YANMAR SCR Technology for IMO Tier III

12th Oct. 2018
YANMAR CO., LTD.
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
Introduction

Transition of environmental regulations

[Bar chart showing the transition of NOx emission regulations from Tier 1 to Tier 3, with percentages and years specified]
Introduction

NOx reduction technology for IMO Tier3

YANMAR selected SCR technology to comply IMO Tier3

The reason why choosing SCR
1. NOx reduction level is the highest.
2. Exhaust gas temperature at engine outlet is higher compared with 2-stroke engine.
3. Few influence to engine performance.
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
Introduction

About YANMAR SCR system

- History of YANMAR SCR technology development
- Outline of YANMAR SCR system
- Certification of SCR System
- YANMAR SCR line up & delivery record
- SCR for main engine

Summary
History of SCR technology development

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Basic technology development</td>
</tr>
<tr>
<td>2008</td>
<td>Research results of Off-road Diesel</td>
</tr>
<tr>
<td>2009</td>
<td>Endurance test (Phase 1)</td>
</tr>
<tr>
<td>2010</td>
<td>Endurance test (Phase 2)</td>
</tr>
<tr>
<td>2011</td>
<td>Endurance test (Phase 3)</td>
</tr>
<tr>
<td>2012</td>
<td>On-board test (Phase 1)</td>
</tr>
<tr>
<td>2013</td>
<td>On-board test (Phase 2)</td>
</tr>
<tr>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
</tr>
</tbody>
</table>
History of SCR technology development

We began developing base technologies of SCR since 2007.

We have experienced 3 times Endurance test and 2 times On-Board test.

Endurance test (on land)
Elemental technology development such as catalyst deterioration and verification of control logic.

On-Board test
Demonstration of the durability of the whole system and the catalyst life.
Verification of SCR system operation method such as maintenance.
### On-board test of SCR system

225,000 ton Cargo vessel

Install SCR to Gen. NO.1,2,3

SCR reactor

#### Supposed ECA

[Image of supposed ECA]

<table>
<thead>
<tr>
<th>SCR operation sequence</th>
<th>Within supposed ECA</th>
<th>Without supposed ECA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (on MGO test)</td>
<td>MGO</td>
<td>HFO</td>
</tr>
<tr>
<td>Fuel (on HFO test)</td>
<td>HFO</td>
<td>HFO</td>
</tr>
<tr>
<td>IMO regulation</td>
<td>Tier3</td>
<td>Tier2</td>
</tr>
<tr>
<td>SCR operation</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>Exhaust gas line</td>
<td>SCR</td>
<td>Bypass</td>
</tr>
</tbody>
</table>

Demonstration of the durability of the whole system and the catalyst life.
Verification of SCR system operation method such as maintenance.
Performance at the end of the test
⇒ NOx reduction rate > 80%
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
Outline of YANMAR SCR system

Reactor design concept

- SCR reactor was unitized from bypass branch to catalytic reactor. And Integration of catalytic reactor and bypass line.
  ⇒ No need for bypass line pipe space.

- Urea injection nozzle is installed on the downstream of the branch to prevent Urea leak to the bypass side.
  ⇒ More safety design for the crew.

- The junction part of bypass line and catalyst line is designed to prevent deterioration of catalyst due to backflow of exhaust gas during bypass operation
  ⇒ Longer life of catalyst.
Integrated control

- All equipments including catalytic reactor are auto controlled integrally by control panel.
1 Control panel and 1 pump unit can operate multiple SCR

- SCR reactor and nozzle unit should be installed for each engine. But 1 control panel and 1 pump unit are installed per 1 vessel.
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR system
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
Certification of SCR system

In “Scheme A”, the engine and SCR system are tested for certification, as one unit, on the test bench.

In “Scheme B”, the engine and SCR are certified respectively.

After that, SCR is fitted to engine, and the engine and SCR system is tested for verification on-board.

YANMAR SCR system is certificated by Scheme A. ⇒ On-board performance is more reliable.
Bench test of SCR system

Catalytic reactor with Bypass Line

Urea water Tank

Engine

Control panel
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
YANMAR SCR system line up (for Auxiliary engines)

For medium speed diesel engines with 355 to 4800 kW.

<table>
<thead>
<tr>
<th>SCR model</th>
<th>Reactor size</th>
<th>Piping size</th>
<th>Engine model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
<td>W</td>
<td>L</td>
</tr>
<tr>
<td>Y16SCR-L</td>
<td>1080</td>
<td>750</td>
<td>2230</td>
</tr>
<tr>
<td>Y165SCR-L</td>
<td>1140</td>
<td>750</td>
<td>2600</td>
</tr>
<tr>
<td>Y18SCR-(A)L</td>
<td>1140</td>
<td>750</td>
<td>2750</td>
</tr>
<tr>
<td>Y22SCR-(A)L</td>
<td>1480</td>
<td>1100</td>
<td>2770</td>
</tr>
<tr>
<td>Y26SCR-6L</td>
<td>1700</td>
<td>1430</td>
<td>3490</td>
</tr>
<tr>
<td>Y26SCR-8L</td>
<td>1920</td>
<td>1430</td>
<td>3360</td>
</tr>
<tr>
<td>Y33SCR-6L</td>
<td>2080</td>
<td>1750</td>
<td>3850</td>
</tr>
<tr>
<td>Y33SCR-8L</td>
<td>2430</td>
<td>1760</td>
<td>3900</td>
</tr>
</tbody>
</table>

※Please contact us for more details.
YANMAR SCR delivery record

Delivery record: **150 units**
Number of orders in hand: **80 units** scheduled for this year

- **Catalytic reactor**
- **Shop test of Urea dosing system at Amagasaki factory**
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
We prepare SCR system not only for Auxiliary engine but also for Main engine.

Our main engine is installed on following vessels mainly.

- Offshore ships
- Fishing Boat
- Training ship
- Patrol boat

The engine room of these vessels is smaller than the Ocean-going Vessel.
### Difference of SCR reactor between auxiliary engine and main engine

In the case of vessel with small engine room, **flexibility of piping is required.**

<table>
<thead>
<tr>
<th>SCR reactor for Auxiliary engine (with bypass)</th>
<th>SCR reactor for Main engine (without bypass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Longer catalyst life</td>
<td>• Short size</td>
</tr>
<tr>
<td>• Redundancy</td>
<td>• Flexibility of piping (1 bend allowing)</td>
</tr>
<tr>
<td>• Space saving with bypass pipe</td>
<td></td>
</tr>
<tr>
<td>• No change in back pressure outside the ECA</td>
<td></td>
</tr>
</tbody>
</table>

© YANMAR Co., Ltd.
SCR for main engine

Bending pipe of SCR

Concern

- Urea is deposited on the pipe surface
  ⇒ Keep injection nozzle away from wall.

- Distribution of NH3 is biased at inlet of the catalyst.
  And NOx reduction rate is decreased.
  ⇒ Sufficient catalyst volume.

We are studying methods to predict these factors more accurately by using 3D model analysis.
**Concern**

- Urea is deposited on the pipe surface
  ⇒ Keep injection nozzle away from wall.
- Distribution of NH3 is biased at inlet of the catalyst and NOx reduction rate is decreased.
  ⇒ Sufficient catalyst volume.

**Prediction by using 3D model analysis**  (Software: FIRE v2017)

**Input**

- Catalyst parameter
  - Size
  - CPSI
  - Pressure drop etc.

- Dimensions and materials of reactor

**Spray conditions**

- Droplet velocity
- Spray cone angle
- Particles size distribution etc.

**Exhaust gas conditions**

- Mass flow
- Temperature
- Pressure etc.
**Bending pipe of SCR**

**Concern**
- Urea is deposited on the pipe surface
  ⇒ Keep injection nozzle away from wall.
- Distribution of NH3 is biased at inlet of the catalyst and NOx reduction rate is decreased.
  ⇒ Sufficient catalyst volume.

**Prediction by using 3D model analysis**  (Software: FIRE v2017)

**Output**
- Catalyst inlet condition
  - NH3 uniformity etc.
- Wall temperature
- Spray Wall Film Formation
  - Wall film mass balance etc.

High possibility of deposition when wall film is formed and wall temperature is lower.
We have improved analysis accuracy by conducting verification test.

On verification test, we increased the urea water injection quantity intentionally to deposit urea.

Wall temperature and Wall film formation of analysis

Actual deposit of Verification test
## Variation of SCR reactor for main engine

Multiple types of reactor are available depending on usage

<table>
<thead>
<tr>
<th>2 Engines-1 Shaft or 2 Engines-2 Shafts (provided redundancy)</th>
<th>1 Engine-1 Shaft (no redundancy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use SCR only within ECA</td>
<td>Always use SCR</td>
</tr>
<tr>
<td>Bypass-less</td>
<td>With bypass line</td>
</tr>
<tr>
<td></td>
<td>With emergency bypass line</td>
</tr>
</tbody>
</table>

![Images of reactor variations](image)

Yellow: Yanmar supply
**Variation of SCR reactor for main engine**

Multiple types of reactor are available depending on usage. Bending type is also the same as Straight type.

<table>
<thead>
<tr>
<th>2 Engines-1 Shaft or 2 Engines-2 Shafts (provided redundancy)</th>
<th>1 Engine-1 Shaft (no redundancy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use SCR only within ECA</td>
<td>Always use SCR</td>
</tr>
<tr>
<td>Bypass-less</td>
<td>With bypass line</td>
</tr>
<tr>
<td></td>
<td>With emergency bypass line</td>
</tr>
</tbody>
</table>

- **Bend pipe**: Yellow : Yanmar supply (※Bend pipe is shipyard supply)
- **Changeover valve**: Piping diameter of bypass line can be small depend on allowable back pressure for engine.
SCR for main engine

1 Control panel and 1 pump unit can operate multiple SCR

Combination of main engine and auxiliary engine is also possible.
● Introduction

● About YANMAR SCR system
  - History of YANMAR SCR technology development
  - Outline of YANMAR SCR system
  - Certification of SCR System
  - YANMAR SCR line up & delivery record
  - SCR for main engine

● Summary
Summary

In-house developed SCR system with high reliability and durability

SCR systems are best matched with the respective engines.

One control panel and pump unit integrate multiple devices. It realized compact and simple system.

Engine and SCR system will be certificated as IMO tier III compliant according to the Scheme A procedure.

Now developing SCR for main engine based on customer's needs.