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Machinery Options for Green Ship

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Abstract

Shipping is critical to global economy being means of transportation for 90 % of world trade goods. Shipping continues to remain the most environmental friendly transportation option compared to other available means due to lowest gCO2/ton.km emissions. It can however not be overlooked that shipping is responsible for 3 % of global CO2 emissions, 14-15 % of global NOX emissions and 16 % of global SOX emissions. International Maritime Organization (IMO) is committed to reducing shipping emissions through policy and regulatory measures. Marine Pollution (MARPOL) regulations have been increasingly demanding to tackle aggravating environmental concerns. IMO has been introducing measures for better energy-effectiveness (i.e. SEEMP) in addition to better environmental performance (i.e. EEDI). Green ship concepts require exploring and implementing technologies and practices on ships to reduce emissions and increase energy-efficiency. Ship machinery is an important area with large potential to reduce emissions and increase cost-and-energy-effectiveness. This paper provides a comprehensive review of the machinery options for green ship. The author will discuss basic concepts, principles and potential of machinery options for green ship in detail.

Keywords: Green ship; engine efficiency; NO_X emission reduction, SO_X emission reduction

1. Introduction

Shipping industry has a critical role in global economy. Intercontinental trade, bulk transport of raw materials, and import/export of affordable food and goods is carried out through ships. It is estimated that almost 90 % of world trade goods are carried by ships [1]. The global shipping volume had a remarkable increase over past four decades i.e. 2.6 billion tons in 1970 to 9.2 billion tons in 2012. This volume is anticipated to grow further owing to growing global production, increasing importance of global supply chains and expected growth in number of economies.

Shipping industry is also one of the stakeholders in environmental issues. According to third International Maritime Organization (IMO) GHG study 2014, international shipping emitted 796 million tonnes of CO_2 in 2012 which is approximately 2.2% of the total global CO_2 emissions for year 2012 [2]. Oceangoing ships are also responsible for 14-15% of global NO_X emissions and 5-8% of global SO_X emissions [3,4]. Shipping is still a better environmental option for transportation compared to other available means due to lowest gCO_2/ton.km emissions as shown in Fig. 1 [5]. IMO is committed to regulating emissions from shipping and made a remarkable progress. This crucial regulations being implemented during ongoing decade are related to control of emissions of sulphur oxides (SO_x), nitrous oxides (NO_x), particulate matter (PM) and greenhouse gases (particularly CO_2) and management of ballast water.

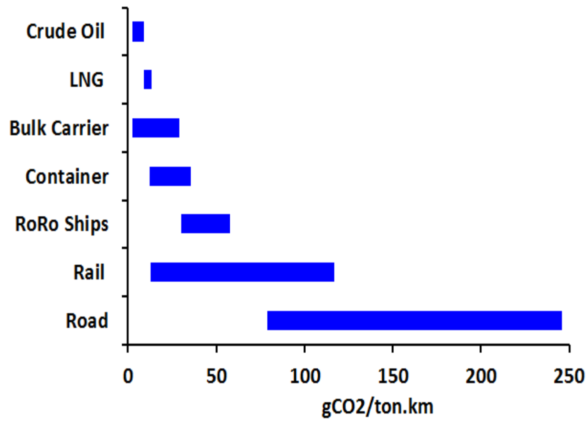

Fig. 1. Ship CO_2 emissions comparison to rail and road (Buhaug et al. 2007).

Marine pollution (MARPOL) regulations Annex VI has introduced caps on sulfur content of fuel oil as a measure to control SO_x emissions (as shown in Fig. 2). The same also serves as an indirect measure of controlling PM emissions, however, explicit PM emission limits have not been defined. These instructions were adopted in October 2008 by consensus. The said instructions enforced as regulations in July 2010 [6].

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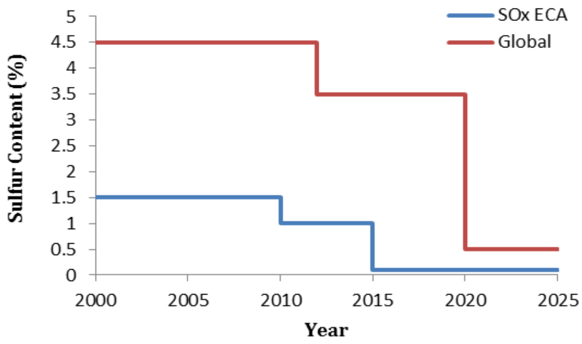

Fig. 2. MARPOL Annex VI Fuel Sulfur Limits

Marine pollution (MARPOL) regulations Annex VI were revised in 2008. This revision focused on control of NOx emissions. The concept of limiting specific emission from marine engines as a function of the revolutions per minute (rpm) was introduced. MARPOL 2008is applicable to new-built ships only. The instructions are divided into three tiers based on date of construction and operational area. The vessels whose keel-laying dates after 1st of January 2011 are required to comply with Tier II requirements. The requirements are easily manageable which can be met by getting an engine tuning by manufacturers. The vessels whose keel-laying dates after 1st of January 2016 and intended for operation in ECAs will be required to meet Tier III requirements. The Tier III requirements are complex and require focused efforts to meet performance marks as shown in Fig.3 [7]. The fourth Chapter of the regulations has introduced two mandatory mechanisms intended to ensure energy efficiency standards for shipping. These mechanism have been termed the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships.

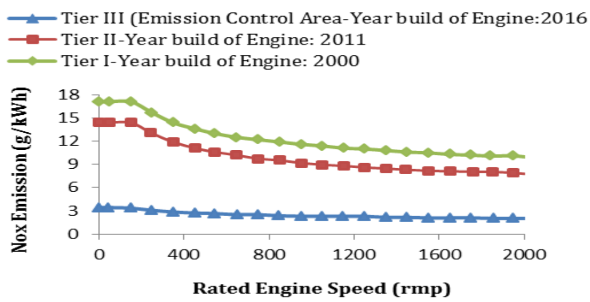

Fig. 3. MARPOL Annex VI NO_x Emission Limits

The EEDI is a performance-based mechanism focused on certain minimum energy efficiency in new ships. Ship designers and builders have been given autonomy to choose suitable technologies to satisfy the EEDI requirements in any given design. The SEEMP formulates a mechanism for operators to improve the energy efficiency of ships in service. The revised MARPOL 2008 regulations apply to ships bigger that 400 tons entering into service after the 1st of January 2013. IMO may award waivers to comply with the requirements of EEDI for up to six and a half years to some ships already under construction.

This paper provides a comprehensive review of machinery options to reduce emissions and increase energy-efficiency. Ship machinery is an important area with large potential to reduce emissions and increase cost-and-energy-effectiveness. The author will discuss basic concepts, principles and potential of machinery options for green ship in detail.

2. Methods for Increasing Engine Efficiency

2.1. Waste Heat Recovery (WHR) System

Waste heat recovery (WHR) system is based on the fact that the waste heat of engines can be used to drive turbines to produce electricity as shown in Fig.4. Thus less fuel is required for electricity which implies fewer emissions and better economics [8]. The performance of WHR system is higher for large ships with high waste heat generation and high electricity consumption. WHR is best suited for ships with main engines' average performance higher than 20,000 kW and auxiliary engines' average performance higher than 1,000 kW [9]. Wärtsilä reported approximately 12% fuel cost savings by use of WHR for higher output engines. Siemens reported approximately 12% energy costs savings as a combination of electrical booster drive and WHR [10]. It can be concluded that WHR system will reduce fuel cost by approximately 8-10%.

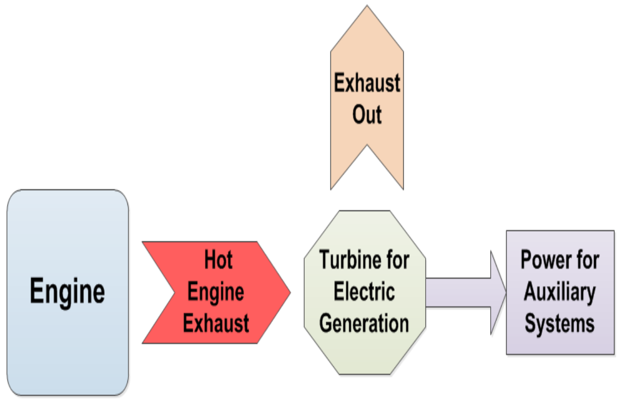

Fig. 4. Waste heat recovery (WHR) system block diagram

Waste heat recovery (WHR) system not only benefits from its fuel savings capacity, it also reduces maintenance and lubricants costs. Wärtsilä (2007) reported approximately 7% lubricants cost savings and approximately 31% maintenance cost savings by WHR system. The lubricants and maintenance costs for a normal bulk carrier are approximately 8% and 4% of the operational cost respectively [11].

2.2. Common Rail Technology

Common rail technology is based on fuel injection that eliminates the principle of one pump/cylinder [12]. Wärtsilä has used common rail technology to develop the "smokeless engine", and reduce NO_x and CO_2 emissions. The common rail technology supports freely adjusting fuel injection timing, adjusting cylinder peak pressure and engine performance as needed. The common rail consists of a series of accumulators interconnected by a small-bore piping as shown in Fig. 5. The double-wall high pressure pipes contribute to better safety and flow-limiting valves prevent uncontrolled injection. The system has redundant high-pressure pumps along with twin-type pressure and speed sensors to ensure engine operation in the event of failures. The injection pressure is adjusted as desired and the injection timing (start and stop) is controlled electronically [14,15].

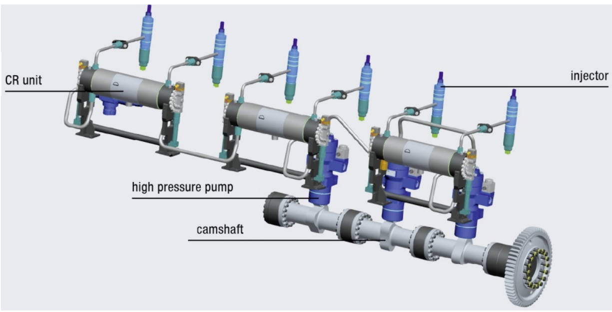

Fig. 5. VTA turbocharger, courtesy of MAN Diesel [13]

2.3. Variable Turbine Area Turbocharger

Turbocharger is a small radial fan pump powered by the energy of exhaust gases of an engine. The purpose is to pump air into an engine's intake manifold to increase air flow rate. The engine burns fuel more completely when the amount of air reaching the combustion chamber is increased (as shown in Fig.6). The result is increased power and fewer emissions.

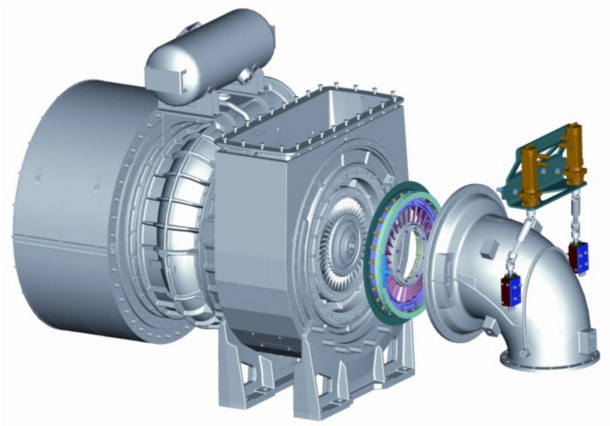
Fig. 6. VTA turbocharger, courtesy of MAN Diesel [15].

The variable turbine area (VTA) turbocharger system consists of a nozzle ring equipped with adjustable-vanes which replace the fixed-vane rings used in standard TCA and TCR turbochargers. The vane pitch regulates the pressure of the exhaust gases impinging on the turbine to vary compressor output. The quantity of charge air can be matched to the quantity of injected fuel more precisely, resulting in increased output and fewer emissions. The important selling point of variable turbine area (VTA) turbocharger system is its easy integration to existing turbochargers in the field [16].

2.4. Automatic Engine Tuning

At present, the tuning of engine performance is a manually performed by marine engineer once a month or when required e.g. after engine overhaul. The manual tuning leaves a margin for performance optimization since operating conditions and fuel oil properties change over time. This margin can be capitalized by continuous and automatic tuning for best performance with automatic-tuning. The continuous tuning is not feasible manually.

The automatic-tuning concept is based on online measurements of combustion pressures in cylinder chambers. The main limitation has been high temperature and pressure environment for the sensor as exhaust gasses cycle. However, the sensor technology has matured to the point that permits constant measuring for more than four years of engine running. The system constantly measures and compares the measured combustion pressures to the optimal reference value. The system then automatically adjusts the fuel injection timing in accordance with the optimal reference value to reach the optimal combustion pressure. The automatic-tuning permits continuous adaptation to wear, changed fuel oil properties and operating conditions e.g. cold or warm climate. The automatic-tuning reduces fuel consumption by approximately 1% for an average vessel, has potential of more than 3% fuel savings in large vessels, reduces maintenance cost and risk of damage [17,18].

2.5. Electronically Controlled Engines

The necessity of electronic control for engines comes from extreme conditions during compression and ignition. Electronically controlled engine system not only enables very precise control of fuel injection and combustion, it also improves engine responsiveness, reduces engine noise and diesel knock, and enhances diagnostic capabilities by scan tools. The system monitors and controls engine speed, fuel injector operation, exhaust emissions, crankshaft position, throttle position, brake and clutch operation, battery voltage, cruise control request, air, oil, fuel, exhaust and coolant temperatures, intake air, and oil and fuel pressures [19,20].

2.6. Fuel Additives and Fuel Catalysts

Fuel additives and fuel catalysts help older engines meet new emissions standards and improve fuel economy. Each fuel additive or fuel catalyst has unique advantages [21-25]. The details are as following:

(1). Fuel economy is enhanced by improving fuel BTU or engine ignition.
(2). Fuel additives, acting as fuel stabilizer, help promote molecular balance by keeping fuel molecules together to ensure better and consistent flame travel in combustion chamber.
(3). ASTM test D-613 shows that fuel additives and fuel catalysts increase cetane ratings by 1 to 3 or more numbers. Cetane improvement ensures better cold starting, reduced misfiring, reduced smoke opacity and faster warm-ups.
(4). Diesel fuel additives significantly reduce the formation of hydro carbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) and particulate matter (PM) by increasing complete combustion. Oxides of nitrogen can be reduced by 10 to 45% and particulate matter can be decreased by 30 to 70%.
(5). Fuel additives reduce smoke opacity by up to 80%.
(6). Fuel additives, acting as water emulsifier, treat water trapped in the bottom of fuel tanks by combining water with fuel which evaporates when fuel in burnt.
(7). Traditional diesel fuel engines build-up carbon in injectors and cylinders. Fuel additives help engines stay free of carbon build-up acting as metal deactivator.

3. Methods For Reduction of NOx And SOx Emissions

NO_X and SO_X emissions are a huge concern for shipping industry since shipping industry is a major source of these emissions. NO_X and SO_X emissions are responsible for formation of acid rain, over fertilization of lakes and soils, ozone depletion, smog formation, and reduction in air quality. Studies have shown that prolonged exposure to NO_X and SO_X emissions can cause adverse health effects including respiratory irritation, lung tissue damage and possibly premature death [26,27]. Selective catalyst reduction (SCR) and direct water injection are popular technologies to control NO_X emissions and exhaust gas scrubbers are popular for controlling SO_X emissions from shipping.

3.1. Selective Catalytic Reduction (SCR)

Selective catalytic reduction (SCR) technology is based on catalyst induced NO_X emissions control. The method comprises of mixing of ammonia with the exhaust gas and passing over a catalyst. The catalyst helps induce a set of reactions between NH_3 and NO_X that otherwise would not spontaneously occur. The result is that more than 90% of the NO_X are removed [28]. SCR systems produce ammonia within the catalyst system by mixing water with urea. The water-urea solution is injected into the exhaust where heat decomposes urea to produce ammonia and carbon dioxide. The mixture is then passed through a reactor where NOx emissions are treated by producing Nitrogen (N_2) and water (H_2O) [29-31].

3.2. Direct Water Injection

Direct water injection is based on lowering the peak combustion temperature to reduce nitrogen oxides formation. The water can be directly injected into the combustion chamber or the intake manifold. The water injection into the combustion chamber is more effective than the intake manifold. The water particles vaporize in the combustion chamber. The combined effect of vaporization absorbing heat, high molar heat capacity of water and reduced partial pressure of oxygen lowers the peak combustion temperature and hence lowers nitrogen oxides formation. It has been reported that the water injection timing and the injection amount are important. The NO_X emissions can be reduced by approximately 60% with direct water injection [12,32,33].

3.3. Exhaust Gas Scrubbers

International Maritime Organization (IMO) issued the legislation MARPOL 73/78-ANNEX VI which requires all ships burning Heavy Fuel Oil (HFO) sailing through the SECA (Sulphur Emission Controlled Areas) to limit their rejected sulphur quantities from average 2.7% sulphur content in HFO down to 1.5–0.1% [34]. Ship operators can now either switch to costly low sulphur fuels or use HFO with exhaust gas scrubbers.

Exhaust gas scrubbers, remove sulphur oxides from engine and boiler exhaust gases, consist of following three basic components.

(1). A cleaning unit for mixing the exhaust SO_X gases from engine or boiler with water i.e. seawater, freshwater or both due to high solubility of SO_X in water. These units are generally located high up in ship in-or-around funnel area for reasons of available space.
(2). A treatment plant for removing pollutants from the "wash" water from the scrubbing process in cleaning unit.
(3). A storage unit or sludge handling facility to retain the sludge removed by treatment plant for disposal ashore.

The system can be "open" type using seawater for scrubbing, seawater is then treated and discharged back to sea. The "closed" type system uses freshwater, treated with an alkaline chemical such as caustic soda, for scrubbing. The wash water is then treated and re-circulated [35,36].

4. Conclusion

Shipping industry is striving to reduce emissions and increase cost-and-energy-effectiveness. Green ship technologies/practices are vital to reduce emissions and increase energy-efficiency. Green ship technologies/practices are generally based on increasing energy efficiency so less fuel is consumed and hence less emissions. Machinery options are particularly important since these options are very effective against NO_X and SO_X emissions during operation cycle in addition to increasing efficiency.

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