GREEN TECHNOLOGIES

ABSTRACT

Ships are the most environmentally friendly form of transportation. Still, with 90% of the world trade being transported by ship, it is inevitable that shipping contributes to unwanted emissions from transportation. In recent years, sustainability in a climate and an environmental perspective has become an issue of highest priority. The strong focus should be on making waterborne trade even more environmentally friendly than it already is. The basic condition is being able to demonstrate a technology for reduction of air emissions within one of the four focus areas: Machinery, Propulsion, Operations and Logistics.

The regulations to be set for safe, secure and environmentally sustainable shipping must be goal-based instead of prescribing specific solutions. Such regulations create ample room for innovation of new efficient technologies and operational standards. Another important aspect is the work done by the International Maritime Organization, which is the key player in setting regulations applicable for all ships irrespective of the flag. In order to keep focus on the important agenda of sustainable and green shipping even in difficult times, we must turn towards innovation and efficient regulation.

So the main focus in this report will be on the technologies like the waste heat recovery system, exhaust gas recirculation, air cavity systems, scrubbers, water in fuel systems which predefines the existence of shipping in the Green World.

Keywords: ECA's, WIF's, EGR, SFOC, scrubbers, power turbines.

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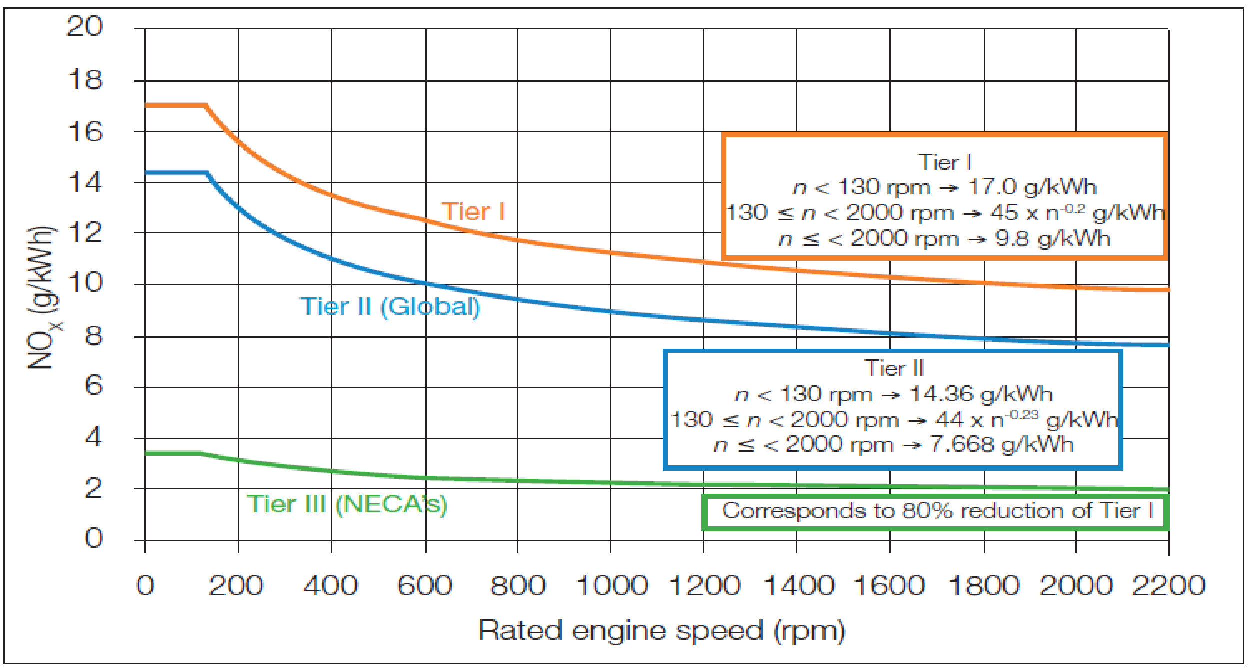
1.0 EMISSIONS REGULATIONS AND IMPACT ON ENGINE PERFORMANCE



1.1 NEW TIER II AND TIER III EMISSIONS REGULATIONS ON ENGINE PERFORMANCE

The emissions regulations in Annex VI of MARPOL 73/78 have now been in force since 19 May 2005, retroactive for engines from 1 January 2000, referred to as the Tier I level. At the moment, a review process is progressing to revise the existing emissions regulations and the NOx Technical Code into a Tier II level.

The decisions on the new limits and regulations have been finalized at the BLG (Bulk, Liquid and Gas) meeting and been approved at the MEPC (Marine Environment Protection Committee) meeting. The scenario and the decisions are outlined in the following.

Tier II, which is into force from 1 January 2011, reduces the existing Tier I level by 2.6 g/kWh NOx in the relevant speed region for new two-stroke engines, and Tier III, which is to enter into force on 1 January 2016, reduces the existing Tier I level by 80% across the entire speed limit NOx curve for new engines, but only in a defined local area near shore. Outside this area, the Tier II level will be in force.

Furthermore, a regulation for existing pre-year 2000 engines will be introduced, since the contribution of emissions from these engines will exist for still many years to come. The NOx limit level for these engines will correspond to the Tier I level for new engines as of today. It is anticipated that the certification procedures and the technical documentation needed will be somewhat reduced in comparison to the requirements for new engines in order to make the regulation practicably possible.

With regard to SOx and PM regulations, this is to be controlled by a limitation in the sulphur content of the fuel used. An alternative measure is the use of scrubbers.

<table>
<tr><th>Implementation date</th><th>SO_x Emission Control Areas</th><th>SO_x Global</th><th>Scrubbers</th></tr>
<tr><td>Existing regulation</td><td>1.5%</td><td rowspan="2">4.5%</td><td>Only in ECA´s</td></tr>
<tr><td>1 March 2010</td><td rowspan="2">1.0%</td><td rowspan="6">Alternative meas-ures (scrubbers) in ECA´s and globally</td></tr>
<tr><td>2012</td><td rowspan="3">3.5%
Review of 2020 fuel situation</td></tr>
<tr><td>2015</td><td rowspan="4">0.1%</td></tr>
<tr><td>2018</td></tr>
<tr><td>2020</td><td rowspan="2">0.5% (HFO allowed)
Alternative 0.5% intro date</td></tr>
<tr><td>2025</td></tr>
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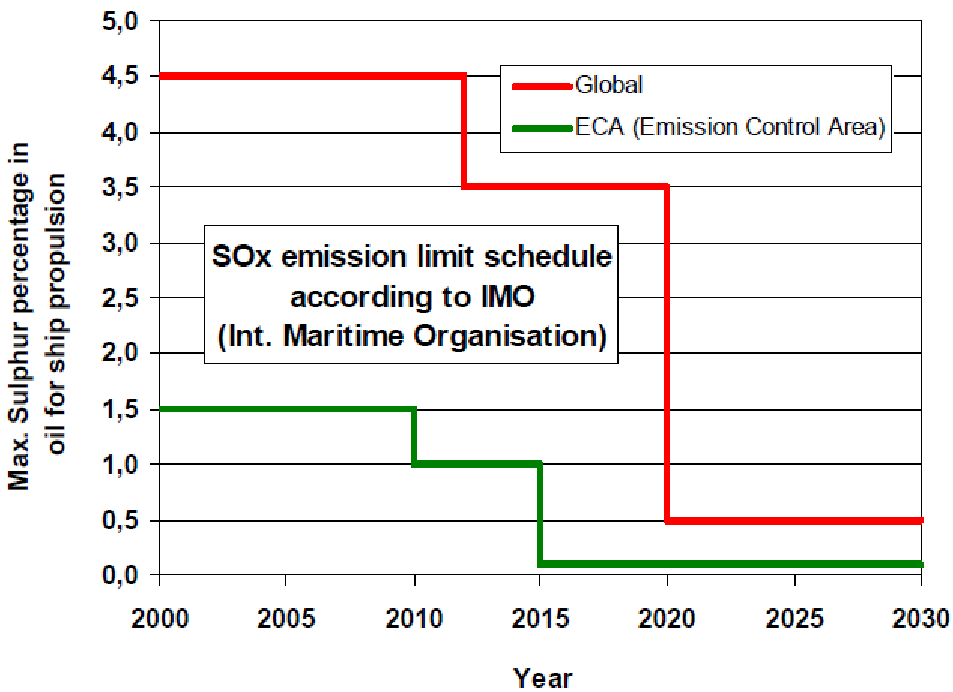
A general worldwide emissions limitation seems to be the only way that all countries can benefit from a reduction in emissions. Emission limits must follow state-of-the-art technology and the ability of the market to adapt to such limits.

The authorities have so far focused on NOx and SOx, but as soon as the IMO Annex VI has been ratified, more attention will be paid to components from the exhaust, such as HC, particulates, CO and CO2.

These considerations involve not only the fuel used and the engine design, but also operational issues and type of cylinder lube oil and dosage used are influencing factors.



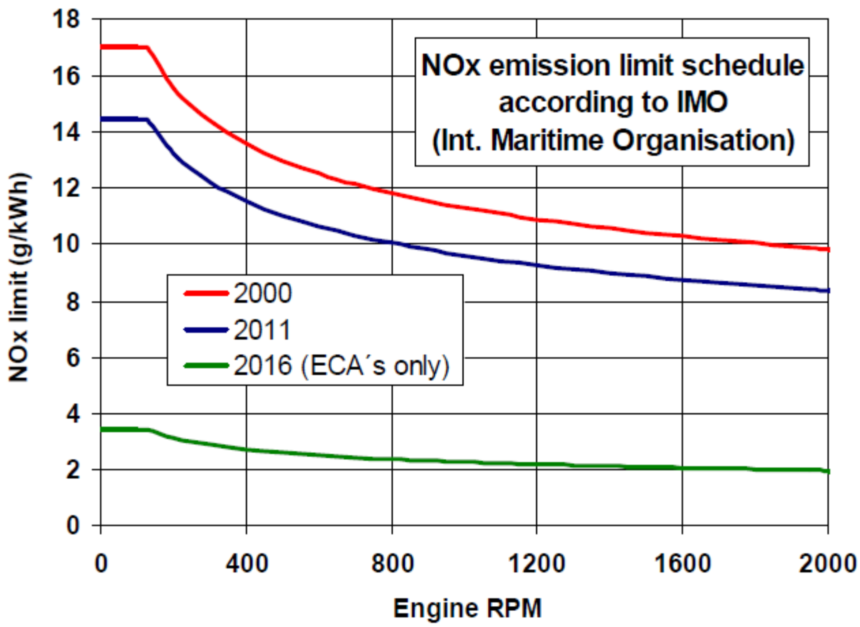
While 4.5 percent sulfur content is currently permitted in ships' fuels, it is scheduled to drop to 3.5 percent by 2012 and be further cut to 0.5 percent no later than 2020. Within some coastal zones designated as Emission Control Areas (ECAs), stricter limits are already in force today. Existing ECAs include the North Sea and the Baltic Sea.

Throughout the world, national and regional governments tend to extent the Emission Control Areas (ECA's). Lately, the US and Canada have put forward a proposal, that will extend their emission control areas to 200 nautical miles from the coast.

It demands use of fuels containing less than 0.1 percent sulphur from 2015 as well as an 80% NOx reduction from 2016. In lieu of low sulphur FO the proposal calls for exhaust gas cleaning devices, so called scrubbers, as the world production of low sulphur fuel oil cannot meet the demand.

The EU is going to limit the sulphur content of fuels to 0.10% in EU ports from January 2010.

Since May 2009, California has limited the sulphur content of fuels to 0.50% in ports and within 24 nautical miles from the coastline.



The rules coming into force concerning NOx emissions are internationally controlled by the IMO and, to some extent, by national governments stating separate requirements for NOx within ECA areas.

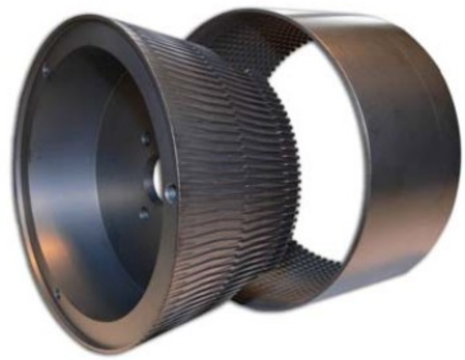
Concerning CO2 it is expected, that rules for ships will come into force in the near future, both internationally and regionally. For the moment, however, the only concrete step is the probably coming rules enforcing CO2 indexing of new ships. 3 % of the worlds CO2 emission has been calculated to come from ship transport (IMO GHG study, July 2009).

2.0 EMISSION REDUCTION METHODS

Listed below are some of the emission reduction measures, which have been mentioned in recent years. The claimed potential for each measure is listed as well. The idea of this concept study is to determine, for a specific ship design, the combined effect of some of these measures.

MEASURE / METHOD	**CO2 Reduction**	**NOx Reduction**	**SOx Reduction**
MACHINERY			
Dual / Multi MCR certification	1 to 3 %		1 to 3 %
Turbo charging with variable nozzle ring			
WHR systems (Waste Heat Recovery)	8 to 10 %	8 to 10	8 to 10 %
EGR systems (Exhaust Gas Recirculating)	-2 to -3 %	80%	19%
Auxiliary systems optimisation	1,5 %	1,5 %	1,5 %
Automated engine monitoring	1 %		1 %
Scrubber systems	3 %		98 %
Optimized control for ship cooling			
LNG fuel	25 %	35 %	100 %
WIF systems (Water In Fuel)	increase 1 to 2 %	30 to 35 %	increase 1 to 2 %
PROPULSION			
ACS (Air lubrication system)	5 to 10 %	5 to 10 %	5 to 10 %
Innovative propeller	Not yet known	Not yet known	Not yet known
OPERATION			
SIMAC GSF student forum	Not yet known	Not yet known	Not yet known
Performance monitoring of silicone antifouling	4 to 8 %	4 to 8 %	4 to 8 %
Lab on a ship	0 to 5 %	0 to 5 %	0 to 5 %

3.0 WATER IN FUEL SYSTEM



3.1 OPERATING ON WIF GIVES THE FOLLOWING POSSIBILITIES

- Based on already obtained experience the effect of adding 50 % water to the fuel is expected to give a 30-35% NOx reduction of the exhaust gas, at the expense of an increase in CO_2 emissions of 1-2%.
- To be used as an alternative measure to reduce the NOx level instead of mechanical adjustments / modification of the engine and thereby being able to fulfill the IMO Tier II limit.
- To be used to reduce CO_2 emission together with turbochargers with variable nozzle area, as the maximum fuel oil reduction potential cannot be obtained operating on fuel only (without WIF) as the NOx emissions would exceed an unacceptable level.

3.2 THE MECHANISM OF WATER IN FUEL

WIF is believed to decrease the NOx formation because the peak temperature is lowered due to the higher heat capacity of water vapour (compared to ambient air) and the heat absorption by water vaporization. It has also been observed, that the formation of PM is lowered when WIF is employed, which can be explained by the phenomenon micro-explosions or secondary atomization of emulsified fuel. This occurs, because the boiling point of water is lower than that of the surrounding fuel oil. The overall effect of the improved mixing of fuel with the combustion air is a decrease of the final CO, THC and PM concentrations. The improved mixing is also due to an increased momentum of the vaporized fuel jet (the mass is increased due to addition of water), which also improves the mixing. The presence of water in the fuel leads to a potential ignition delay, which means that more time for premixing of fuel and air is available. The last effect of WIF is an increased amount of hydroxylradicals due to the higher water concentration. Hydroxyl radicals are essential in the oxidation of CO and THC.

3.3 WATER IN FUEL ON MAN TWO-STROKE ENGINES

MAN diesel delivers the main components of the system, assembled in a so-called WIF unit, plus the necessary modifications to the main engine.

3.4 MODIFICATIONS TO MAIN ENGINE

In general the needed changes to ME/ME-C and ME-B engines are very limited, whereas the mechanical camshaft engine types MC and MC-C requires more changes. (Refers to MAN engines)

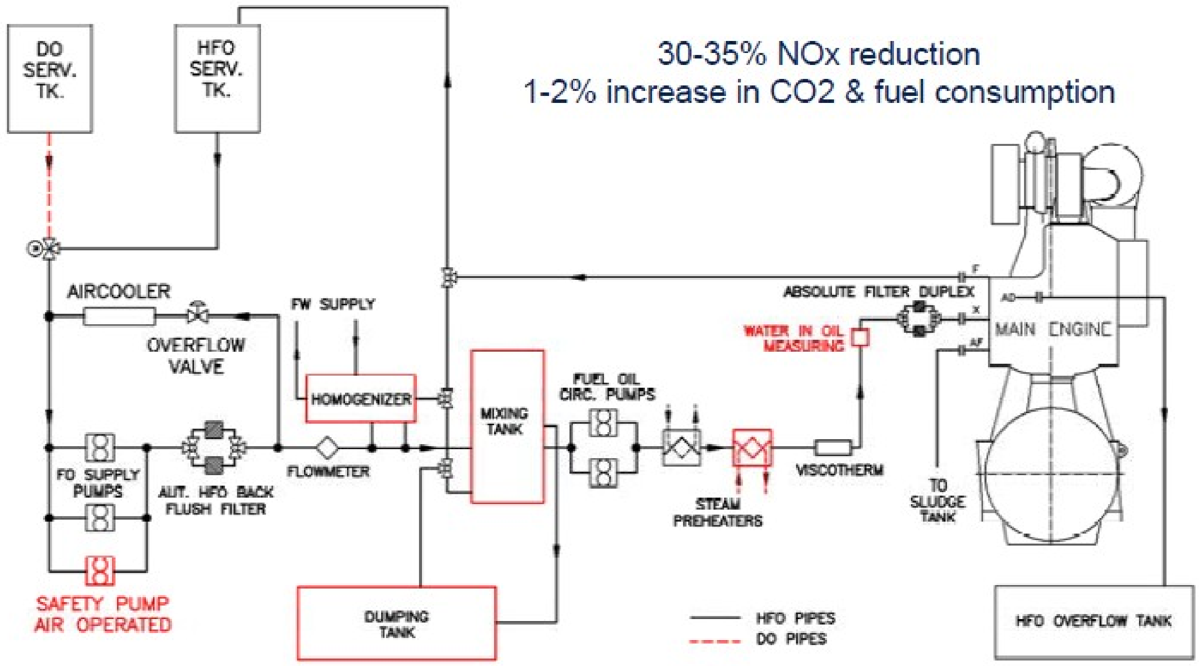
3.5 MODIFICATIONS TO AUXILIARY SYSTEMS

When adding water to the fuel, the emulsion needs to be heated to a higher temperature than without water and the pressure in the system has to be increased in order to avoid evaporation of the water. Furthermore, the auxiliary engines will be required to be supplied from a separate fuel oil system, as they will not be capable to operate on the same amount of water. The amount of water added is 50 % of the fuel, corresponding to app. 13.5 tones of fresh water per 24 hours.
This means that a larger fresh water generator is needed; but enough heat is available from the main engine jacket cooling water system.

For new buildings the extra investment is limited, as many of the components just differ a little from its specification and placement in the systems. For existing vessels the piping system and many of the components needs to be replaced, which will be relatively costly.

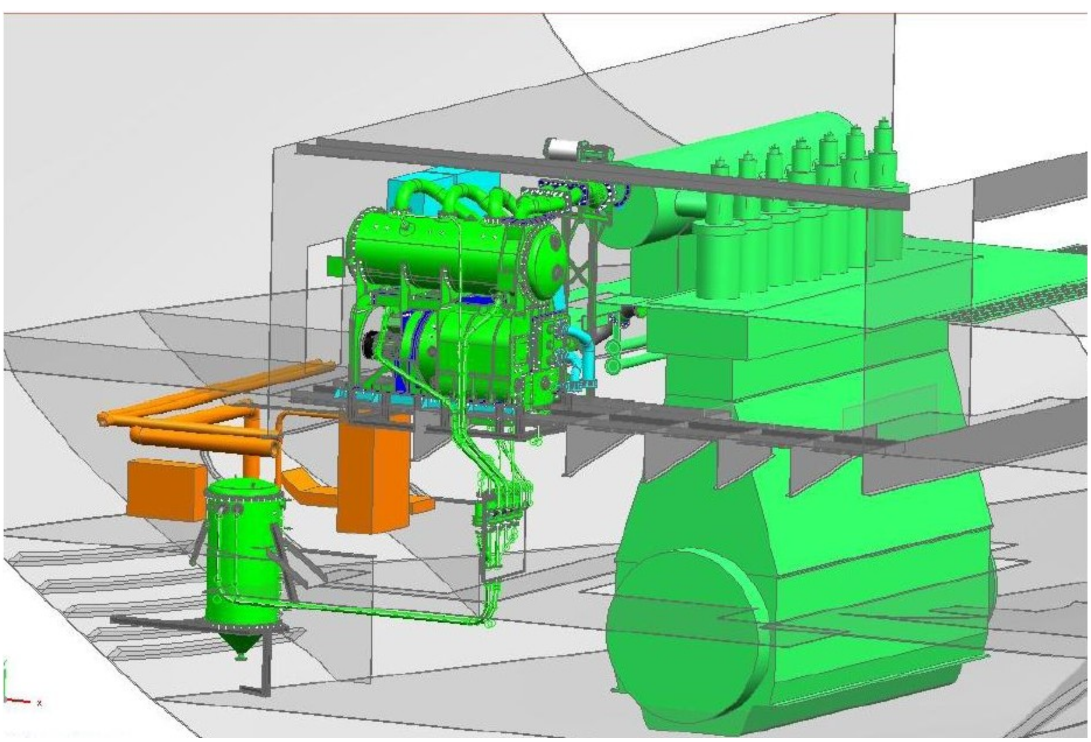
The WIF fuel system for the main engine is shown in the diagram below. The new components are; water in fuel measuring device, homogenizer, dumping tank, and an air driven back-up fuel oil supply pump for securing pressure in the fuel system, in case of black-out. The supply pump pressure must be increased from the normal 6 bar to 13 bar, meaning that all components in the re-circulation circuit, including the homogenizer, mixing tank, circulating pumps, pre-heaters, viscotherm, filter and main engine, must be designed for this pressure.

The preheating temperature must be increased to180 deg. C, which cannot be obtained by heating with 6 bar service steam. A 14 bar steam system has been introduced, in order to boost the temperature of the fuel emulsion.



WIF fuel system for the main engine

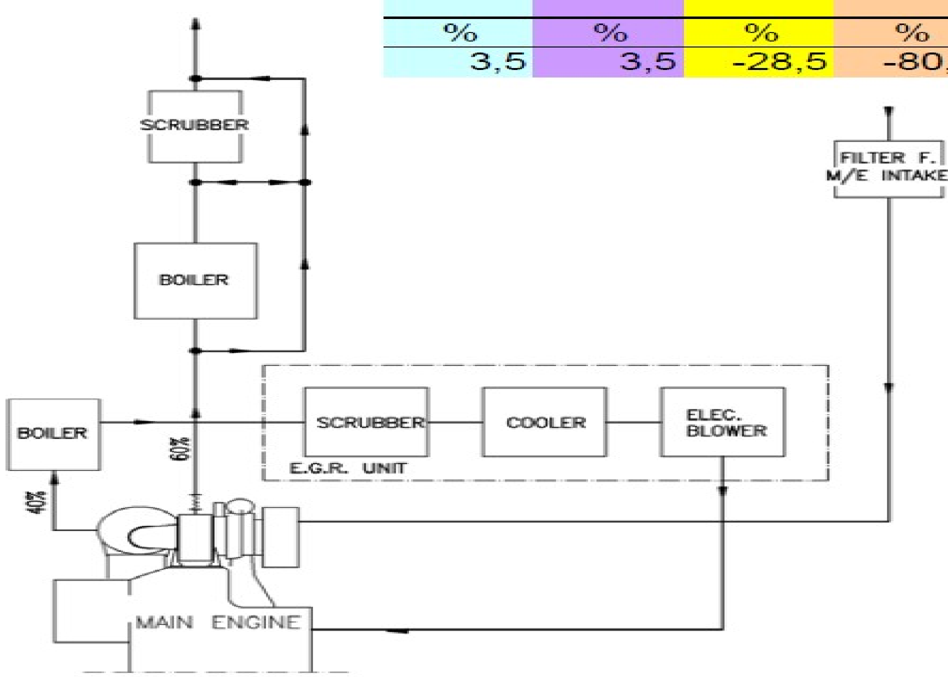
4.0 EXHAUST GAS RECIRCULATION



EGR system installation – arrangement overview in engine room

This is a well known method of reducing NOx emissions from internal combustion engines. The basic concept of the EGR technology is to reduce the peak combustion temperature, which suppresses the thermal formation of NOx . EGR obtains this, partly because the heat capacity of the re-circulated exhaust gas is higher than that of normal combustion air (ambient air). Furthermore, the lower oxygen content (compared to the ambient air) in the re-circulated exhaust gas lowers the chemical reaction rate for the combustion of the fuel, thereby also reducing the peak combustion temperature.

SFOC	CO2	SOx	NOx	PM
%	%	%	%	%
3,5	3,5	-28,5	-80,0	-49,7

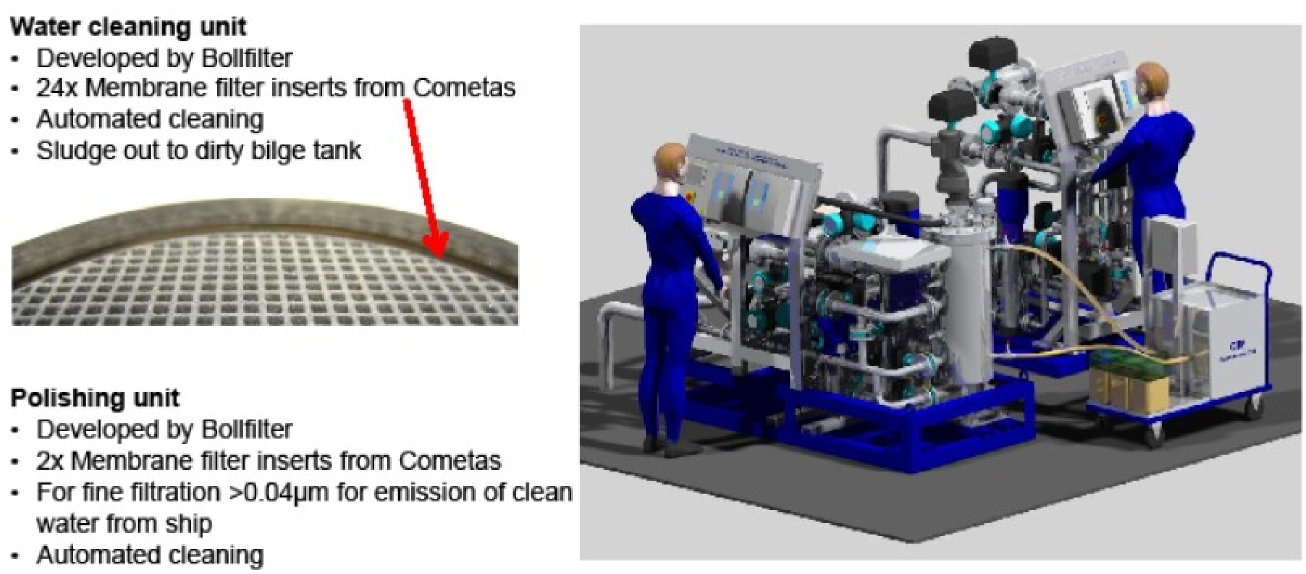


5S50ME - B9 EGR + WIF emission changes v/s reference

EGR system consists mainly of a pipe connection from the main engine’s exhaust gas receiver, via an EGR unit, to the scavenge air receiver. The EGR unit consists of three parts:

- A scrubber unit which removes SOx and particle matters from the re-circulated gas, to prevent this from damaging the engine. The scrubber uses re-circulated fresh water, which is being cleaned continuously and neutralized with NaHO, in a special water cleaning unit.
- A cooler ensuring that the re-circulated gas does not raise the scavenge air temperature significantly above the temperature of the air from the charge air coolers.
- A frequency controlled blower, which overcomes the pressure differential between the exhaust gas receiver and the scavenge air receiver, and controls the flow. The electrical power consumption of the blower is about 85 kW when the engine runs at 85 % SMCR, corresponding to service speed.

The recirculation ratio is 0.3 at full engine load, increasing to 0.4 for engine loads below 75 % SMCR. The fresh water consumption of the scrubber corresponds roughly to the water condensation from the exhaust gas, meaning that the requirement for fresh water is negligible.



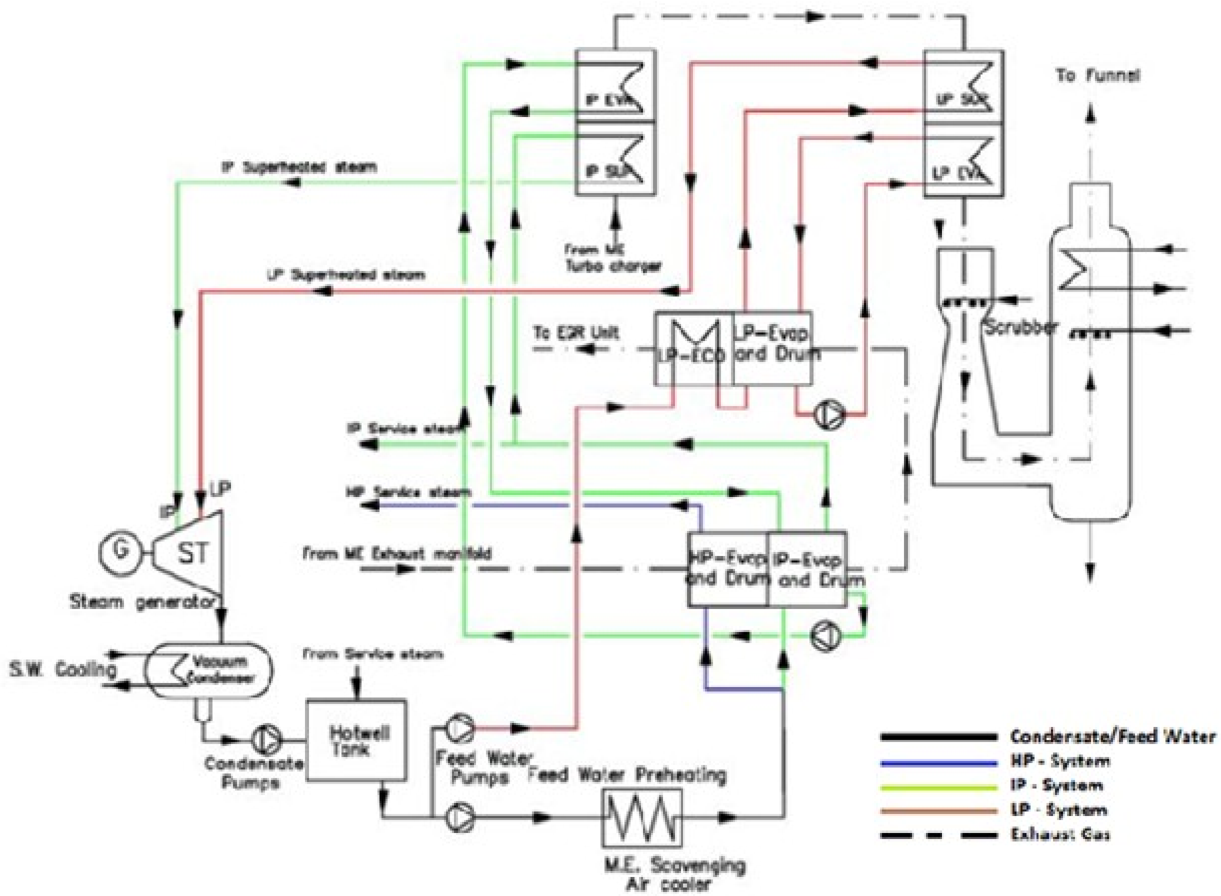
EGR water handling system

5.0 WASTE HEAT RECOVERY SYSTEM

Waste heat recovery systems, with different degrees of sophistication, have been used on ships for decades, and with respect to CO2, it gives by far the largest emission reduction, of the systems in the case study discussed ahead. Experience from existing installations, e.g. large container vessels owned by A.P.Moller-Maersk, shows a potential for recovery of 10-15 % of the main engine power.

The steam turbine generator, which replaces one of the existing diesel generators, has been designed by MAN Turbo, and has an electric output of 500 kW, when sailing at service speed, corresponding to 8.3 % of the main engine output. The reason for this relatively modest output is, partly that the so called power turbine *) has been omitted for simplicity on this relatively small system, partly that a substantial portion of the generated steam must be used for fuel heating, not least due to the WIF system, and finally that the main engine exhaust gas temperature is relatively low, due to the de-rating. There is simply less wasted heat to utilize.

The power turbine (omitted) is similar to the turbine part of a turbocharger, and some of the exhaust gas is led through this, thereby bypassing the turbochargers. The power turbine is part of the steam turbine generator unit. It typically provides 15 - 25 % of the WHR output.



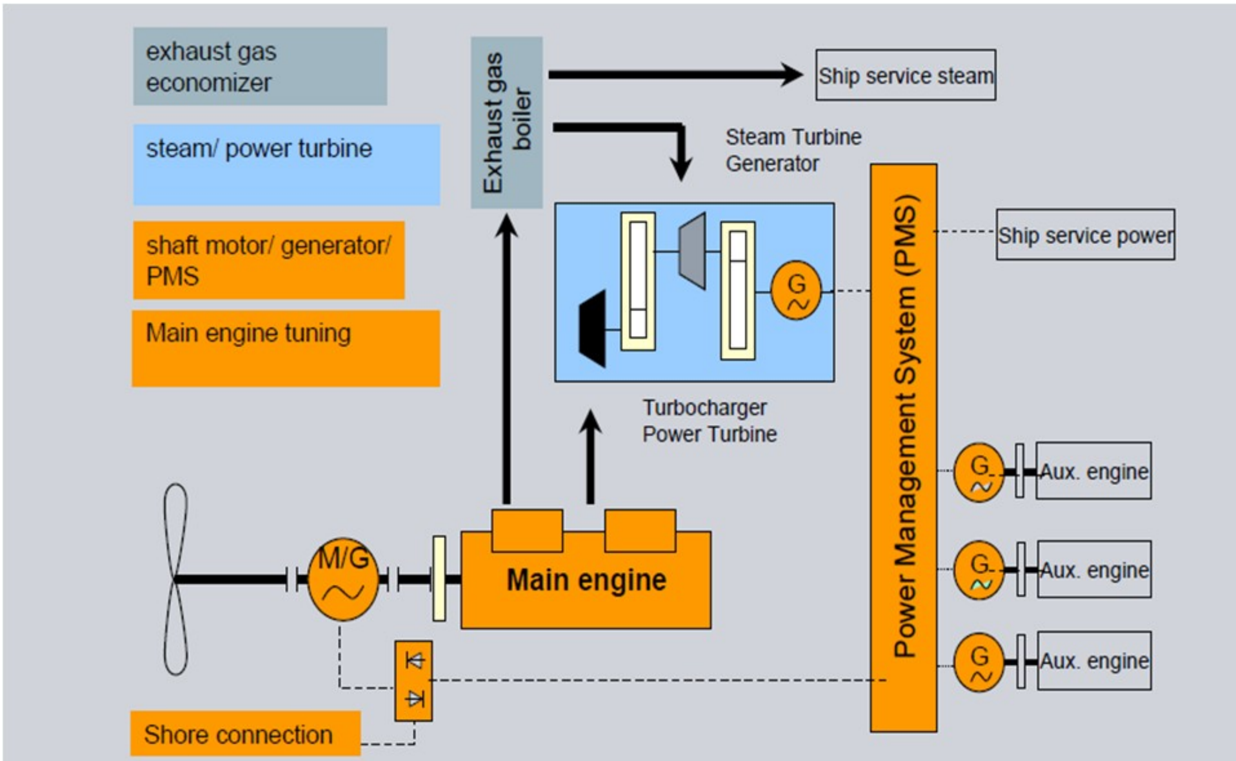
Plant Diagram

The vessels(Seahorse 35 – Case Study) boiler plant has been designed by Aalborg Industries, and consists in total of six individual boilers, out of which four (intermediate and low pressure boilers) produces steam for the steam turbine: High pressure (HP), intermediate pressure (IP) and low pressure (LP) exhaust boilers in the EGR circuit in the engine room. As the exhaust gas in the EGR system is under pressure, these boilers are of the fire tube type.

This also makes it possible to utilize the boilers as steam drums in the HP, IP and LP pressure systems respectively. IP and LP exhaust boilers as part of the uptake in the casing. These boilers are of the water tube type with forced circulation from the IP and LP steam drums respectively.

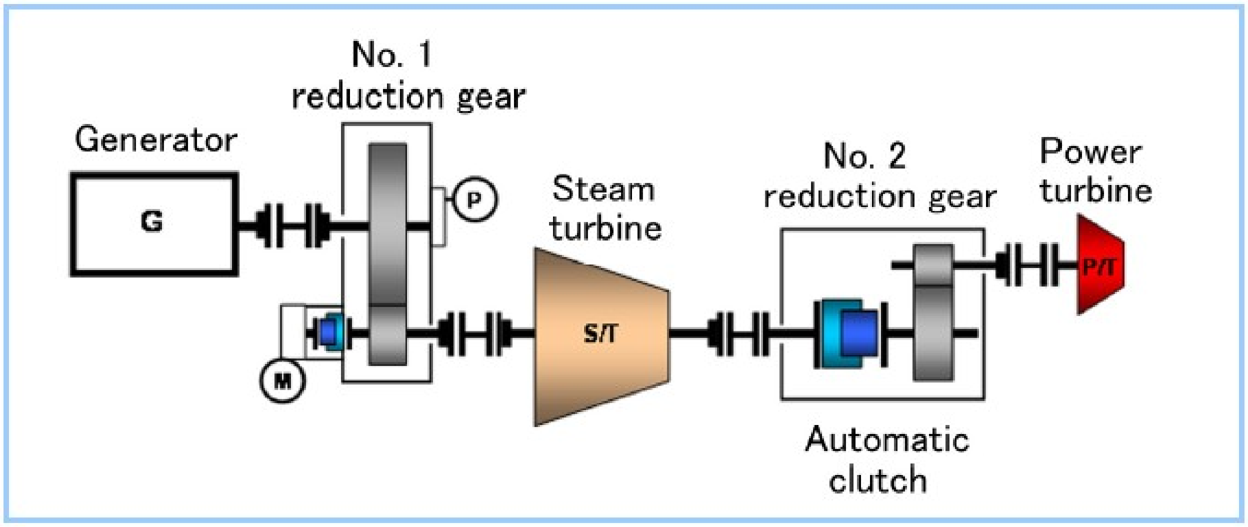
As the exhaust boilers are not able to be heated by oil-firing, unlike the original composite boiler, a small oil-fired boiler is also needed for start-up and harbor service.

5.1 SUPER WASTE HEAT RECOVERY SYSTEMS



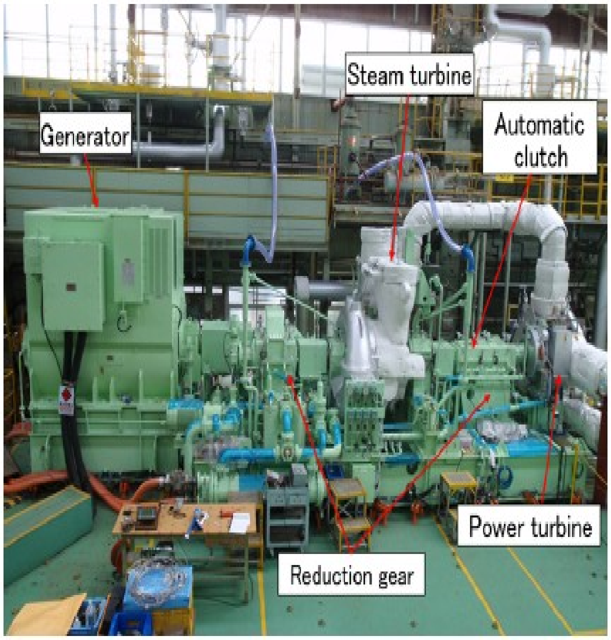
Conventional waste-heat recovery systems for a main diesel marine propulsion engine supplies electricity to a ship using an exhaust gas economizer and a steam turbine. A super waste-heat recovery system has been developed consisting of a conventional combined system with a gas economizer, a steam turbine and a power turbine (gas turbine) utilizing a portion of the exhaust gas, and an automatic clutch. In this compound system, the power turbine is engaged and disengaged with the steam turbine through the automatic clutch to drive a generator.

The power turbine is coupled to the steam turbine through the automatic clutch. After the steam turbine begins to cover the load, the power turbine starts operating. When the rotation speed of the power turbine reaches that of the steam turbine, the automatic clutch engages the turbines so that the rotating torque of the power turbine is added to the steam turbine to drive the generator. In this compound generating system consisting of parallel operation of steam and power turbines, when the total electricity demand of the ship is below the full capacity of the heat recovering generator, the steam system takes the main role with complementary power support from the power turbine.



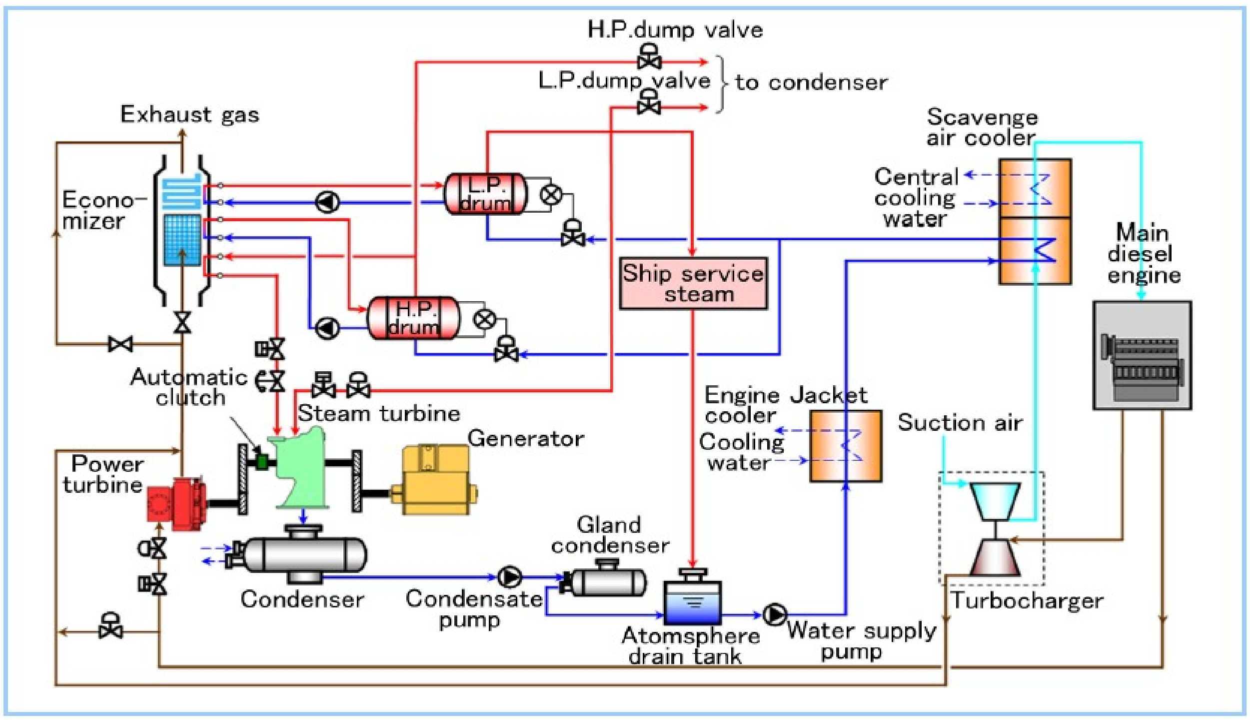
Construction of the steam and power turbine

The power turbine is coupled to the open end (opposite the generator) of the steam turbine shaft through the automatic clutch. The power turbine rotation is reduced by one-stage reduction gears from 20,000 rpm to 8,700 rpm to couple it with the steam turbine. The power turbine and the pinion gear in the reduction gear are connected with a flexible coupling, and the wheel gear in the reduction gear and the steam turbine shaft are coupled with the automatic clutch and flexible coupling.



Main engine output and speed	MCR 45,740 kW × 78 rpm
Steam turbine model	Mitsubishi ATD52CLM
Steam turbine maximum output	2,500 kW
Steam turbine speed	8,685 rpm
Inlet steam pressure and temperature	0.588 MPa (G), 267°C
Degree of vacuum in the condenser	6.0 kPa
Power turbine model	Mitsubishi MPT42
Power turbine maximum output	1,700 kW
Power turbine speed	19,414 rpm
Generator maximum output and speed	4,000 kW, 1,800 rpm

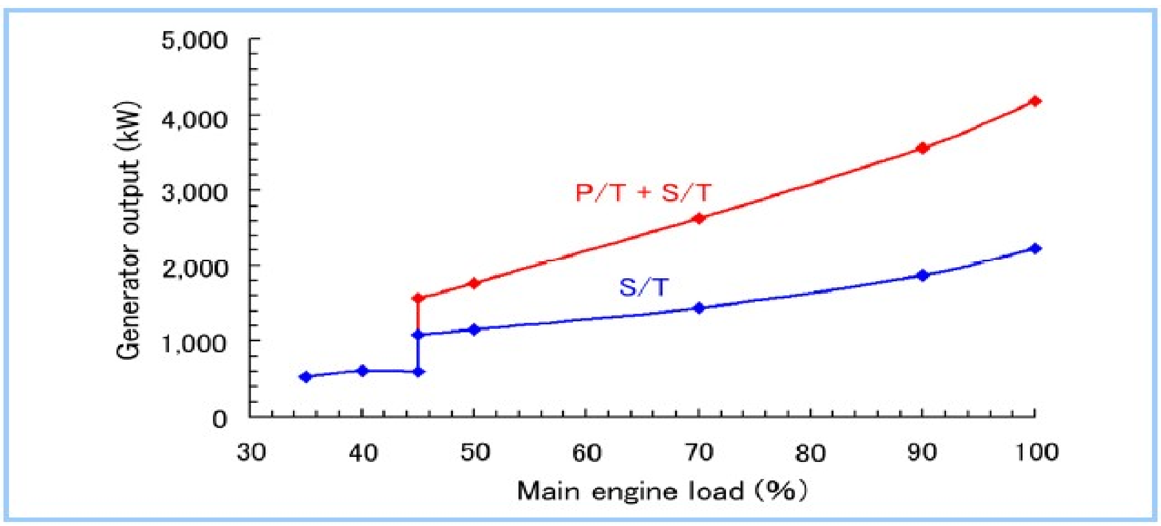
Test operations with combined turbines **Specifications for M.E & SWHRS**



Plant Diagram

The plant uses a two-stage pressure exhaust-gas economizer. Condensed water at 38ºC is sent to the engine jacket cooler, which raises its temperature to approximately 75ºC. Then the water is heated up to approximately 135ºC by the turbocharger compressor outlet air and sent to the steam separator in the exhaust gas economizer. Up to 13% of the exhaust gas is extracted from the exhaust manifold and used to drive the power turbine. A bypass valve installed on the exhaust extract line is used to prevent the scavenging pressure from rising suddenly due to the power turbine trip or other factors.

During operation, the exhaust gas bypasses the exhaust gas economizer and is released to the air through a duct when the engine load is 30% or lower due to the small amount of energy in the engine exhaust gas. This avoids soot deposits on the economizer tubes from foul exhaust gas. When the power is 35% or higher, the steam turbine starts; at 45%, the power turbine starts. When the total electricity demand of the ship is lower than the capacity of this system, all diesel generators are stopped and the system covers the entire electrical load of the ship, making use of the load optimizing control of the steam and power turbines to obtain the highest level of energy efficiency.



5.2 THE CHARACTERISTICS OF THIS SUPER WASTE-HEAT RECOVERY SYSTEM INCLUDING THE LOAD CONTROL ARE LISTED BELOW.

(1) The steam and power turbines are connected to the generator in tandem and are load controlled.

(2) The steam energy to drive the steam turbine is ordinary waste heat that is usually exhausted outside the ship. However, the amount of steam generated by the heat energy is recovered so that it does not become excessive by utilizing the steam turbine electrical generation capabilities to their maximum potential.

(3) The steam turbine initially supplies electricity for the ship, and the power turbine covers any shortfall.

(4) As described above, the fuel consumption of the main diesel engine can be reduced by decreasing the amount of exhaust gas extracted for the power turbine.

(5) The power turbine is coupled to the steam turbine through an automatic overrunning clutch. When the gas valve of the exhaust extract line is closed, only the steam turbine operates.