EMISSION CONTROL IN RESPONSE TO MARPOL ANNEX VI REGULATION 13

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Abstract The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI regulation 13 comes into effect on September 1, 2017. "The fuel emissions generated by a single container ship are equal to 50 million cars". (Vidal, 2009) Ergo, the impact of shipping on the global environment is highly significant. Currently, MARPOL Annex VI Regulation 13 suggests that environmental protection is as important as monetary considerations.

This report identifies multiple emission control methods used to adhere to the new legislature in accordance with MARPOL, regarding emission reduction requirements. The methods are presented with numerical data and evaluated. Based on the analysis of the technologies; a selection of the most suitable process for industry is presented as a suggestion for retrofit and ship design.

Keywords: MARPOL Annex VI, emission reduction, green shipping

1. Introduction

The factors considered when choosing a mode of shipping are time and money. Time impacts how much time the goods need to reach their destination? Is there a time constraint? Money determines how much it costs to transport. When focusing on the cost and dealing in bulk, shipping by sea is the first choice for most international trade. Increasing the size and speed of vessels is beneficial to further increase profit margins based on the higher delivery rate and quantity. Fuel efficiency provides further opportunities to increase revenues. As the shipping industry developed with mankind and society, the expansion of environmentalism and protection has become increasingly evident. In November, 1973 the International Maritime Organization (IMO) adopted the

International Convention for the Prevention of Pollution from ships or MARPOL in order protect the environment.

In the last 40 years, environmental considerations have assumed an increasingly influential role in shipping and ship architecture. This paper focuses on ANNEX VI of MARPOL, which contains the regulations for the Prevention of Air Pollution from Ships. The regulations are divided into three tiers: Tier I - ships constructed between January 1, 2000 and 2011; Tier II - constructed after January 1, 2011; and Tier III - constructed on or after January 1, 2016.[1] This paper reviews different engine modifications and auxiliary attachments in order to effectively compare solutions that best align with the new and future regulation limits for Tier III vessels. According to Solhaug and Eide-Fredriksen, "It should be noted that the Tier III limits cannot be achieved without additional means, such as Selective Catalytic Reduction (SCR) and Water Injection" (2008, p.1). The emission limits are so low that marine engines are guaranteed to exceed if modifications are not made. Therefore, this investigation is essential for current and future shipping success.

For the purpose of this paper, the processes being analyzed are separated into two methods based on their form of emission reduction: primary and secondary. The primary methods are technologies that alter the combustion process in order to reduce the emissions that are produced. Secondary methods reduce emissions without affecting engine performance with emission reduction following combustion but prior to expulsion into the environment.[2]

2. Primary Methodology

Primary methods that manipulate the combustion process in such a manner provide the ability to reduce the production of a given chemical. However, the elemental makeup in fuel is relatively fixed, which means that manipulation focuses on additives that influence combustion.

NO_X generation is affected by two factors; high temperature in the combustion chamber and what is known as the excess-air factor. Excess-air factor is a term that describes when the volume of air that is forced into the combustion chamber exceeds the air requirement for combustion of the amount of fuel injected.[3] This is desired for increased performance due to the increase in O_2, and is obtained by either supercharging or turbocharging. The excess air, subsequently equates to excess Nitrogen as well and when exposed to the high temperatures during combustion the Nitrogen and

[1] 6. International Maritime Organization, 2009 p.24-25

[2] 8. Mitu & Memet, 2010 p.1-5

[3] 4. Clean Air Technology Center, 1999 p. 3

Oxygen react to form NOx.

Direct Water Injection (DWI) is the first primary method to be analyzed. The concept of DWI technology is relatively simple: inject water to lower the internal temperature. The reduction in temperature results in the reduction of NOx generated, due to its relationship with high temperatures. The water that is injected does not interfere with combustion because, immediately following injection, the water is subjected to intense temperatures and evaporates. The heat absorbed by the water during evaporation, results in a reduced chamber temperature. This technology has the capability to reduce NOx formation levels by 70%, with an increased water injection volume. The elemental structure of the fuel is fixed so when one emission is reduced, others will increase. With water injection, CO_2 emissions increase as NOx levels decrease. The fuel efficiency of the engine is also negatively impacted by DWI technology. In order to decrease NOx formation levels, water injection volume must increase, but with the increase in water, there is also an increase in fuel consumption. A 30% emission reduction can be achieved without compromising fuel efficiency; however, if a greater reduction percentage is obtained, then fuel consumption increases significantly.[4]

DynaCERT is a private and relatively new company. CERT is an acronym for Carbon Emission Reduction Technology. The technology injects a mixture of pure hydrogen and oxygen gas into the combustion chamber in order to achieve a more complete burn during combustion. Pure hydrogen and oxygen is extracted on location from distilled water using DynaCERT's patented electrolysis technology before injection. Hydrogen, a carbonless fuel, when substituted with diesel, forms a mixture that produces fewer carbon emissions. The hydrogen used in conjunction with fuel increases energy output with each combustion cycle. Each piston/engine has operating limits such as peak pressure and maximum temperature and with the supplementation of hydrogen as fuel, diesel injection will require reduction in order to retain operating levels. Graph 1 provides data demonstrating that the supplementation of 6% hydrogen-oxygen mixture will increase fuel savings approximately 15%.[5]

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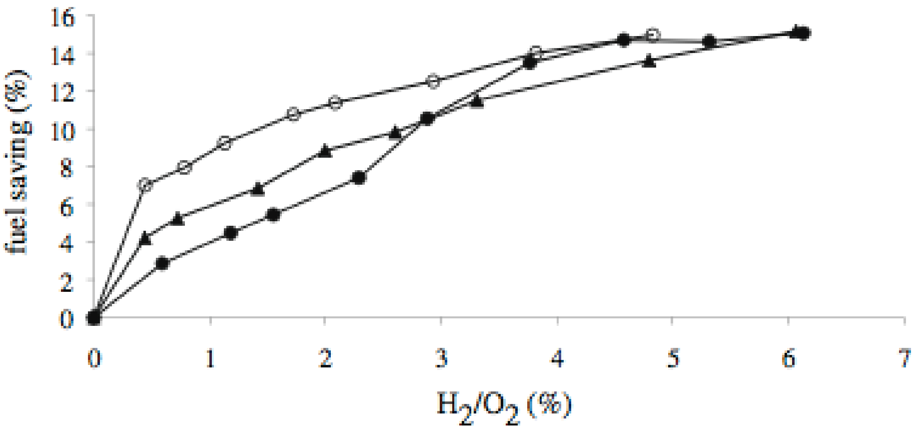
[4] 3. Chybowski, Laskowski, & Gawdzińska, 2015 p.397

[5] 2. Bari & Esmaeil, 2010 p.378

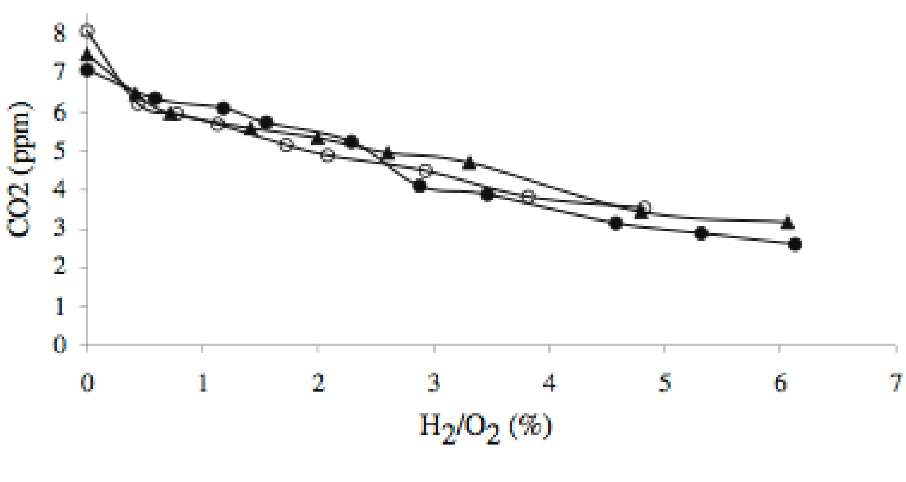
Graph 1



Note: From *Effect of H_2/O_2 addition in increasing the thermal efficiency of a diesel engine* (p. 381), by University of South Australia, 2009, Mawson Lakes, AU: Bari, S. & Esmaeil, M.

The fact that hydrogen is a carbonless fuel results in a faster flame speed meaning that there are fewer carbon molecules in each combustion cycle and that the duration of combustion is significantly shorter. Subsequently, peak temperature duration is much shorter. "The quantity of emitted CO_2 is proportional to fuel consumption – therefore, any reduction in CO_2 is only obtainable by lowering fuel consumption" (Stein, 2014, p. 182).

Graph 2



Note: From *Effect of H_2/O_2 addition in increasing the thermal efficiency of a diesel engine* (p. 381), by University of South Australia, 2009, Mawson Lakes, AU: Bari, S. & Esmaeil, M.

Combustion, along with added hydrogen, results in a more complete burn. With the addition of hydrogen to the combustion chamber, the engine becomes much more fuel-efficient. The presence of hydrogen lowers the CO_2 production, as seen in Graph 2.

3. Secondary Methodology

Supplementing engine exhaust systems with auxiliary attachments are the secondary methods for emission reduction; these attachments remove the emissions that are produced. These methods are far less cost effective because energy is wasted two fold, producing the undesired emissions then requiring energy to remove the emissions. The reduction percentages for the secondary methods compared to primary are significantly higher because primary technologies are required to take the engine performance into account vs secondary, which are not so restricted.

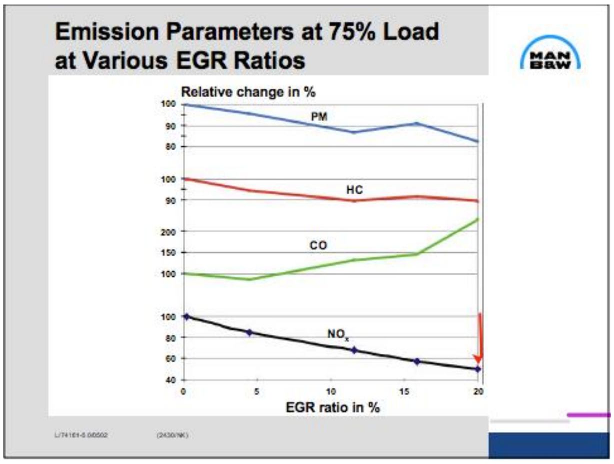
Selective Catalytic Reduction (SCR) technology uses the application of ammonia into the exhaust gas in a specific temperature range of 290-350ºC. A catalyst is positioned inside the exhaust stack in order to activate the reaction, ammonia then reacts with the NOx and chemically binds forming nitrogen and water.[6] This method operates with an attachment located after the exhaust manifold, allowing the engine construction to be unaltered. The system is extremely effective in removing the NOx emissions; reduction is between 90-99%. This technology can function on all ships; it can be implemented as a retrofit on old ships or installed in new builds.[7] This is proven technology with the highest percentage reduction in NOx of all the methods investigated; however, it has no impact on carbon emission reduction in the exhaust.

Exhaust Gas Recirculation (EGR) technology follows the discharge of the combustion chamber. The exhaust gases flow through a filter and a cooler prior to being re-circulated back into the combustion chamber. The reduced temperature and the chemical makeup of the exhaust gases work simultaneously to lower NOx formation levels during combustion. Far less oxygen is present in the re-circulated air than in natural air. The lack of oxygen in the combustion chamber lowers NOx formation.[8] There is a development of these methods as in all technologies. Older data collected stated that the top reduction percentage for an existing ship is 20%, whereas 40% NOx reduction for a new build could be achieved. However, clearly shown on Graph 3 MAN Diesel conducted experiments that prove EGR can reach up 80% reduction.

[6] 5. Diming, Bin, Piqiang, & Zhengxing, 2010 p.72

[7] 1. Azzara, Rutherford, & Wang, 2014 p.3

[8] 9. Stein, 2014 p.197



Note: From *Emission Reduction Methods* (p.12), by MAN B&W Diesel A/S, 2002, NA: Kjemtrup, N. Retrieved from http://www.arb.ca.gov/ports/marinevess/presentations/072602/manbw072602.pdf

With the increase in EGR ratio percentage, the NOx reduces consistently, which proves that technology is effective but the graph also states the increase in GH gases simultaneously.

The disadvantage to this method is that the exhaust gases being re-circulated back into the combustion chamber contain particulates and HHG gases. The air filter cannot fully clean the gases, and because of this there is increased build-up in the combustion chamber. Carbon build up increases wear, load, and reduces fuel efficiency. The reduction in fuel efficiency increases the carbon emission production, percentages will continue to increase with carbon build-up and in turn, causes decreased effectiveness and profitability.

4. Conclusion

Chybowski, Laskoski and, Gawdzińska described the opportunity of minimizing total operating costs as well as fulfilling Tier III regulations by utilizing multiple technologies at the same time.[9] A combination of these analyzed technologies is the most logical action in moving forward. When investigating the data collected, Selective Catalytic Reduction, despite the costs, is necessary to achieve the reduction levels established by MARPOL. Combining the SCR with the DynaCERT technology will effectively reduce the net cost impact of the SCR installation and operation by considering the fuel savings. The data collected are general statistics, and are not ship, engine, or fuel specific. The MARPOL ANNEX VI regulatory limits are subject to change and are dependent based on the body of water and distance from shore.

[9] 3. Chybowski, Laskowski, & Gawdzińska, 2015

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