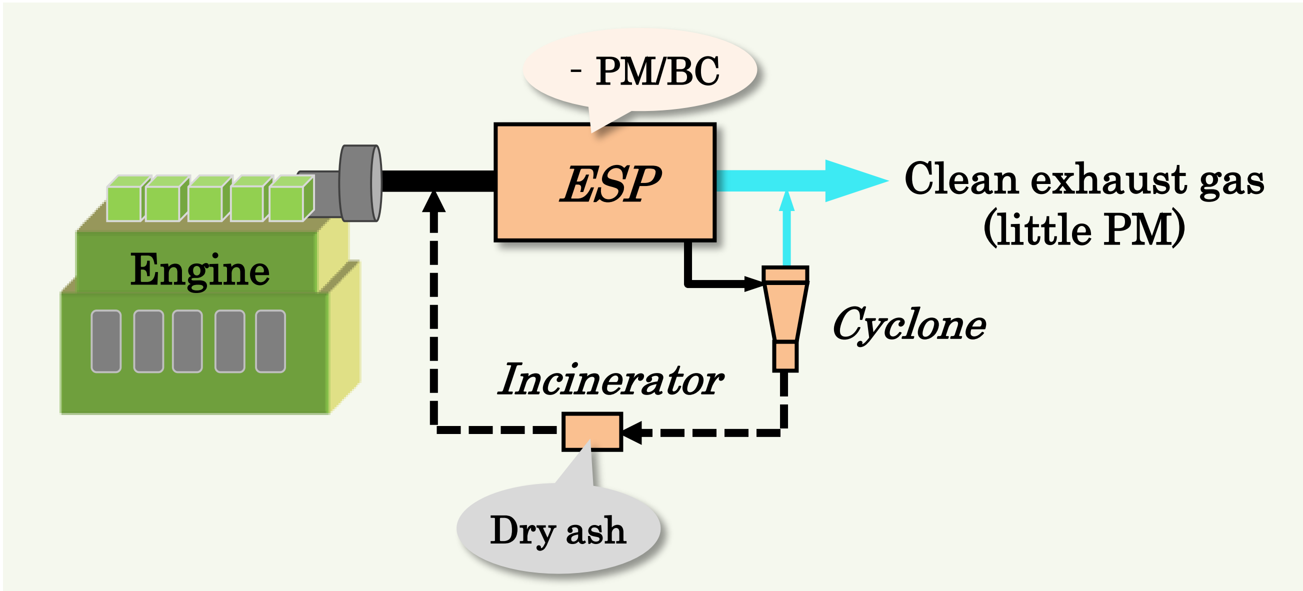
(4) Peeled agglomerated PM: Finally, collected in the Cyclone dust hopper.

PM collection mechanism was verified by experiment, as explained later.

Note: The ESP can collect solid particles (soot, metal, ash) and mist (condensed SOF), but cannot gaseous materials (gas-phase SOF).

Outline of developed ESP-C system (2/2)

--- Configuration and advantages of ESP-C



<u>Advantages of ESP-C</u>

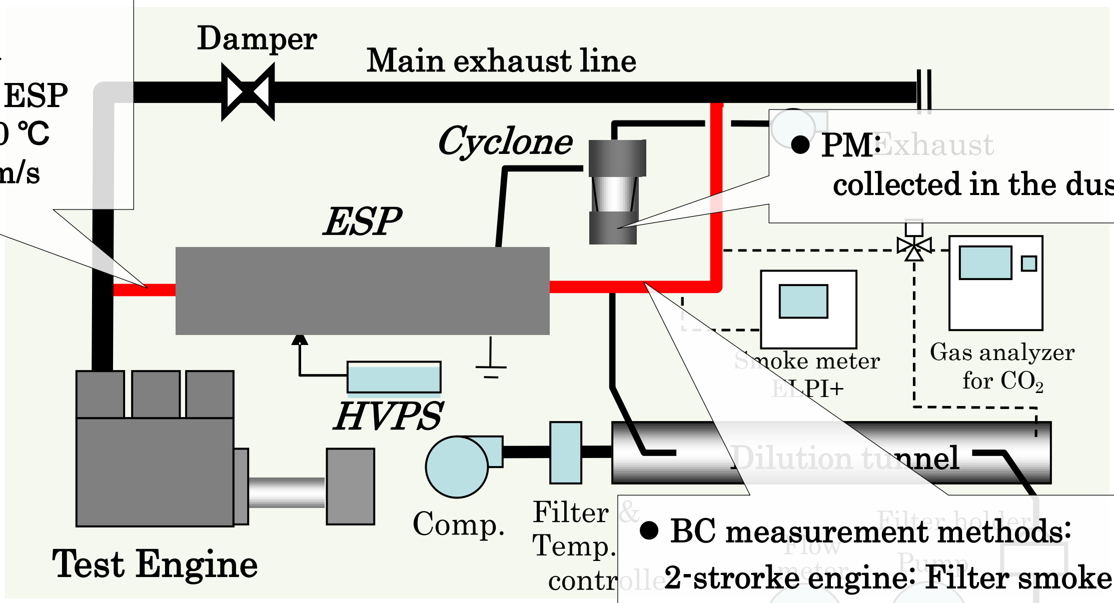
1) ESP and Cyclone do not clog.
   → ESP-C can be operated continuously without maintenance.
2) PM collected in Cyclone dust hopper is burned in the shipboard incinerator.
   → The final waste of the ESP-C is a small amount of dry ash.
3) ESP has low pressure loss and low power consumption.

Outline of experiments (Figure 2)

Test engines and main conditions

- Two-stroke marine diesel engine
  - ・ 1,275 kW, 162 rpm, 3 cyl.
  - ・ MDO, HFO（S 2.26 %）
- Four-stroke diesel engine
  - ・ 3,500 kW, 750 rpm, 6 cyl.
  - ・ MDO, HFO（S 1%）

- Branch flow to ESP
  - ・ about 4,500 m^3/h
- Exhaust gas flow in ESP
  - ・ Temperature: 300 ℃
  - ・ Gas velocity: 10 m/s



- PM: collected in the dust hopper

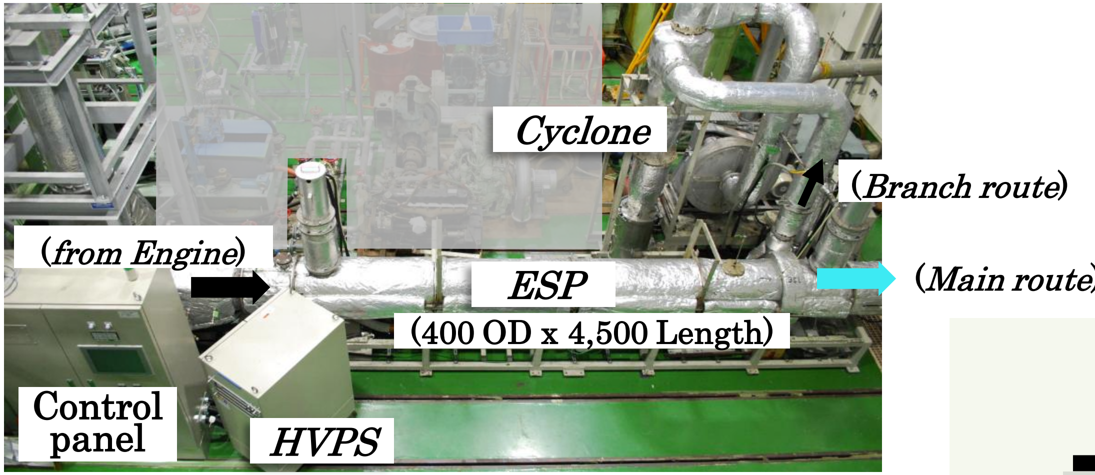
- BC measurement methods:
  2-strorke engine: Filter smoke meter- → FSN
  4-strorke engine: ELPI+ → PM/BC concentration

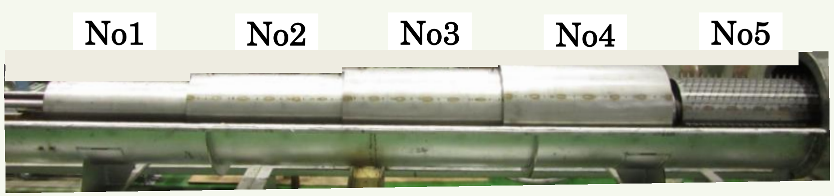
Provisional goal in experiments

- BC collection efficiency η_{BC} 80%
  at Gas velocity in ESP 10 m/s

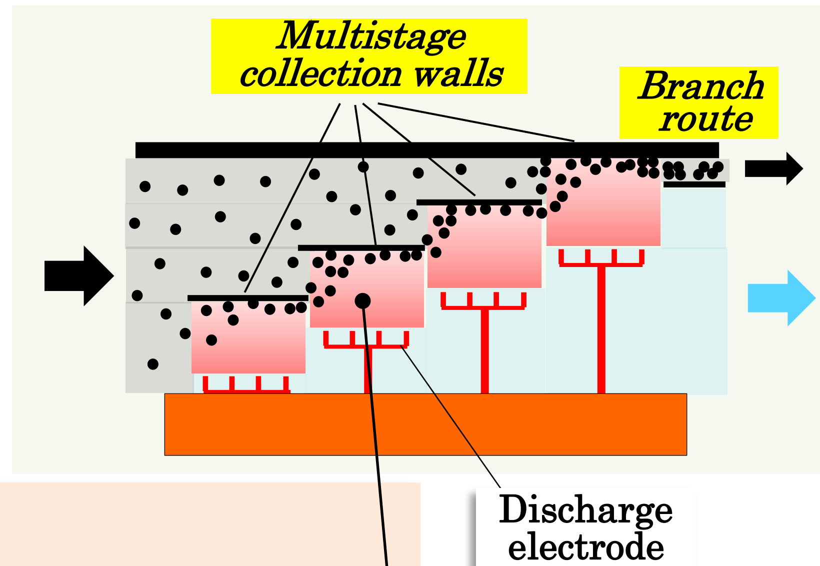
$\eta_{BC} = 1 - (\text{BC ESP-outlet})/(\text{BC ESP-inlet})$

Improved ESP-C used in experiments (Figure 3)





Multistage collection walls (circular section)



<u>Main points of improvement</u>

1) To realize high collection efficiency of ESP:

→ *Multistage collection walls*

→PM flows only in the strong electric field region.

2) To downsize Cyclone:

→ *Branch route* → Cyclone flow can be reduced.

3) To downsize ESP:

→ *Explained later*

Experimental evaluations with two-stroke engine

1,275 kW
162 rpm, 3 cyl.

1-1) BC collection efficiency η_{BC}

- Experimental conditions: load 75%, 290 ℃
- Smoke meter method --- FSN

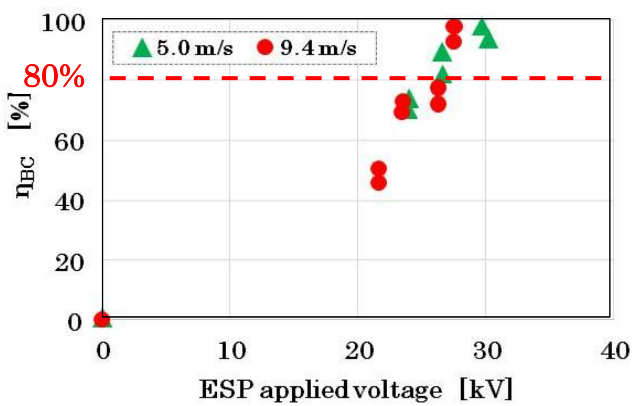


Figure 7 η_{BC} vs Voltage (MDO)

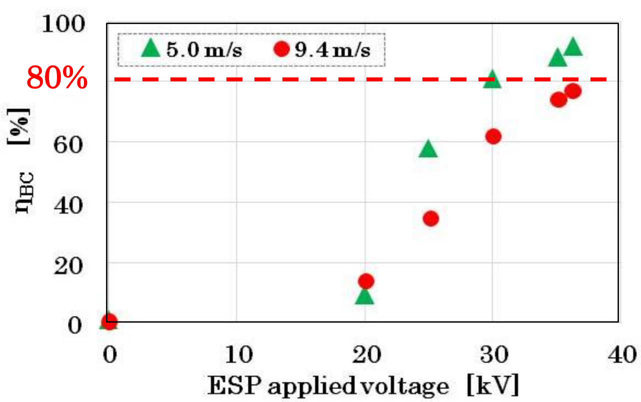
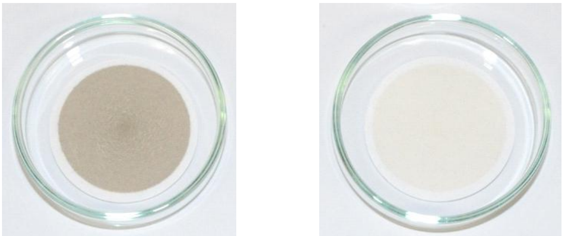


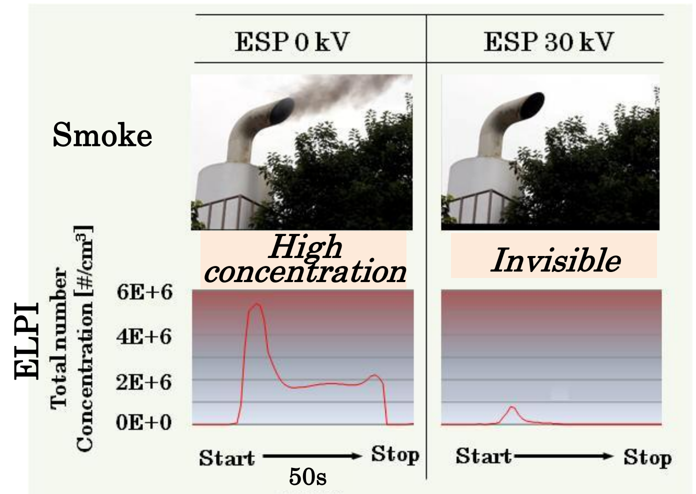
Figure 11 η_{BC} vs. Voltage (HFO)

1-2) PM measurement filter, HFO (Figure 9)



a) 0 kV b) 36 kV

2) Reduction of smoke at engine start



1) BC is reduced with high efficiency by ESP-C for both MDO and HFO; 10 m/s, 30--35 kV, η_{BC} 80%
2) Smoke at engine start can be significantly reduced by ESP-C. Smoke is hardly visible.

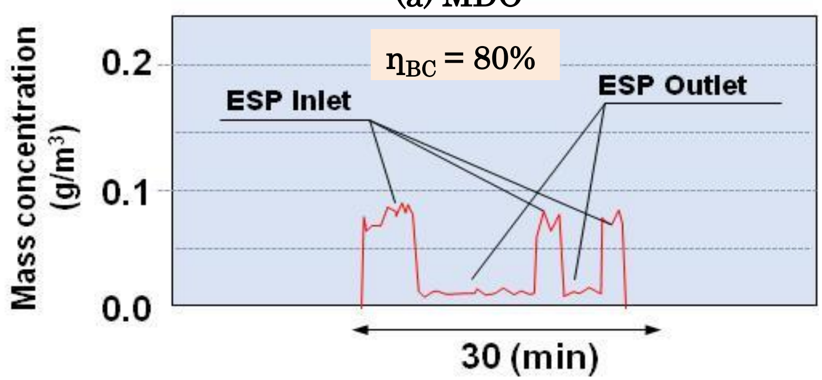
Experimental evaluations with four-stroke engine

3,500 kW
750 rpm, 6 cyl.

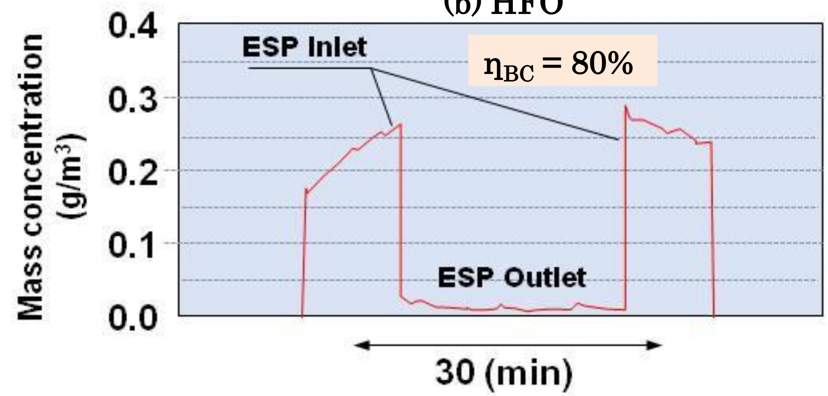
1) PM/BC mass concentration at ESP inlet and outlet (Figure 13)

- Experimental conditions: load 75%, 300℃, 10 m/s.
- ELPI+ (hot dilution at 250 ℃): PM/BC concentration. - Applied voltage: about 33 kV.

(a) MDO



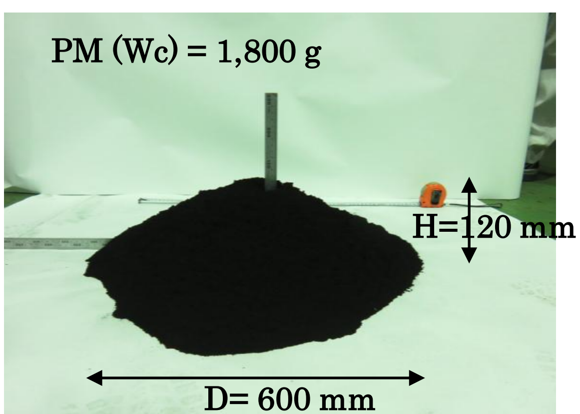
(b) HFO

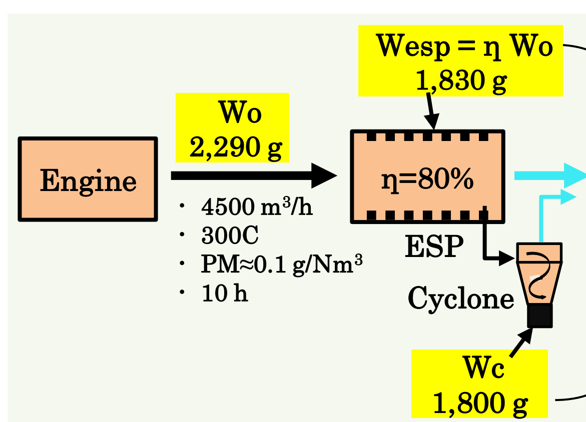


ESP-C can reduce PM/BC concentration with high efficiency of 80% for MDO and HFO.

2) PM/BC mass (Wc) collected in the Cyclone dust hopper (Figure 14)

- load 75%, HFO, Operation time 10 h, in steady state

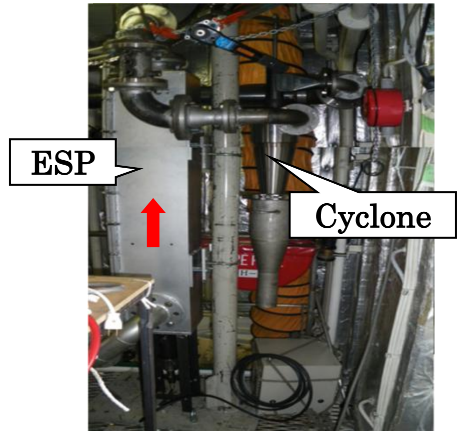




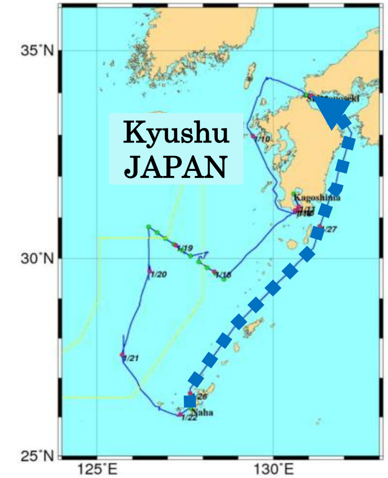
Wesp (ESP) ≈ Wc (Hopper)
↓
The collection mechanism was verified.

Onboard test with ESP-C

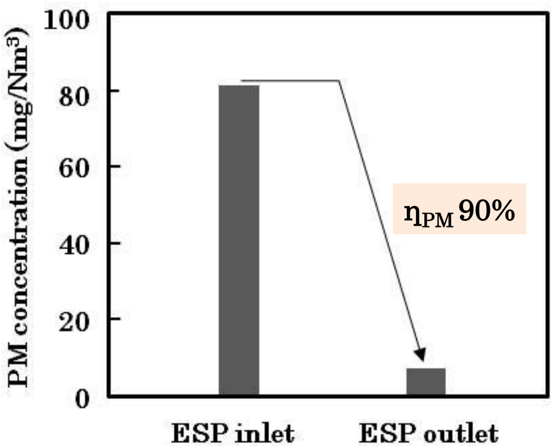
Koyo maru (Training ship)
2,730 GT, Two-stroke engine, 3,900 kW
70% load, MDO



Vertical setting ESP
(225 W, 225 H, 1200 L mm)



Route: from Naha to Shimonoseki
Wind speed 10 - 14 m/s, Wave height 4 m



PM concentration
Dilution tunnel method, ISO 8178-1

PM collection efficiency was good
for even vertical ESP and load fluctuations caused by waves.

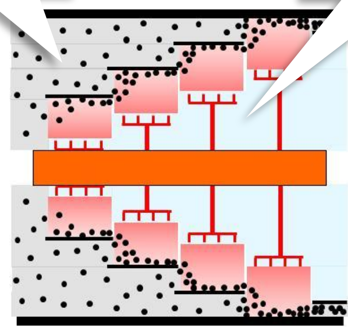
Downsizing of ESP for practical application

1) Problem of ESP with circular cross section

The collection efficiency is satisfactory, however this ESP has dead space.

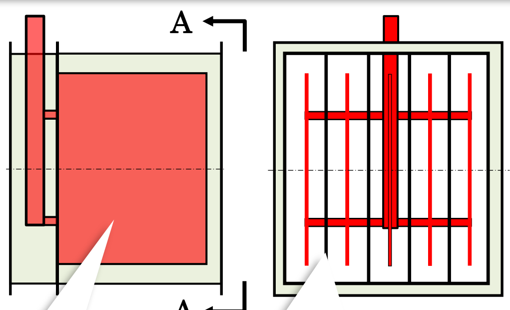
Dead space

Dead space



2) ESP with rectangular cross section

Both the collection efficiency and the downsizing will be satisfied.



Discharge electrode

Collection cell (multi-cell structure)

3) Assembly of ESP

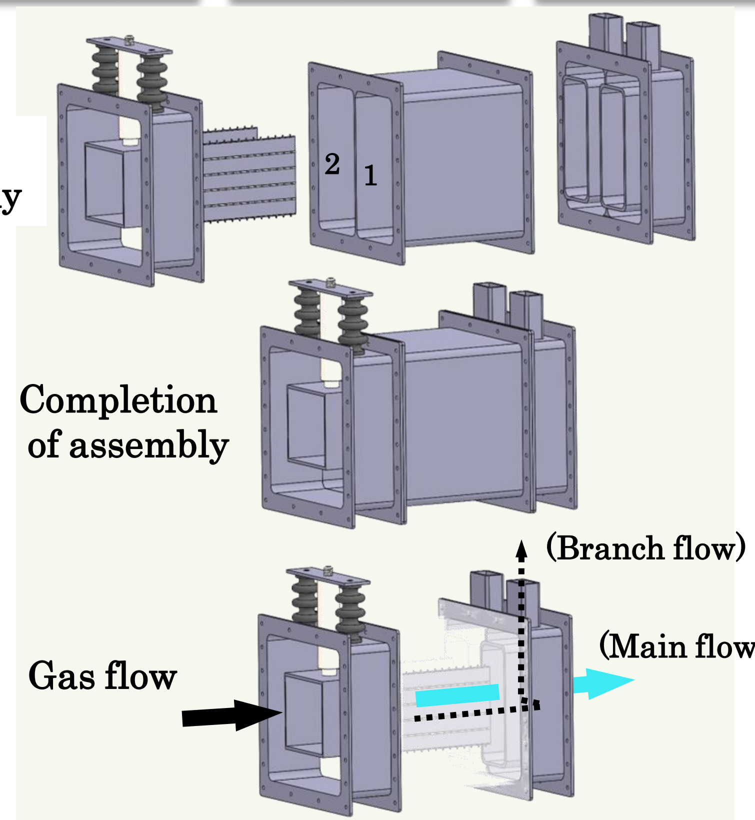
--- Example of two-cell structure ---

(a) Discharge electrode part

(b) Collection wall part

(c) Branch route part

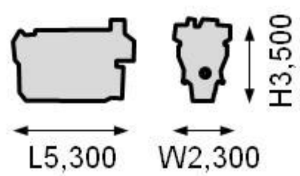
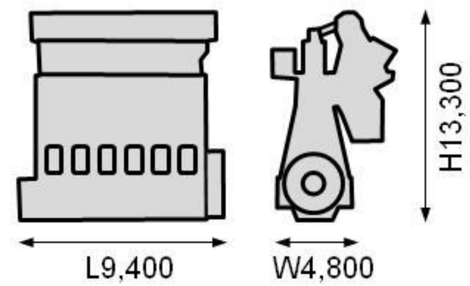
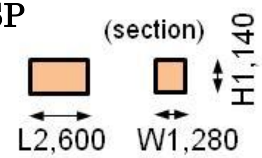
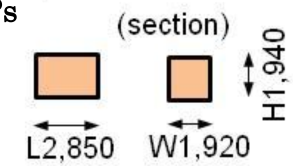
Before assembly



Under experimental design

Comparison of main dimensions of engine and ESP

Figure 16 Main dimensions of the engine and ESP

	4-stroke Medium-speed engine	2-stroke Low-speed engine
Specifications of Engine	・3,500 kW ・320φ, 400 st, 6 cyl. ・750 rpm ・Exh.Gas : 20,200 Nm^3/h	・21,600 kW ・720φ, 3090 st, 6 cyl. ・85 rpm ・Exh.Gas : 119,000 Nm^3/h
Dimensions (Engine)		
Dimensions (ESP)	One ESP 	Two ESPs 
SV	SV = 11,200 1/h	SV = 11,800 1/h

The newly developed ESP is much smaller than the conventional ESP.

Note. Space velocity (SV) ≡ Q / V (1/h)

Q : Gas flow rate entering the ESP (m^3/h), V: Volume of ESP (m^3)

Design condition: Collection efficiency η_{BC} 80%

Control system for ESP-C

Real-time monitoring of exhaust gas and ESP-C control are possible.
"Temperature, Gas flow rate, Applied voltage, Current, Control mode, etc."

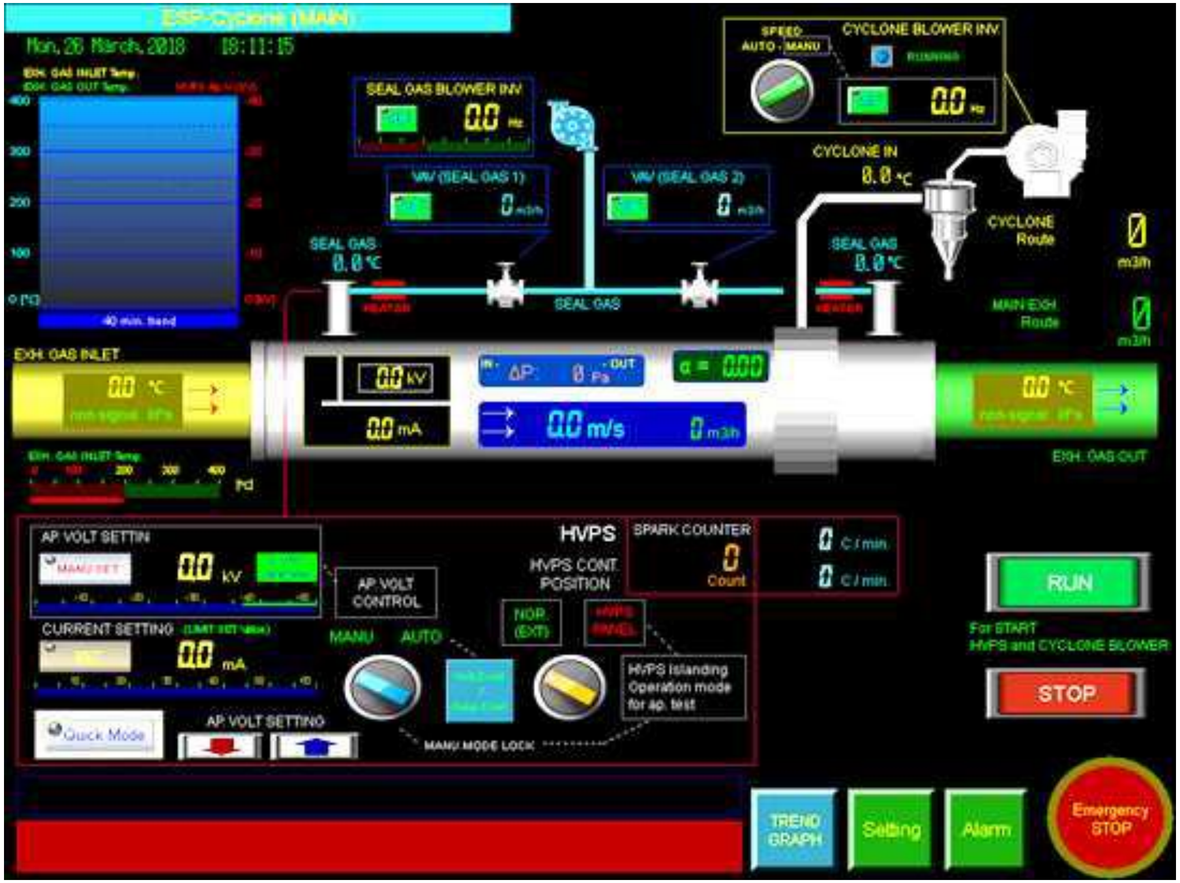


Figure 18 Operation display of the ESP-C system

ESP-C system for industrial use

The unit structure of the ESP-C system
realizes excellent in applicability with existing engines.

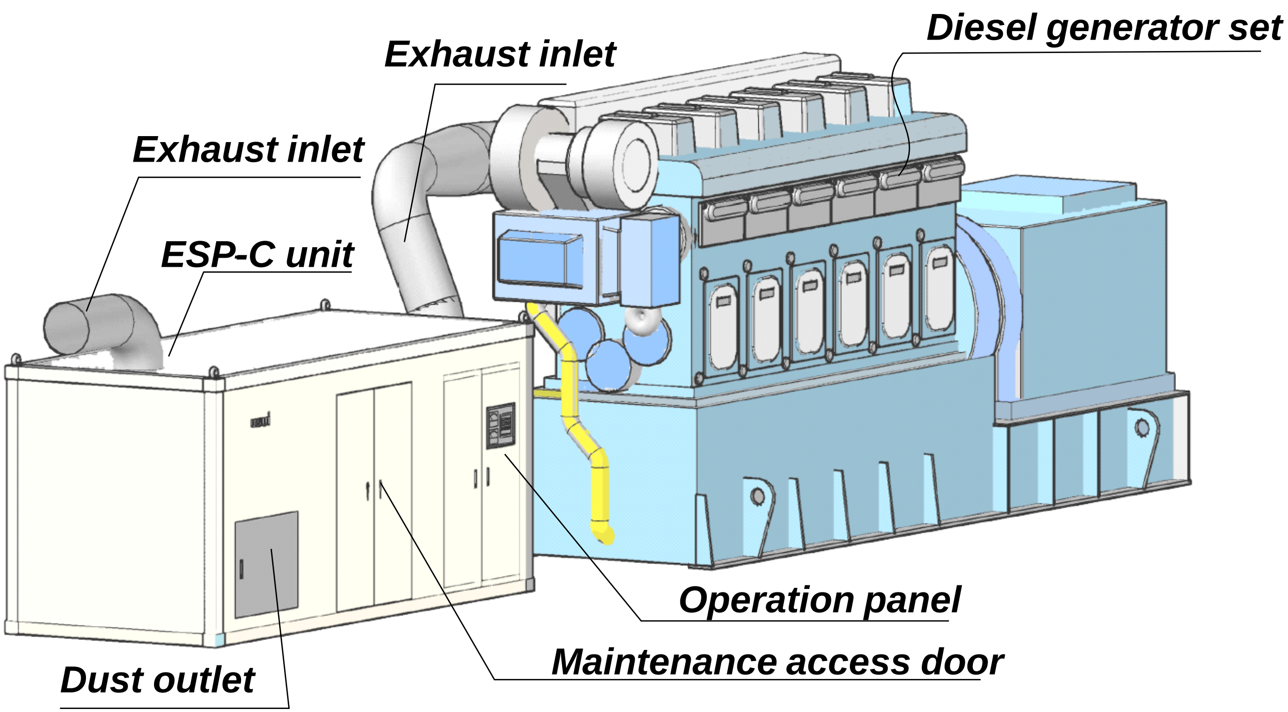


Figure 19. Example of the layout of the ESP-C system connected to a diesel generator set
Diesel engine: 1400 kW
ESP-C unit : 2000 mm(W), 2500 mm(H), 3500 mm(L)

Application of ESP-C system to EGCS

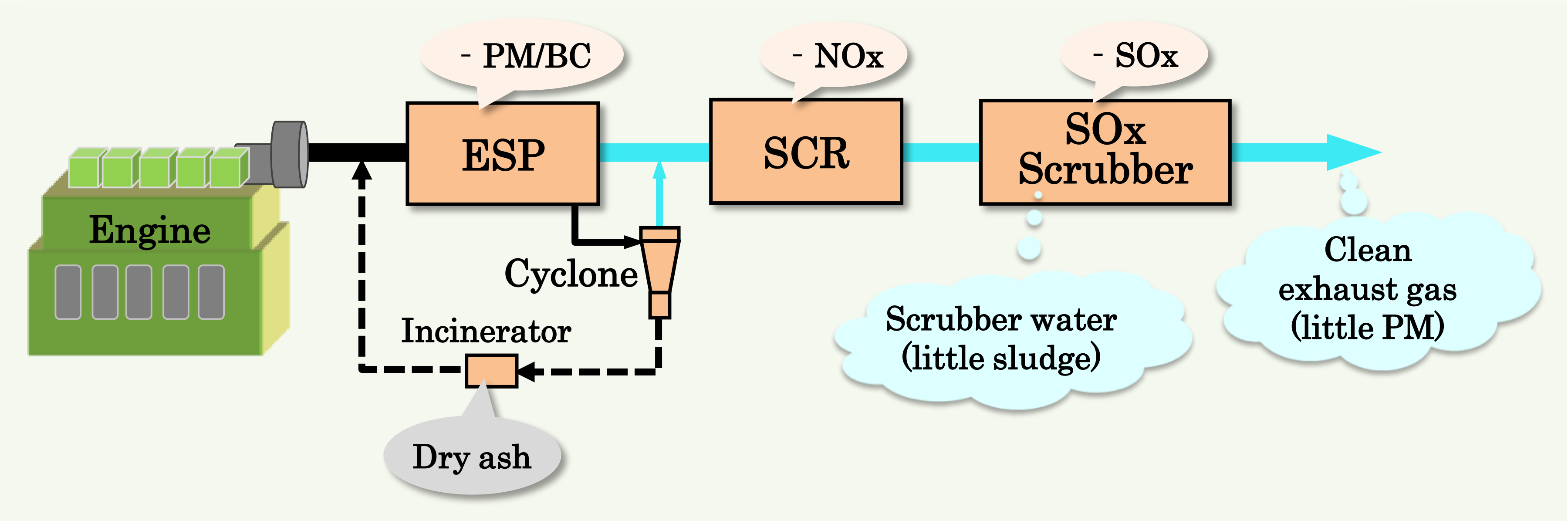
<u>Advantages of ESP-C from the viewpoint of application to EGCS</u>

1) ESP-C can efficiently collect soot (BC) and a certain amount of SOF.
2) The drop in temperature of exhaust gas during ESP is very slight.

⇩

A new EGCS comprising a combination of ESP-C with an SCR and SOx scrubber is excellent overall.

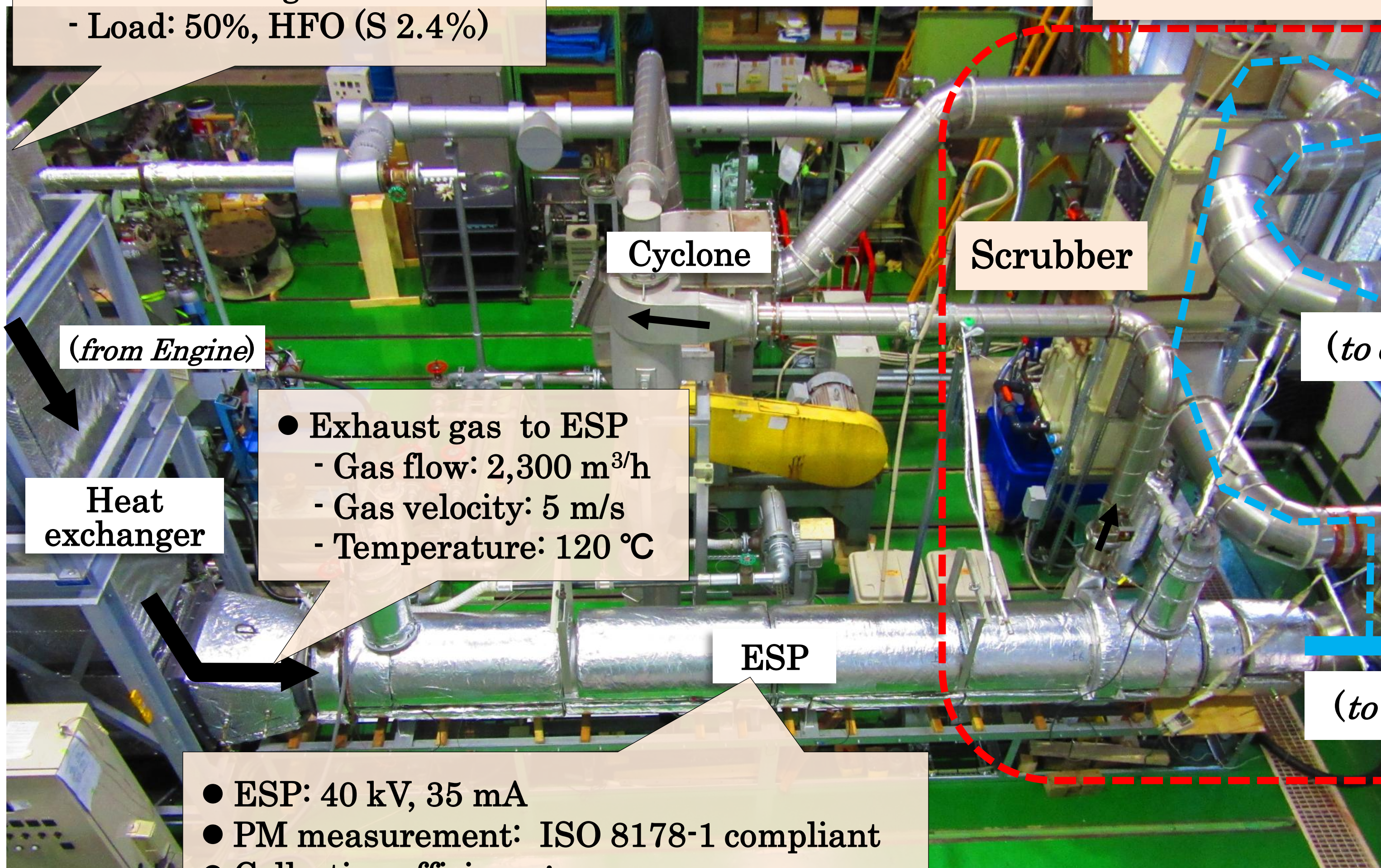
The new EGCS can efficiently reduce BC, NOx and SOX.



Experiments combining ESP-C and SOx Scrubber (1/2)

- Two-stroke engine :1275 kW
  - Load: 50%, HFO (S 2.4%)

Scrubber experiment



- Exhaust gas to ESP
  - Gas flow: 2,300 m^3/h
  - Gas velocity: 5 m/s
  - Temperature: 120 ℃

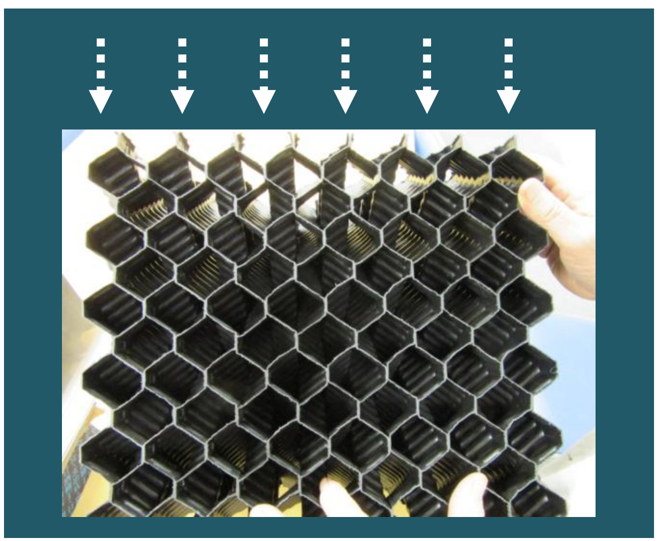
- ESP: 40 kV, 35 mA
- PM measurement: ISO 8178-1 compliant
- Collection efficiency:

  $\eta_{PM} = 60\%$, $\eta_{ISF} = 80\%$, $\eta_{SOF} = 55\%$

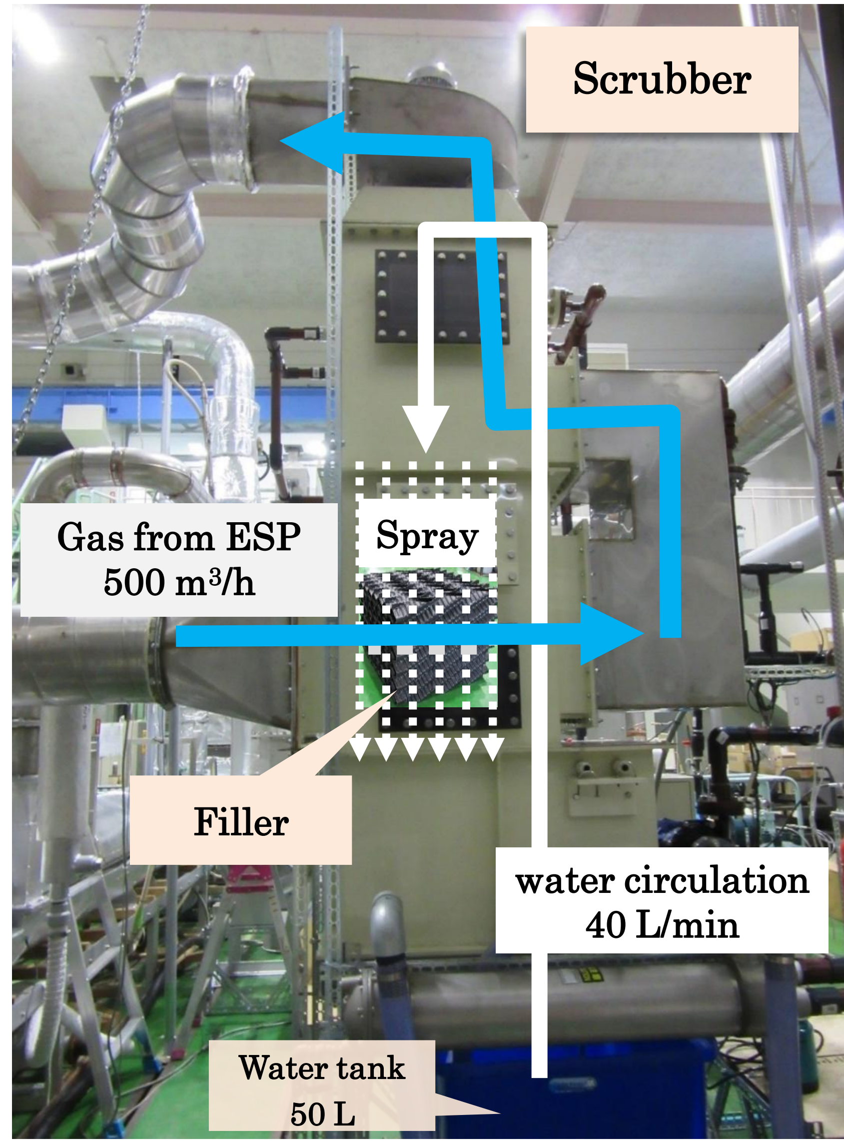
Experiments combining ESP-C and SOx Scrubber (2/2)

<u>Scrubber operating conditions</u>

- Exhaust gas: 500 m³/h
- Water: Tap water, 50 L
- Continuous water circulation: 40 L/min
- Liquid-to-gas ratio: 4.8 L/Nm³
- Processing time: 180 min



Filler: Slanted honeycomb, Polypropylene
(400W x 400H x 300L)



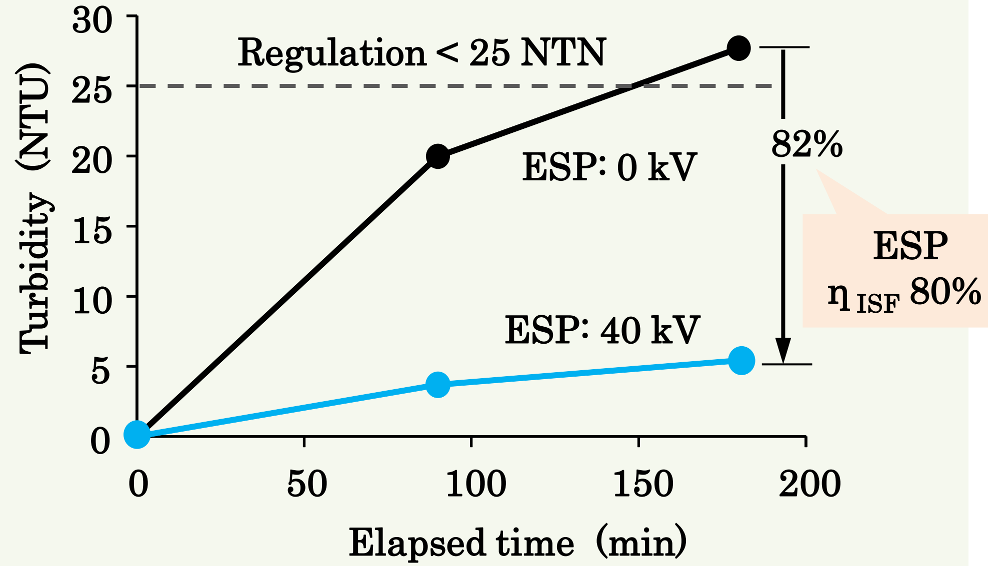
Turbidity of scrubber waste water

Waste water in tank

ESP: 0 kV　　ESP: 40 kV

(a) Transparency of waste water

(After 180 min circulation usage)



(b) Change in turbidity of waste water with elapsed time

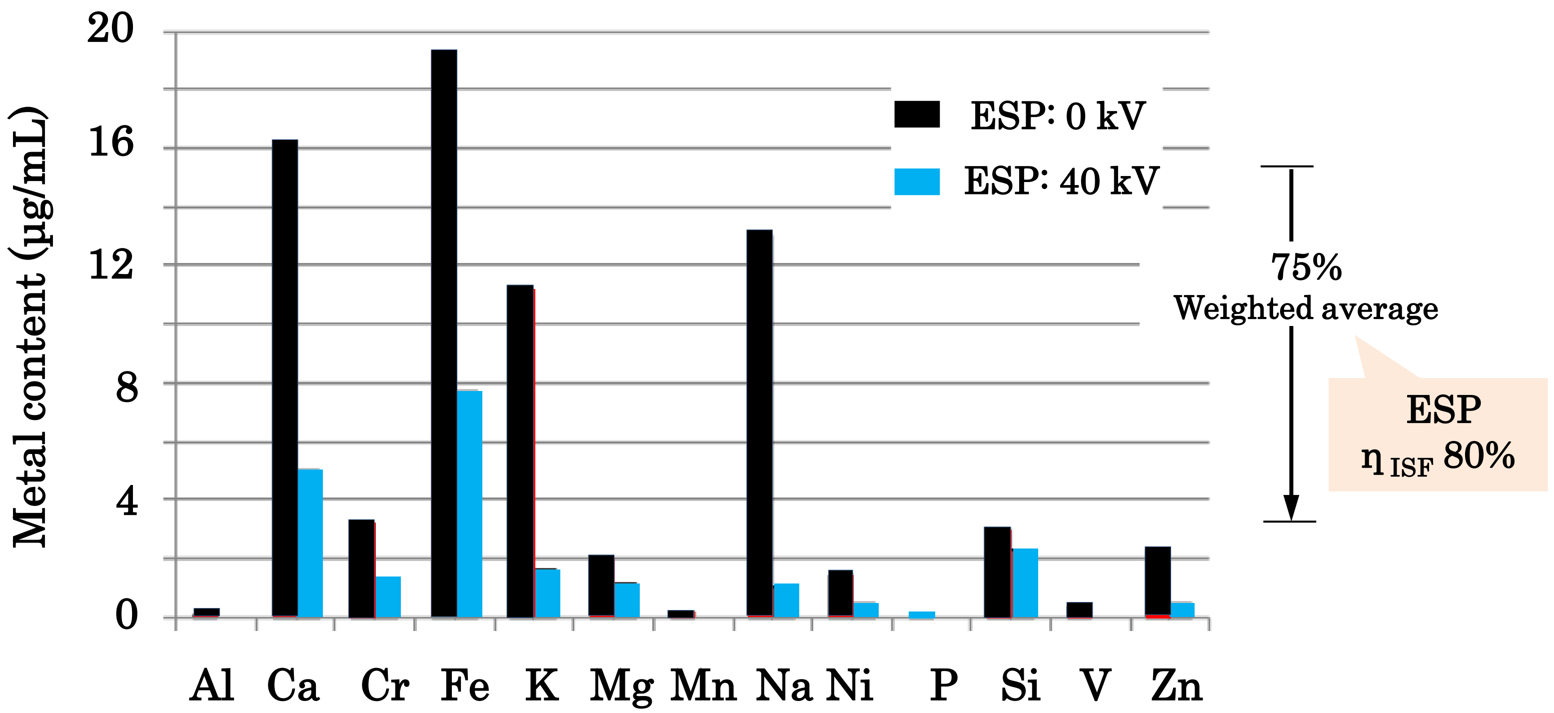
When exhaust gas is treated with ESP, the appearance and the turbidity of the waste water are markedly improved.

(Note)

- Components of ISF (Insoluble fraction) are BC, metal, ash, etc..
- Reduction rate of BC and metal basically correspond to that of ISF.

Metal content in waste water (After 180 min circulation usage)

(Measurement: ICP emission spectroscopy)



The combination of ESP-C and wet scrubber is excellent overall.

Conclusions

1. The ESP-C system collects the BC emitted from marine diesel engines efficiently.
2. The ESP-C system was downsized to enable its installation in ships, and a maintenance-free system was realized.
3. A new EGCS comprising a combination of the ESP-C system, an SCR system, and a SOx scrubber was proposed.
4. The ESP-C system is strongly anticipated to help satisfy the regulations on exhaust emissions from marine diesel engines, which are expected to become more stringent in the future.

ESP-C project goal: "Stop the melting of Arctic ice"

The polar bears can
relax and smile again
On large thick ice floes.

白熊の笑み戻りけり厚氷