Technologies Update for IMO NOx Tier III Regulations

16th June 2016

Naohiro Hiraoka

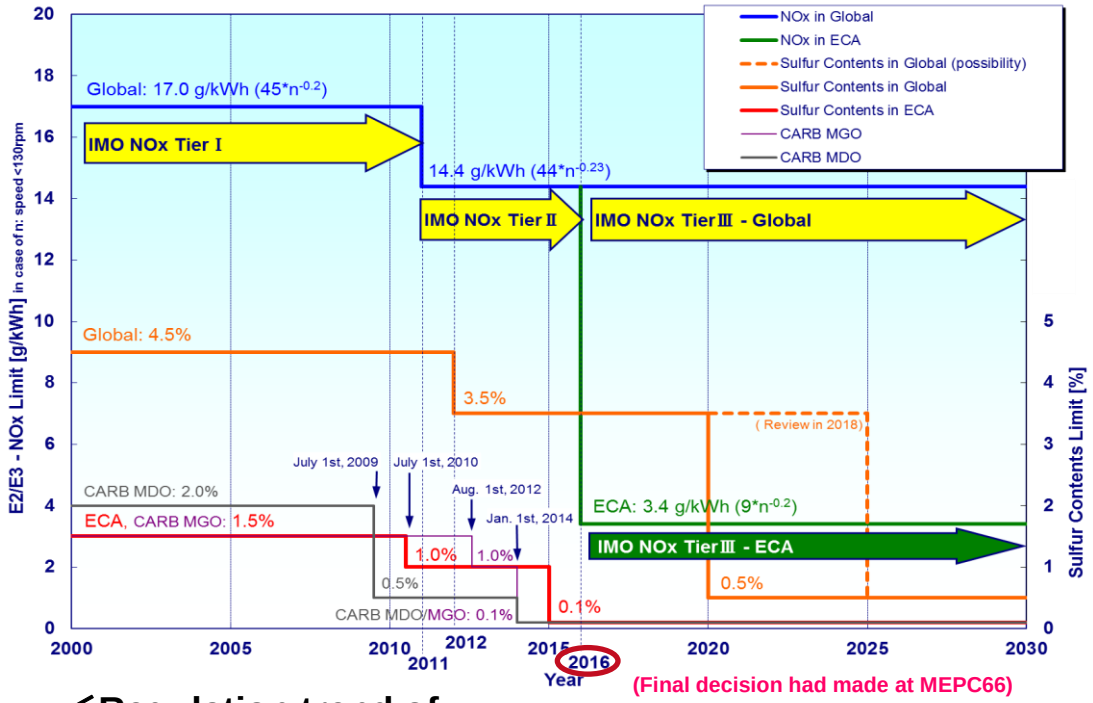
MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.

Contents

1. Regulation trend
2. Compliance plan
3. Low Pressure EGR
4. Low Pressure SCR
5. Comparison among Tier III technologies

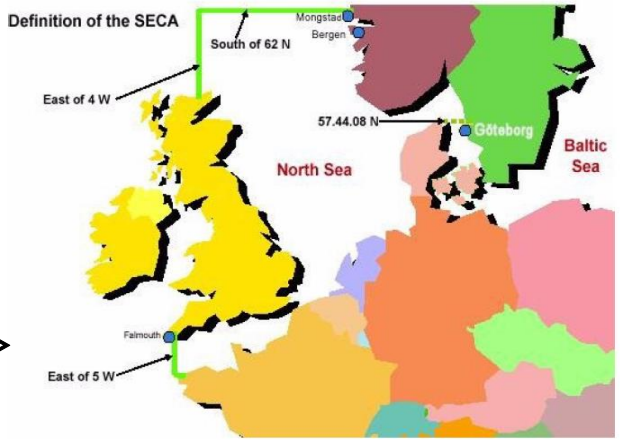
Contents

1. Emission Regulation of IMO & CARB



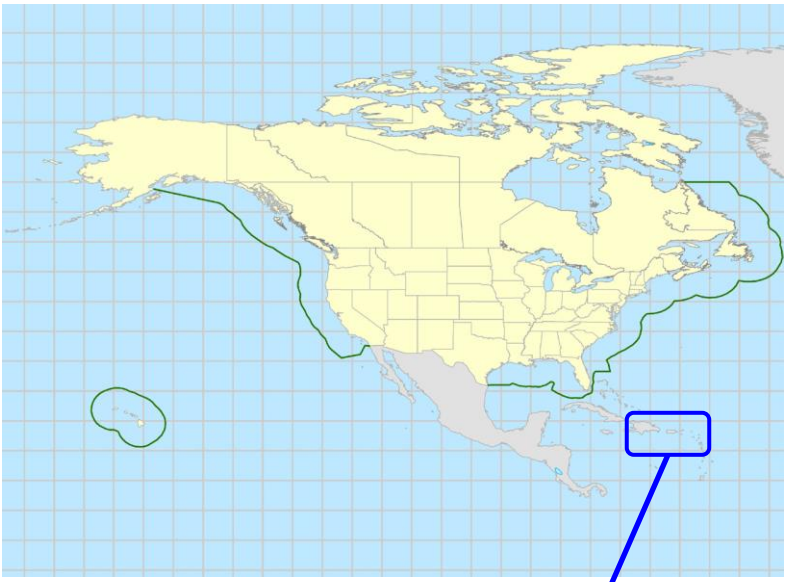
(Final decision had made at MEPC66)

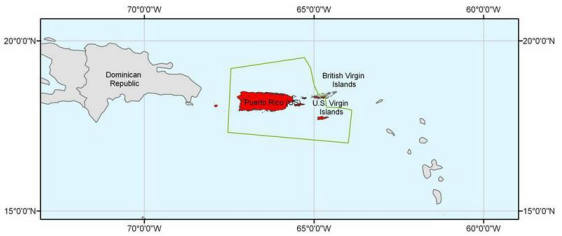
＜Regulation trend of NOx and SOx emission by IMO/CARB＞



Possibly become NOx-ECA (2020?)

＜ECA＞（SOx）





＜ECA＞（NOx＆SOx）

Contents

2. Compliance with IMO-NOx Tier III

How to operate the ENGINE

Outside of ECA => Basically same as Tier II specification.

Inside of ECA => NOx reduction technology (76% less than Tier II)

① METHODS IN-ENGINE

- EGR (**E**xhaust **G**as **R**ecirculation) with low press. loop

② AFTER TREATMENT

- SCR (**S**elective **C**atalytic **R**eduction) after Turbocharger*

MHI-MME develops Low Pressure system

For both measures, operation change between Tier II and Tier III mode is switching off/on. (Then, exhaust gas valve will be switched off/on.)

* The national project called “Super Clean Marine Diesel” was carried out by the Japan Ship Machinery & Equipment Association (JSMEA) financially supported by the Nippon Foundation, led by the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT).
The research and development contract for the large slow speed diesel engines’ application was carried out by JSMEA, Akasaka Diesels Limited, Oshima Shipbuilding Co., Ltd., Sakai Chemical Industry Co., Ltd. and Mitsubishi Heavy Industries, Ltd.

2. TierⅢ Compliance Policy

- Regarding to middle and large size LSE-Eco/LSH-Eco type engine which bore diameter is larger than 45cm, we apply Low Pressure EGR basically.

  Regarding to small size engine, we recommend Low Pressure SCR.

- Regarding to LSE mechanical engine and LSII type engine, we apply Low Pressure SCR.

(Note) This compliance policy might be changed without advanced announcement.

2. TierⅢ Compliance Policy

Engine Type		Applied TierⅢ Technology	
		EGR	SCR
UEC80LSE-Eco		○	-
UEC60LSE-Eco		○	-
UEC50LSH-Eco		○	-
UEC50LSE	Eco	○	-
	Mechanical	-	○※1
UEC45LSE	Eco	○	Alternative
	Mechanical	-	○
UEC35LSE	Eco	Alternative	○
	Mechanical	-	○
UEC33LSE	Eco	Alternative	○
	Mechanical	-	○
UEC43LSII		-	○
UEC37LSII		-	○
UEC33LSII	Eco	-	○
	Mechanical	-	○

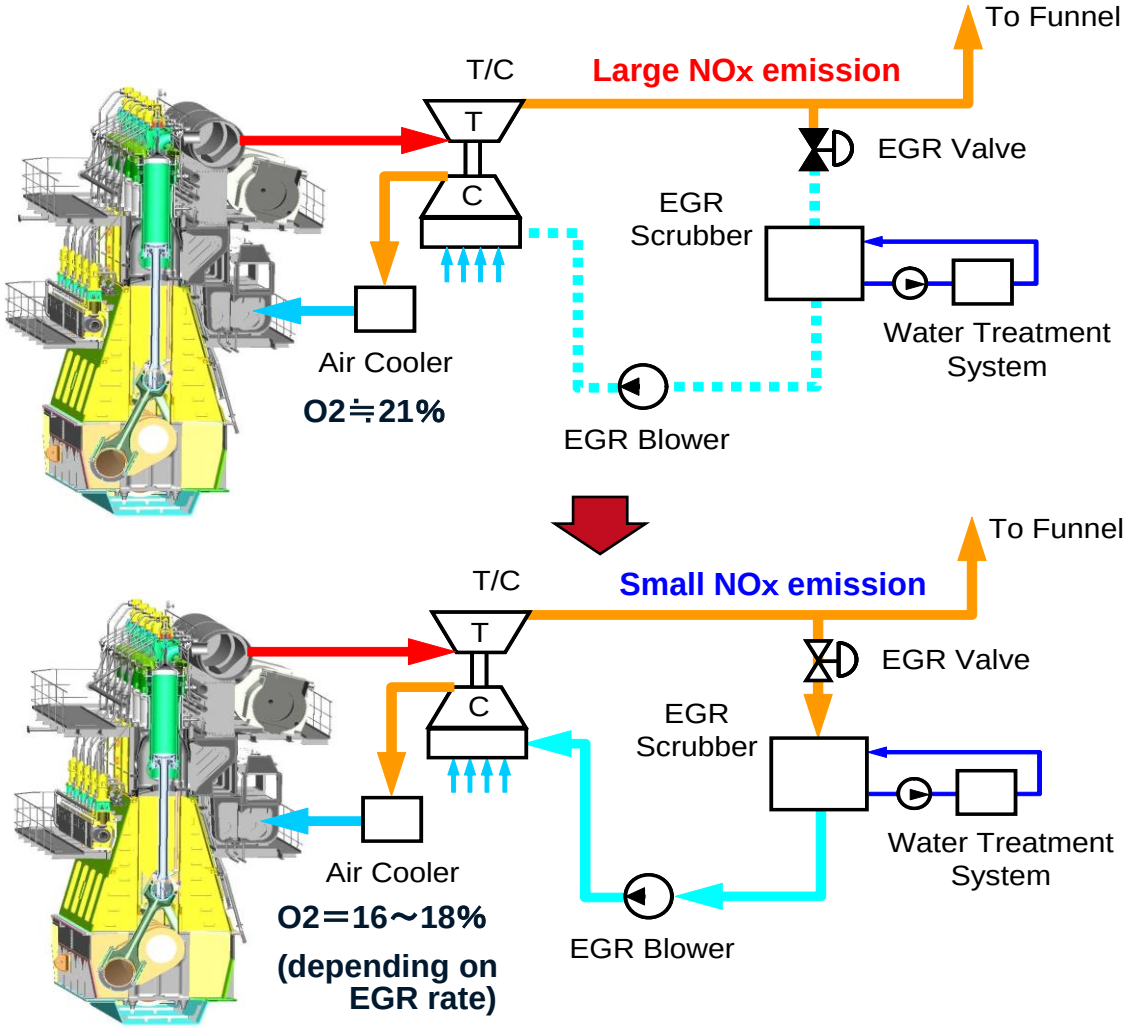
○：Equipped
※1：On request

(Note) This compliance policy might be changed without advanced announcement.

Contents

2. EGR technology

- EGR (Exhaust Gas Recirculation) is the in-engine NOx reduction technology by slow speed combustion in combustion chamber.



＜Non-EGR operation (Global Area)＞

- Non-EGR operation is same as traditional engine (Tier Ⅱ).
- Scavenging media is air. (O2 concentration≒21%)
- Because of efficient combustion, NOx emission is large.

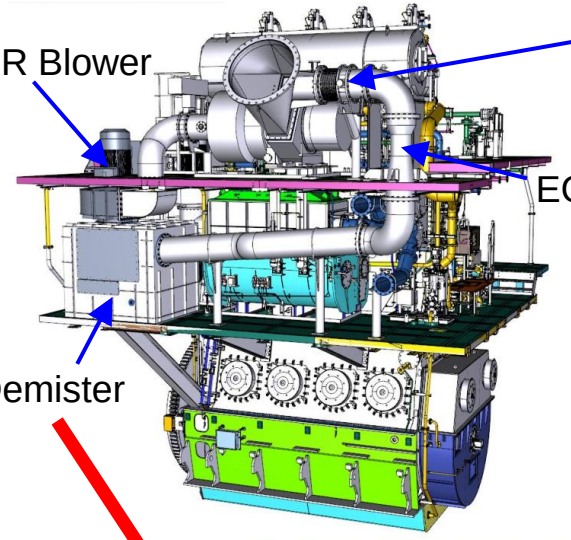
＜EGR operation (in ECA)＞

- EGR valve is opened, then a part of exhaust gas will be recirculated.
- Scavenging media is mixture of air and recirculated exhaust gas. (O2 concentration≒16～18%)
- Slow-speed combustion leads less thermal-NOx production.

2. EGR scrubber development

- **EGR scrubber has developed from land-base type (1st generation) into small-sized 2nd generation type.**

Overview of EGR system in 4UE-X3 (1st generation)

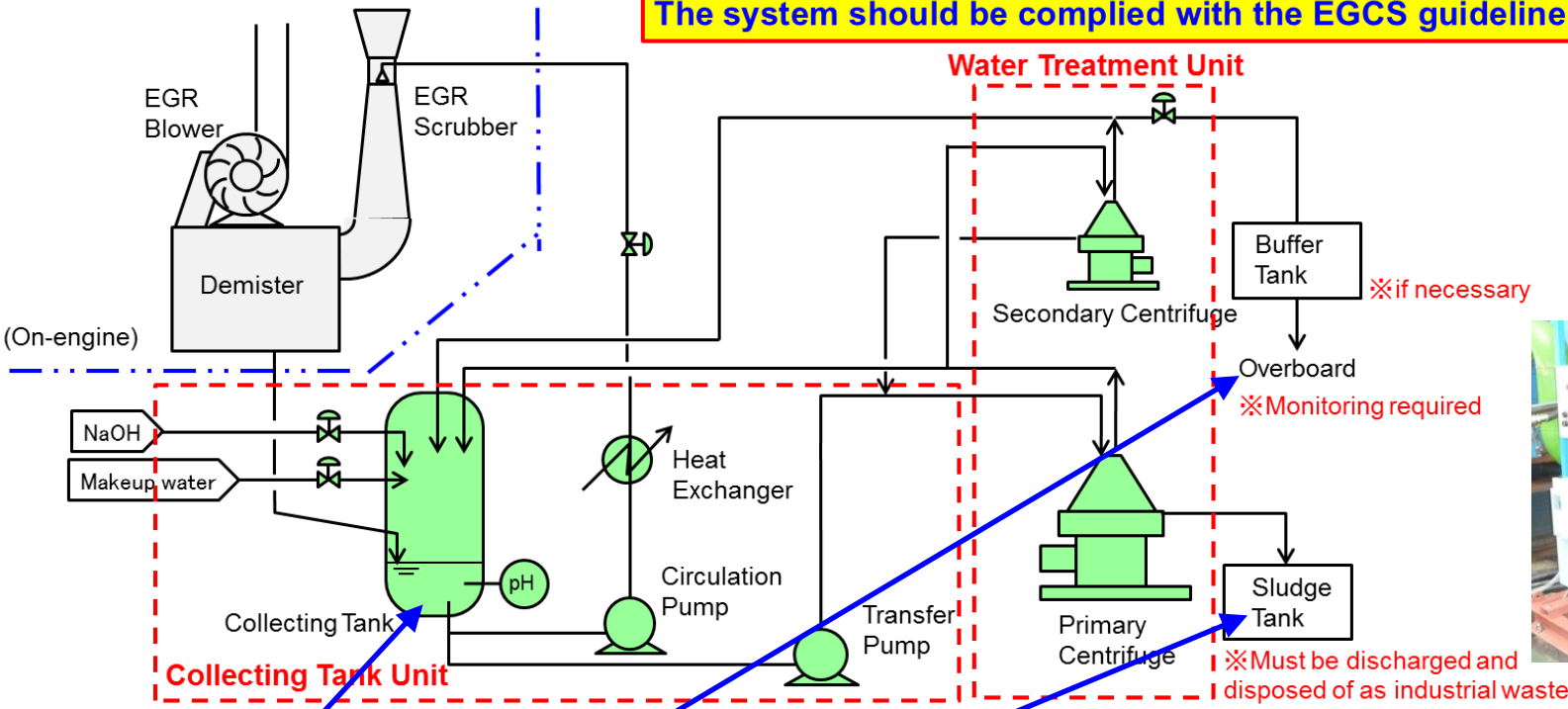


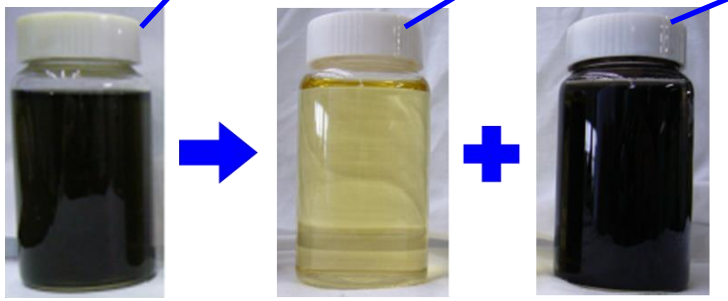
On-engine EGR system (2nd generation)

⇒*Developed downsizing and optimization*

2. Water Treatment System

The system should be complied with the EGCS guideline.





(before treatment) (after treatment) (sludge)

- **Water Treatment System consists of Primary/Secondary Centrifuge, Pumps, Tanks, Heat Exchanger, Valves and Sensors.**
- **Primary Centrifuge is responsible for cleaning scrubbing water, and Secondary Centrifuge is responsible for cleaning waste water for overboard.**

2. Advantage of Low Pressure EGR

SIMPLE SYSTEM

LP-EGR has

“Smaller numbers of equipment and pipes”.

SIMPLE OPERATION

LP-EGR controls

“Smaller numbers of equipment”.

SMALL CAPEX and OPEX

LP-EGR leads

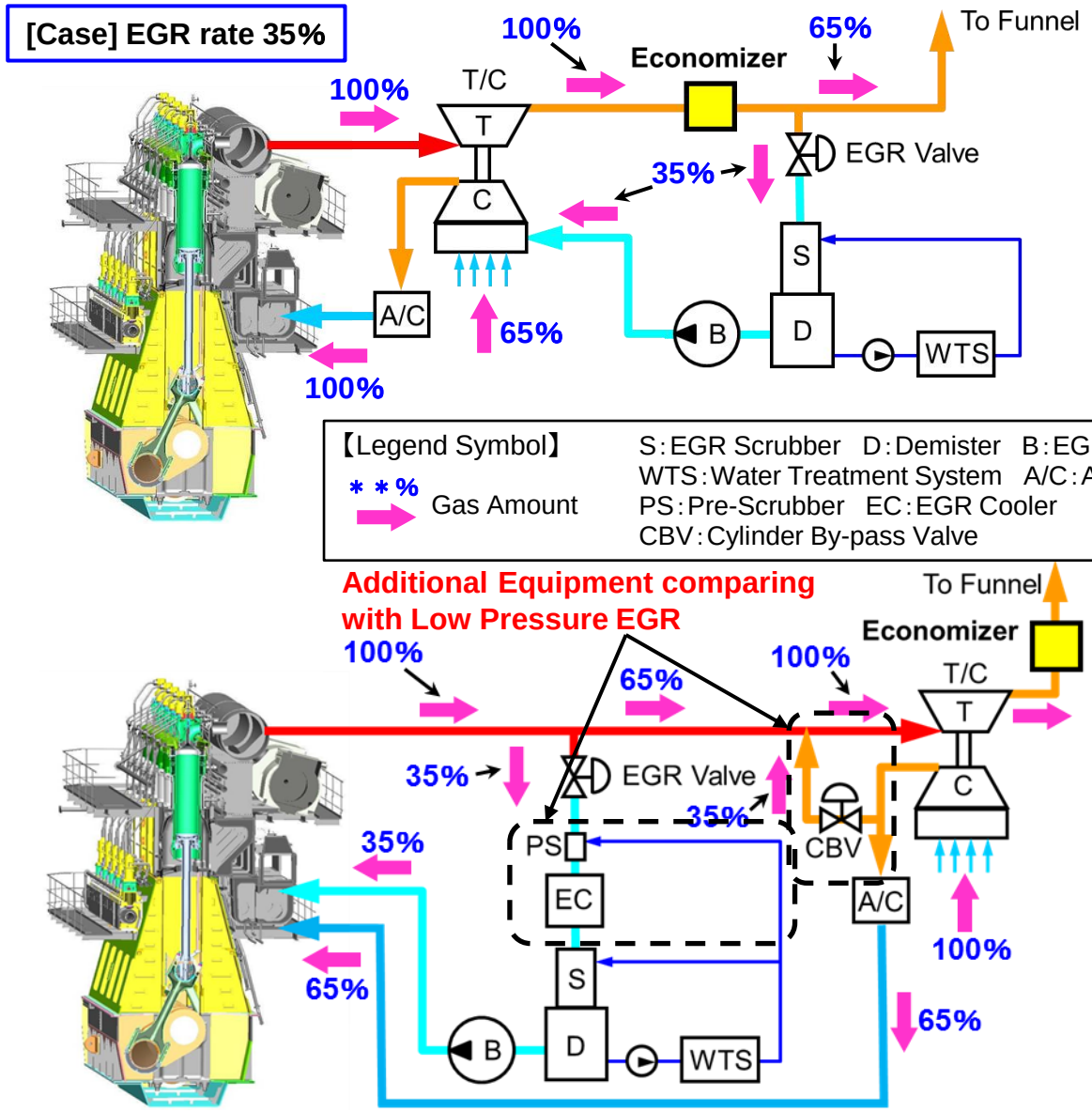
“Lower material cost and electric power”.

LP-EGR can make

“Additional boiling unnecessary”.

⇒ LP-EGR system has great advantages

2. Comparison between LP and HP EGR System



＜Low Pressure EGR＞

- Scrubber for cleaning EGR gas is simple structure because of low pressure and low temperature
- EGR Blower power is smaller than HP-EGR because of utilizing T/C suction pressure

＜High Pressure EGR＞

- Scrubber structure for cleaning EGR gas is complicated because of high pressure and high temperature
- EGR Blower power is bigger than LP-EGR because of join EGR gas to scavenging air with raising pressure

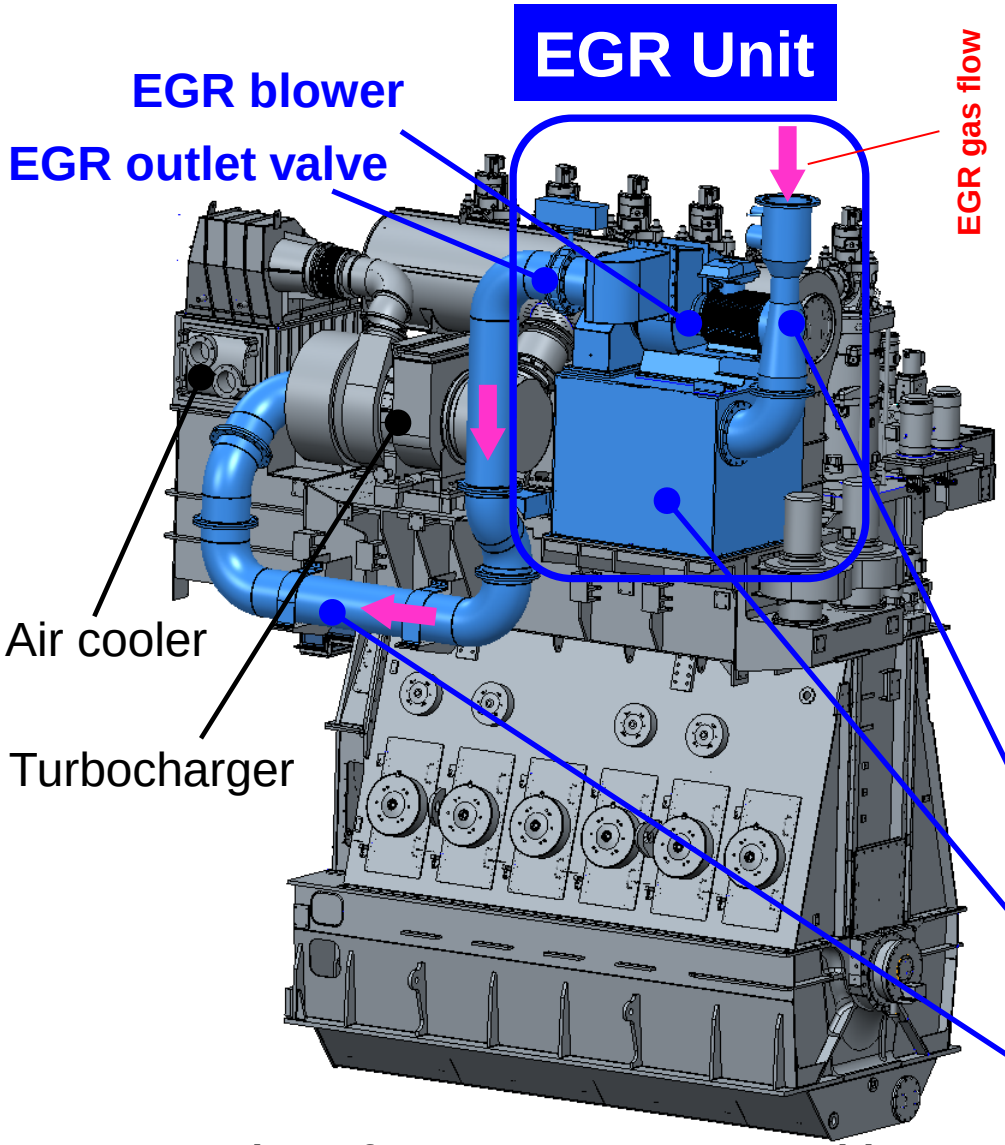
3. Verification Item of Onboard Durability Test

【Target】

- Designing on-engine LP-EGR system, the world's first "Compliance with IMO NOx TierⅢ regulation by LP-EGR". Further, the world's first installing LP-EGR system onboard and executing sea trial.
- Regarding the Water Treatment System(WTS), by combination of two centrifuges, after optimization of water treatment performance and entire EGR system, comply with waste water regulation the EGCS guideline in EGR operation using HFO.
- Confirmation of long-term durability.
  - ➢ *Performances using HFO, LSMDO and MGO*
  - ➢ *Durability of Demister, T/C compressor wheel and WTS*
  - ➢ *Load following capability in voyage and robustness of control system*

⇒Final verification of total system onboard and feedback to EGR system specification optimized.

3. LP-EGR (reference engine and vessel)

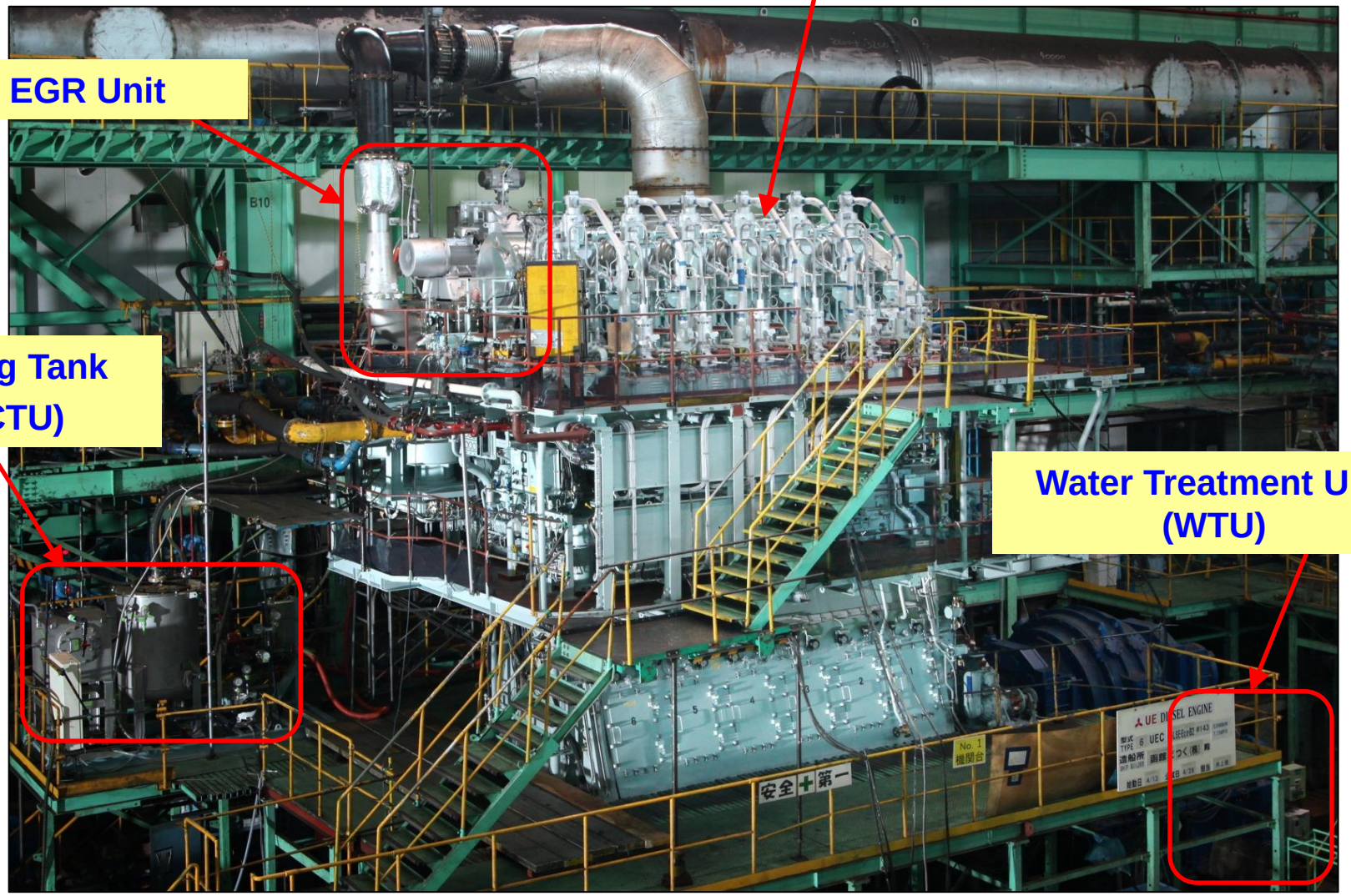


Overview of 6UEC45LSE-Eco-B2 with LP-EGR

Engine type	6UEC45LSE-Eco-B2-EGR
Bore x Stroke	450 mm x 1930 mm
Fuel injection/ Exh valve drive	Electrically controlled
Vessel type	**Bulk Carrier**
Vessel size	34,000 DWT
Schedule	
Shop test	April 2015 [done]
Sea trial	August 2015 [done]
Vessel delivery	August 2015 [done]

3. Shop Test with LP-EGR system（Overview）

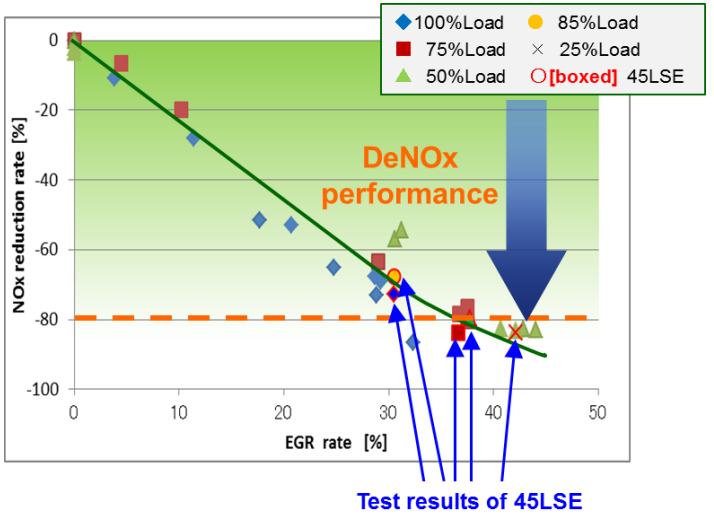
6UEC45LSE-Eco-B2-EGR



3. Summary of Shop Test Results

Reliability of EGR system

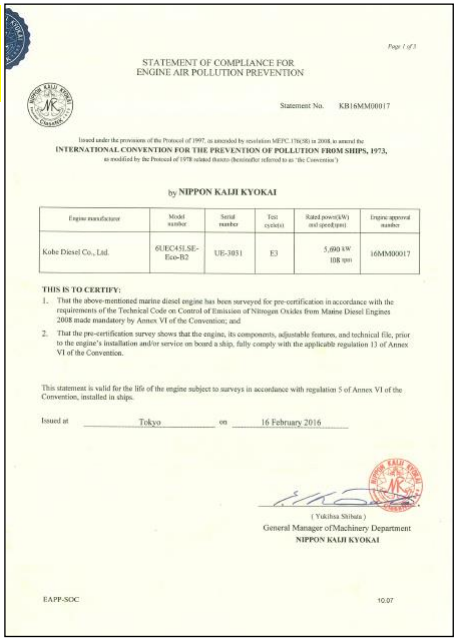
- Confirm good load response/performance with EGR system.
  e.g. EGR mode on/off, load response,
  110% load operation, emergency stop etc.



NOx emission performance

- Carried out NOx test attended by ClassNK.
- NOx E3 mode: 3.2g/kWh
  ⇒ Comply with NOx TierⅢ regulation (3.4g/kWh).

Tier III approval



STATEMENT OF COMPLIANCE FOR
ENGINE AIR POLLUTION PREVENTION

Statement No. KB16MM00017

issued under the provisions of the Protocol of 1997, as amended by resolution MEPC.176(58) in 2008, to amend the
INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS, 1973,
as modified by the Protocol of 1978 related thereto (hereinafter referred to as "the Convention")

by NIPPON KAIJI KYOKAI

Engine manufacturer	Model number	Serial number	Test cycle(s)	Rated power(kW) and speed(rpm)	Engine approval number
Kobe Diesel Co., Ltd.	6UEC45LSE-Eco-B2	UE-3031	E3	5,000 kW 108 rpm	16MM00017

THIS IS TO CERTIFY:

1. That the above-mentioned marine diesel engine has been surveyed for pre-certification in accordance with the requirements of the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines 2008 made mandatory by Annex VI of the Convention; and
2. That the pre-certification survey shows that the engine, its components, adjustable features, and technical file, prior to the engine's installation and/or service on board a ship, fully comply with the applicable regulation 13 of Annex VI of the Convention.

This statement is valid for the life of the engine subject to surveys in accordance with regulation 5 of Annex VI of the Convention, installed in ships.

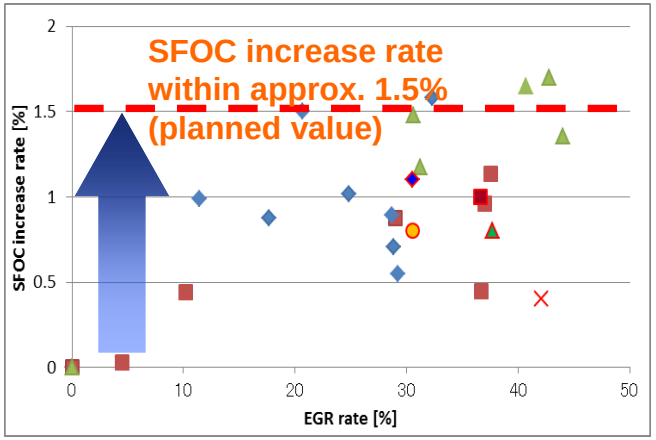
Issued at Tokyo on 16 February 2016

(Yukihisa Shibata)
General Manager of Machinery Department
NIPPON KAIJI KYOKAI

EAPP-SOC 10.07

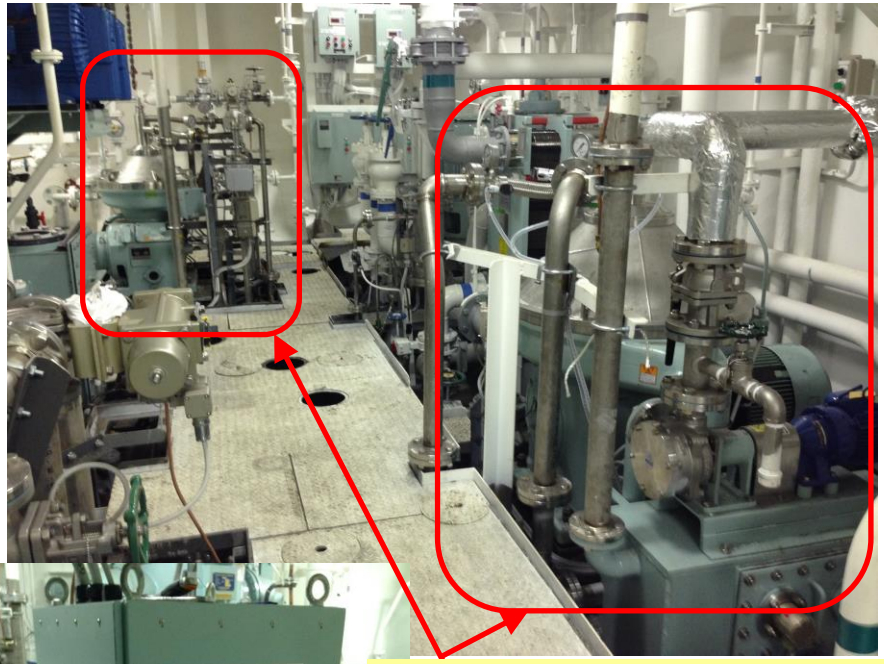
Engine performance

- Confirm keeping SFOC penalty and exhaust gas temperature and so on within planned value.



3. Overview of system installation into the vessel

Engine installation



Water Treatment Unit (WTU)

Control Panels

Waste Water Monitoring Sensor Unit (WWMSU)

3. Summary of Sea Trial Results

Reliability of EGR system

- Confirmed good load response/performance with EGR system the same as shop test.
  e.g. EGR mode on/off, load response, emergency stop and so on.
- Whole system operation including Water Treatment System.

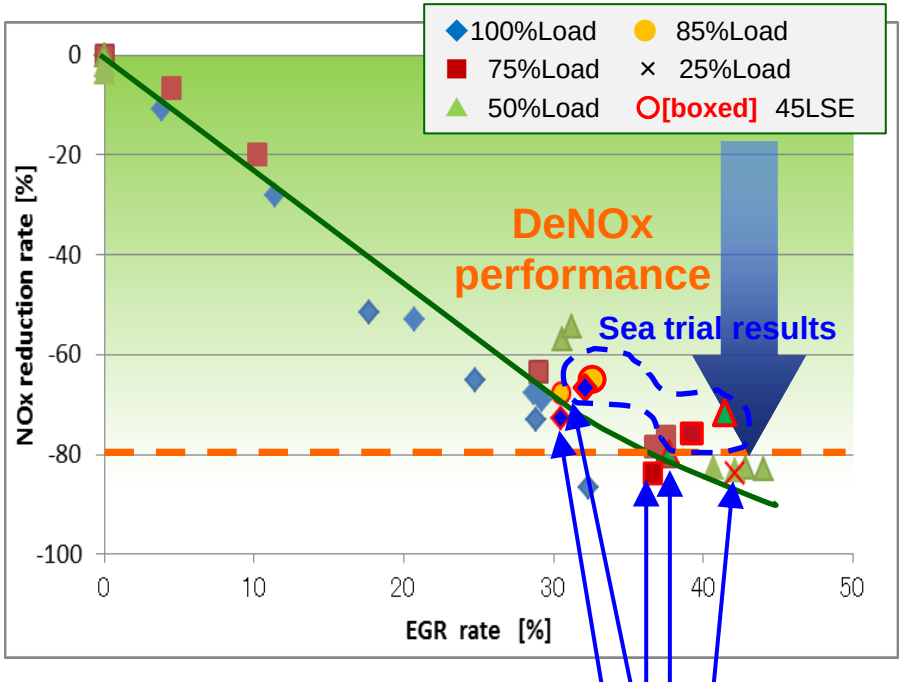
Performances of NOx emission and Engine

- Confirmed good performances of NOx and SFOC the same as shop test.
- Obtained performance data in operation with both MDO and HFO.

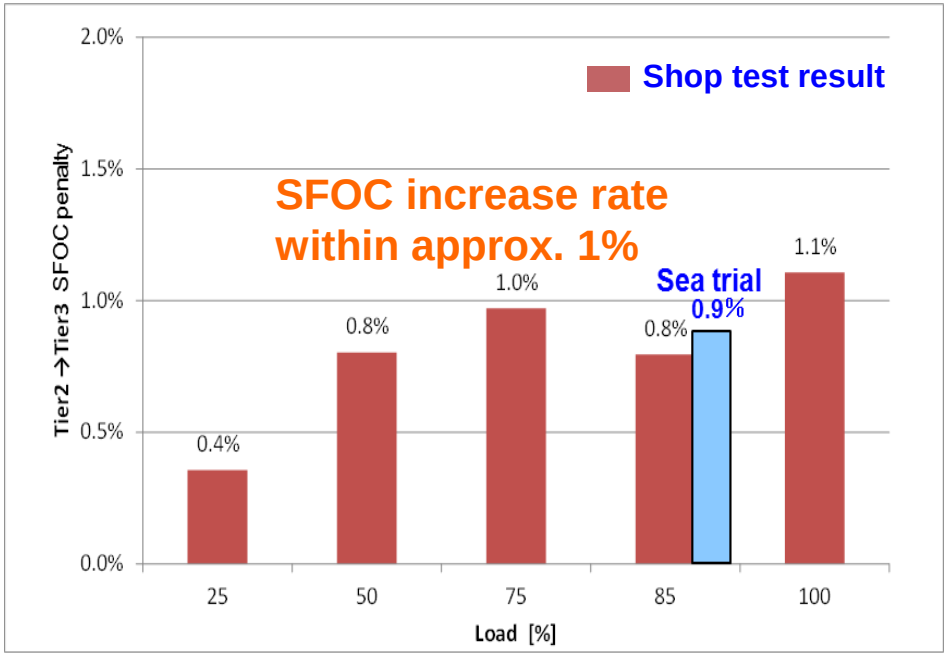
Water Treatment System

- Confirmed waste water quality in operation.
- Confirmed proper system of waste water monitoring and control.

3. Sea Trial Result（comparison with past test）

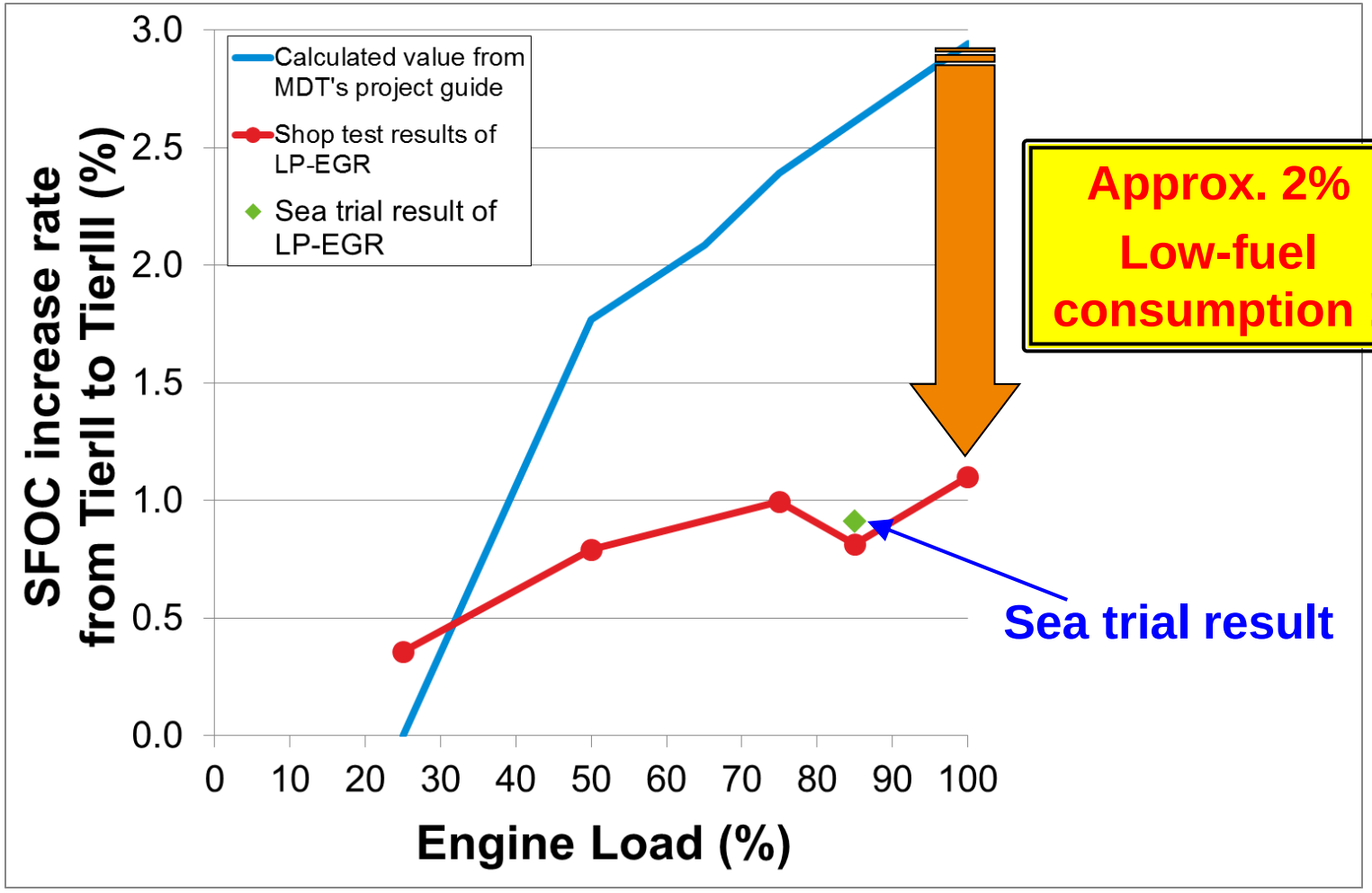


Shop test results of 45LSE



⇒Confirmed the same performance comparing with past test results regarding DeNOx performance and SFOC penalty.

3. Sea Trial Result（SFOC penalty at NR）



⇒Confirm SFOC penalty of the sea trial almost same as the shop test results at NR in condition with using HFO.

3. Sea Trial Result（Water Treatment System）

Confirm below items regarding with waste water.

- ETM, OMM, Record Book
  →Manuals necessary to be onboard. Reviewed by ClassNK.
- Test Procedure, Test Report
  →Confirmed at mooring operation and sea trial. Reviewed and witnessed by ClassNK.

⇒Confirmed the system complied with IMO's 2009 Guidelines for EGCS. Permitted regarding overboard waste water by the Panamanian Flag.

Waste water sampling

Approval documents

PANAMA MARITIME AUTHORITY
Technical Office – Segumar Tokyo
No. 38 Kowa Bldg. - Rm 805 4-12-24, Nishi-Azabu,
Minato-ku, Tokyo, Japan 106-0031

Tel: (81) 3-3499-3661
Fax: (81) 3-3499-3666
E-mail: segumar@panaconsul-tokyo.com

TO: NIPPON KAIJI KYOKAI (NKK)

DATE: AUGUST 17, 2015

FROM: GENERAL DIRECTORATE OF MERCHANT MARINE, SEGUMAR -TOKIO

SUBJ: M/V: DREAM ISLAND IMO: 9748253 CALL SIGN : 3EWU7
DISCHARGE OF WASHWATER FROM EXHAUST GAS RECIRCULATION (EGR) SYSTEM AUTHORIZATION

OUR REF: SGG 68/15/001

THIS ADMINISTRATION HAS BEEN INFORMED BY MANAGER/OWNER AND CONFIRMED BY **NIPPON KAIJI KYOKAI (NKK)** THAT SUBJECT VESSEL INSTALL ON BOARD A EXHAUST GAS RECIRCULATION (EGR) COMPLIES WITH THE WASHWATER REQUIREMENTS OF RESOLUTION MEPC.184(59), "2009 GUIDELINES FOR EXHAUST GAS CLEANING SYSTEMS".

BASED ON ABOVE MENTIONED FACT WE HAVE NOT OBJECT TO AUTHORIZED THE SUBJECT VESSEL TO DISCHARGE WASHWATER OVER BOARD AFTER VERIFY, THROUGH CONSTANTS MONITORING, THAT DISCHARGING WATER COMPLY WITH THE REQUIREMENT OF RESOLUTION MEPC.184(59).

ALL THE WATER AFTER MONITORING WHICH NOT COMPLY WITH RESOLUTION MEPC.184(59) WILL RETAIN ON BOARD AND DISCHARGE TO RESECTION FACILITY AT PORT.

PLEASE PROCEED ACCORDINGLY AND NOTIFY ALL CONCERNED PARTIES.

BEST REGARDS,

ENG. SAMUEL GUEVARA
SENIOR TECHNICAL OFFICER
PANAMA MARITIME AUTHORITY
SEGUMAR - TOKYO

NIPPON KAIJI KYOKAI

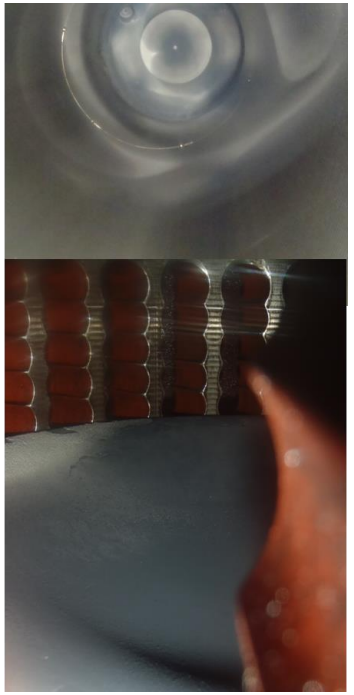
STATEMENT OF FACT

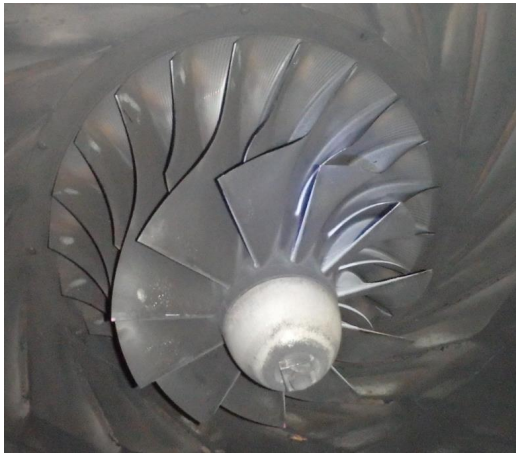
NIPPON KAIJI KYOKAI

STATEMENT OF FACT
for
Washwater Monitoring System

3. Overhaul Inspection Result after Sea Trial

Good condition ! ⇒





Turbocharger Compressor wheel

EGR Blower wheel

- Confirmed a little amount deposit of sodium sulfate and soot.

  ⇒ Continue to follow condition in long-term durability test.

3. Long-term Onboard Durability Test

Updated status is below.

- **EGR operation hour : approx. 400h (approx. 12% of TRH)**
  HFO operation : approx. 200h
  LSFO operation : approx. 200h

- **Achievement : optimizing some parameters about WTS**

- **Experience : some minor troubles**
  - Change piping material of O2 sensor
  - Leakage from shaft sealing of aux. blower
  - Bugs of control panels

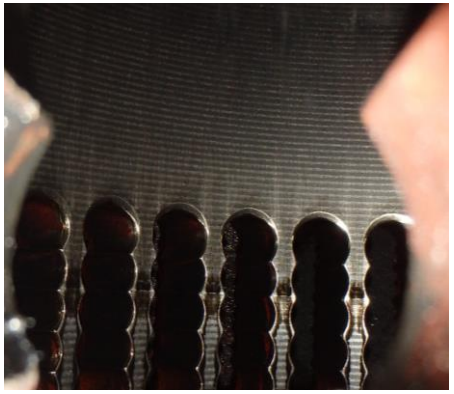
3. Inspection Check Results

Parts for major concern are in good condition.

⇒Under investigation.

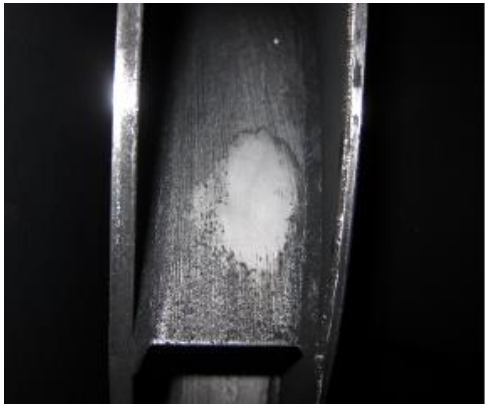
【Piston ring】

【Turbocharger compressor wheel】



【Cylinder liner】

【Scavenge Air Trunk】



【EGR blower impeller】

3. Evaluation in future

- **Evaluation items are as below.**

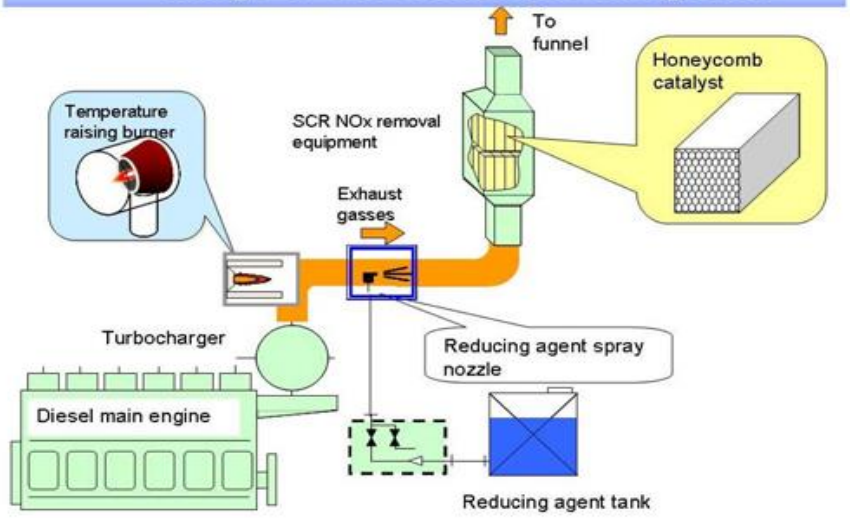
  Term of durability test： 2015.8 ～ 2017.1（plan）

Test item	Purpose	Action
Performance Test	・Confirm performance variation between EGR mode ON and OFF in normal operation. ・Confirm performance variation across the times in EGR operation.	Acquisition of performance data and log data Measuring exhaust gas
Load Following Test in harbor	・Confirm load following capability of M/E and EGR system in harbor.	（Log data in EGR control panel） （Measuring exhaust gas）
Load Following Test at rough sea	・Confirm load following capability of M/E and EGR system in EGR operation at rough sea. ・Confirm level settings of various tanks.	（Log data in EGR control panel） （Measuring exhaust gas） （Inspection check）
Periodical Inspection (engine stop)	・Confirm long term durability of whole EGR system.	Inspection check
Inspection check after long term disuse (1st Dock)	・Confirm reliability of long term disuse EGR system.	Inspection check
Evaluation of User-Interface	・Confirm operability and maintainability of EGR system.	Hearing survey to crew

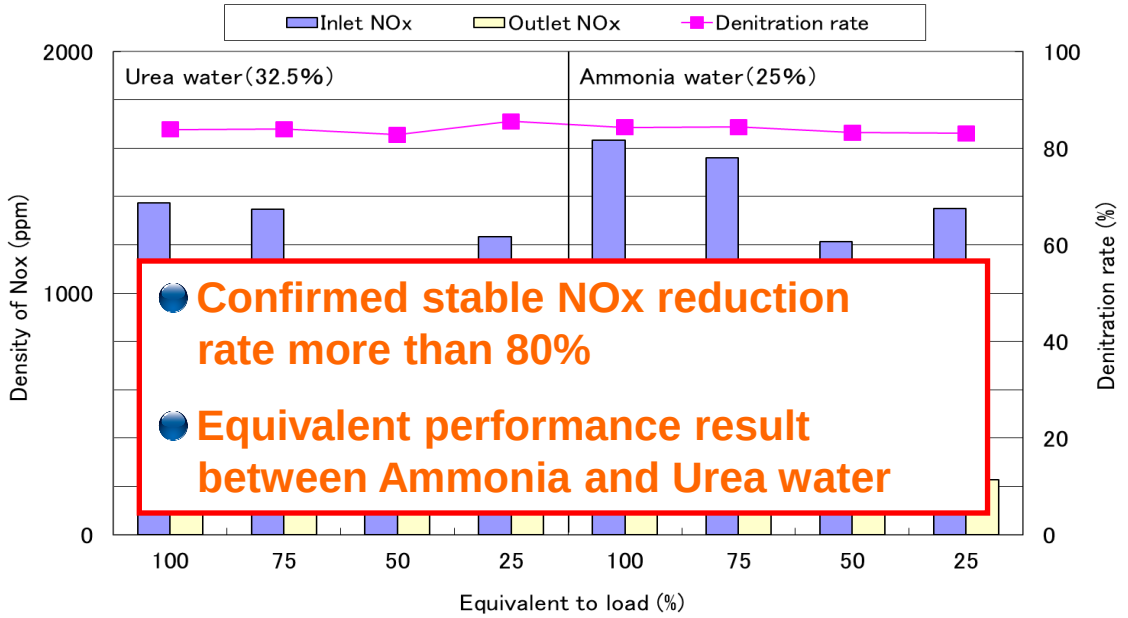
Contents

4. SCR Development (Summary of SCMD project)

Image of SCR NOx removal system



<Onboard test result>



- Confirmed stable NOx reduction rate more than 80%
- Equivalent performance result between Ammonia and Urea water

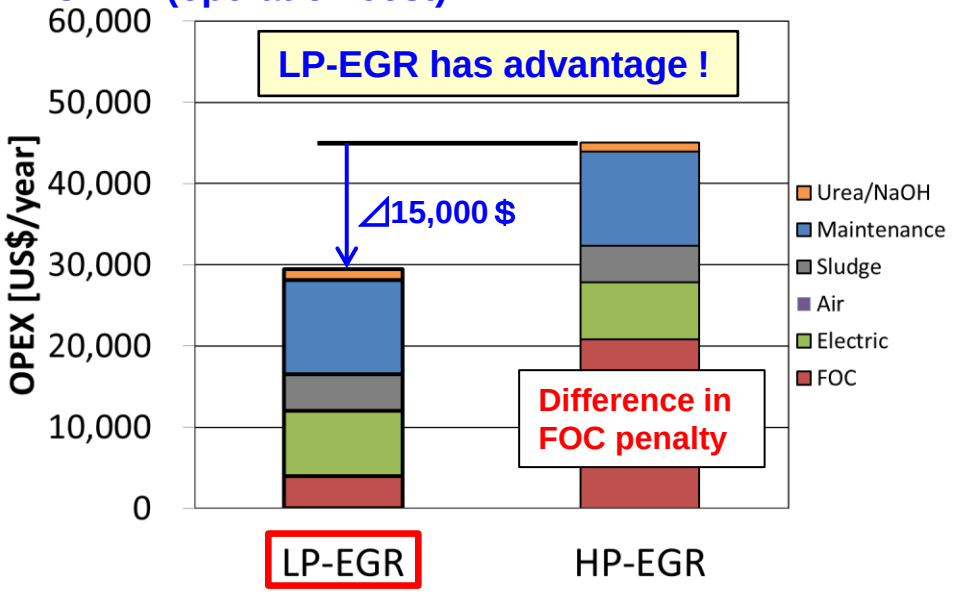
<Summary>

- Confirmed DeNOx rate more than 80% by onboard test in Super Clean Marine Diesel Proj.
  - ⇒ Results already submitted to IMO / MEPC
- Implementation of long-term durability test
  - ⇒ Quantification of performance changing rate
- Optimization of commercial SCR system
  - ⇒ Improving the prediction accuracy of SCR lifetime and minimizing life cycle cost

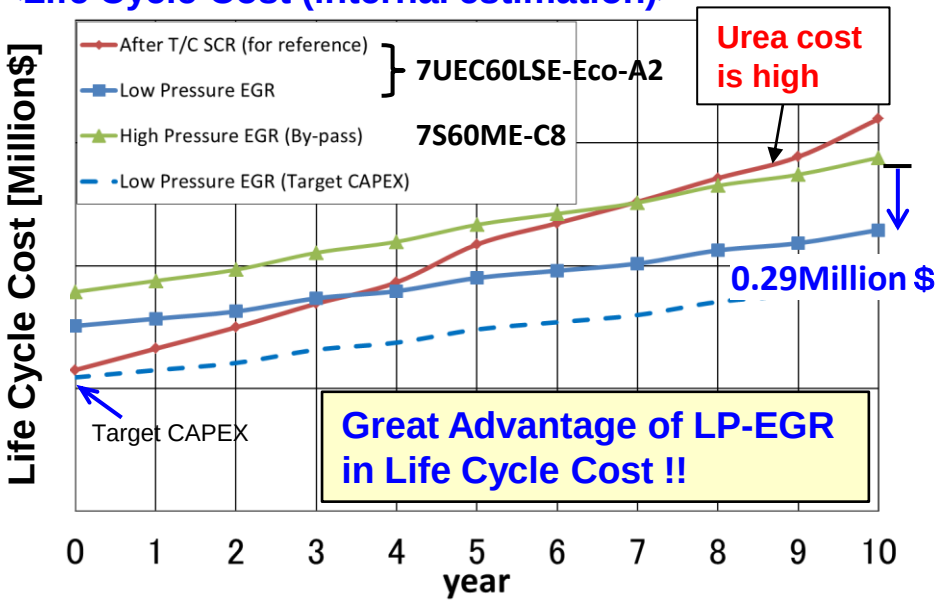
Contents

5. Life Cycle Cost Comparison between LP and HP EGR

<OPEX (operation cost)>



<Life Cycle Cost (internal estimation)>



Estimation Condition

- Running hour: 6,000 h/year, including ECA 10%（600 h/year）
- CAPEX: LP-EGR is based on 4UE-X3 test engine, Aft-SCR is based on maker quotation
- Refill Fresh Water: Lack in low load condition is estimated as fuel cost for water production by fresh water generator
- Fuel Oil: Use low sulfur fuel oil both SCR and EGR in ECA (500 US$/ton)
- Utility: LP-EGR is based on optimized condition
- Maintenance: Exchanging catalyst is not included in one year OPEX

Low Pressure EGR has advantages below.

- **Both CAPEX and OPEX are lower than High Pressure EGR.**
- **Life Cycle Cost is the lowest because SCR uses a quantity of urea water.**

5. Comparison among TierⅢ Systems

		Low Pressure EGR (MHI-MME)	Low Pressure SCR (MHI-MME)	High Pressure EGR	High Pressure SCR
Technical aspect	Feature	EGR gas is recirculated from T/C outlet to T/C inlet	After T/C SCR with low temperature and low pressure	EGR gas is recirculated from T/C inlet to Scavenging air trunk	Pre-T/C SCR with high temperature and high pressure
	Perfor-mance	⊿NOx80% within SFOC approx. +1%	⊿NOx80% with SFOC approx. +2%	⊿NOx80% with SFOC +2～3% EGR rate relatively high? Or EGR gas mixing insufficient?	・⊿NOx80% with SFOC degradation approx. +1～2% ・Acidic ammonium sulfate deposit on EGE by slip NH3 in HFO operation

5. Comparison among TierⅢ Systems

		Low Pressure EGR (MHI-MME)	Low Pressure SCR (MHI-MME)	High Pressure EGR	High Pressure SCR
Technical aspect	Com-position	・Need exhaust gas pipe between Economizer and EGR Scrubber ・Because of LP system, EGR composition is simple	・Need exhaust gas bypass for Global Area ・Flexibility of SCR reactor layout	・EGR gas pipe is closed in engine ・Complicated composition because of EGR Cooler, 2 step Scrubber, T/C cutout valve, CBV etc.	・Need much engine room space for SCR reactor upstream of T/C
	Opera-bility	Central control by EGR Control Panel, simple operation	Able to control separately from main engine control	Complicated control for T/C cutout, CBV operation synchronized engine, etc.	Complicated control for bypass valve aiming for dynamic characteristic

5. Comparison among Tier Ⅲ Systems

		Low Pressure EGR (MHI-MME)	Low Pressure SCR (MHI-MME)	High Pressure EGR	High Pressure SCR
Economical aspect	CAPEX	△ Low cost than HP system because of LP simple system	○ Simple system	× Expensive because of HP system, and many components	△ Expensive than LP SCR (guessed)
	OPEX	○ ・No need of additional boiling, thus, SFOC degradation is small ・Less electric power consumption for EGR Blower ・Less maintenance cost because of less components	× Large urea cost even if using LS-MDO／MGO	△ ・Large fuel cost for EGE additional boiling, thus, SFOC degradation is large ・Large electric power consumption for EGR Blower ・Large maintenance cost because of many components	× Large urea cost even if using LS-MDO／MGO Small fuel cost in case of using HFO availability

5. Summary

- **Mitsubishi Low Pressure EGR system has sufficient performance for meeting IMO TierⅢ regulations with low SFOC penalty.**

  Mitsubishi LP-EGR system has the merits: Simple system and operation, Low CAPEX and OPEX.

- **Mitsubishi LP-EGR system can be applied into not only UE engine but also other brand engines widely because of easy combination for low pressure system.**

- **LP-SCR is also ready and proven.**

MITSUBISHI HEAVY INDUSTRIES
MARINE MACHINERY & ENGINE CO., LTD.

Our Technologies, Your Tomorrow

PROJECT MEET

Thank you for your kind attention !!