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EGR OPERATION INFLUENCE ON THE MARINE ENGINE EFFICIENCY

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Abstract. In the work presented, the focus is on the influence of the EGR operation on the engine performance factors. Basic principles of the EGR operation are considered and experiment with electronically controlled engine is carried out on a Kongsberg marine simulator. The influence of the EGR on the efficiency, specific fuel consumption and CO2 emissions is evaluated. Recommendations for the performance adjustment of the supercharging system are stated.

Keywords: EGR (exhaust gas recirculation); marine engine simulator experiment; EGR basic concept; EGR influence evaluation

Introduction

The EGR technology is increasing its share on the new orders of two stroke marine Diesel and Otto engines. The recent development of the MARPOL Annex VI NOx requirements has forced the engine manufacturers to implement new concepts to face the stricter limits. The conventional well-known engines are not capable of dealing with these stricter limits. For the significant NOx reduction, internal modification of the engine process or post treatment systems can be used. Both approaches have their pros and cons. With the trend of dual fuel two stroke engines being installed on the new buildings, it is increasingly clear that with the EGR technology there is additional advantage to better control the combustion and the ignition by modeling the charge reactivity with its oxygen content (Codan et al. 2013). The latter is achieved by exhaust gas recirculation (EGR) system.

With the integration of additional components other than the conventional reagents involved in the combustion (oxygen mostly), it is important to know what the impact of the EGR on the combustion process and the related efficiency is. The latter is subject to the developing changes in the requirements on the energy efficiency of the marine power plants.

The EGR system is not commonly seen in the marine applications yet. Nowadays there is not much information among marine professionals on the features and basics of this system. behind the few specimens in the marine fleet and the knowledge of the engine manufacturers, overall there is scarce information about the new growing technology.

Regarding the predefined problem the aim of this publication is:

– To investigate the influence of the EGR operation on the marine engine efficiency and performance parameters.

The tasks related to the aim execution are:

– To analyze the capabilities of the EGR systems to influence the marine engine operation. To present the basic concepts for EGR schemes on the modern marine internal combustion engines.

– To plan an experiment for evaluation of the EGR operation influence on the engine performance parameters, including CO2 emissions.

– To record and analyze the experiment results.

– Referring to the results obtained, to state conclusions and to formulate recommendations for the operators.

Due to this, it is necessary to evaluate the influence of the EGR operation to the engine efficiency. The task in this publication is to describe the basic concepts of the EGR operated marine engines and to evaluate its impact on the engine performance. This would be beneficial for marine engineer officers and students.

The approach in this case is to use a marine simulator for the purpose of the engine performance evaluation. The experimental object is MAN 6S70ME-C – single turbocharger engine with high pressure EGR integrated in the Kongsberg engine room simulator of an oil tanker situated in Nikola Vaptsarov Naval Academy. The use of a simulator for the experiment purpose is a convenient approach to simulate different conditions within reasonable limits (Bakalov 2019).

Concept of EGR operation

The operation of an EGR on a marine engine targets the high temperature NOx formation and serves as a reduction measure. The concept relies on the recirculation of part of the exhaust gases back to the scavenge manifold, consequently reducing the oxygen content in the cylinder and increasing the carbon dioxide content. With this combination the compression of triatomic gas instead of diatomic gas results in a lower temperature on the end of the compression stroke (Yanguo et al. 2016). Additionally, the rate of combustion is slowed down; thus the combustion peak temperatures do not reach the peaks for high temperature NOx formation. At the same time the charge amount and pressure are kept as the conventional values and the mean indicating pressure is maintained too. The oxygen content is still sufficient to complete the combustion of the fuel supplied without shortage.

As the oxygen content in the fuel-air mixture is considered vital for the combustion process and its efficiency, there is a contradiction between the EGR operation and the high efficiency. The question is how much the process of combustion is deteriorated with the oxygen reduction. The trade-off between the EGR operation and the drop of engine efficiency must be in a reasonable range and the NOx reduction should not increase the CO_2 emissions.

There are several options for the EGR-supercharging system co-operation set up.

A high pressure EGR and low pressure EGR systems are known (Codan et al. 2013). For the different EGR concepts, there are significant differences of the set-up of the intake and exhaust system. The high pressure EGR requires forced returning of the recirculated gases back to the inlet of the engine on the turbocharger compressor delivery side. For that purpose, it is necessary to use a forcing fan to overcome the pressure difference between the exhaust and the scavenge pressure. For the low pressure EGR, the exhaust gases are recirculated to the inlet part of the turbocharger compressor. These differences determine consecutive fundamental deviations between both concepts in the turbocharging system behavior.

On the high pressure EGR systems, the simple approach is to use a variable frequency drive (VFD) electrical motor to drive the EGR fan, to adjust the flow rate of the recirculated gases. The control command depends on the readings of the oxygen content in the scavenge air receiver linked to the NOx emissions in the exhaust gases stack. Regulating valves may also be utilized to adjust the resistance in the exhaust system and in the scavenge air manifold. The simpler way is to change the throughput of recirculated gases by changing the EGR fan speed.

The amount of gases recirculated is approximately up to 40/50 percent of the entire amount for the specific load mode[1), 2), 3)]. This redirected amount of gases

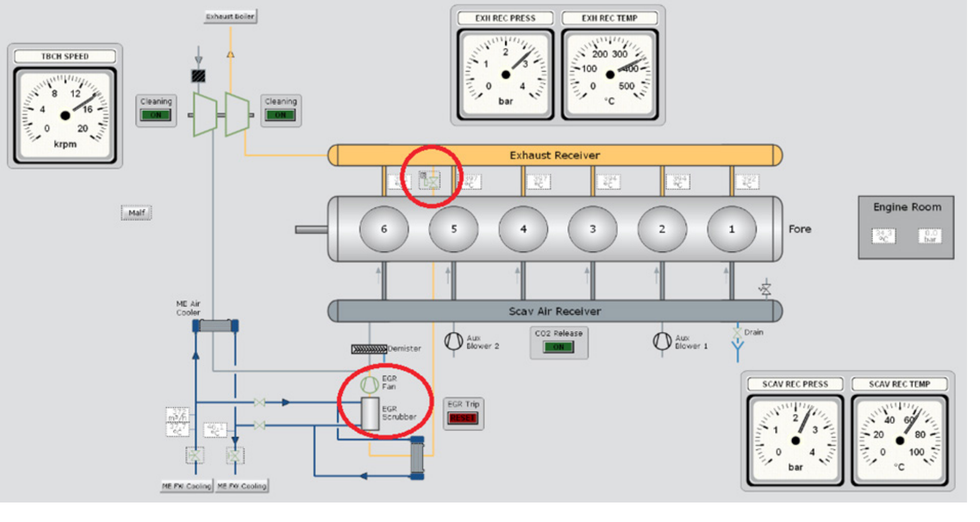

Figure 1. Engine with high pressure EGR

would not pass through the turbocharger turbine side, thus the performance would deteriorate the overall efficiency of the engine. Separately, there are additional power consumers related to the EGR auxiliary systems which increase the fuel consumption.

The figure 1 presents the EGR system arrangement in the supercharging system with the EGR valve and the EGR scrubber before the EGR fan to force the recirculated gases to the scavenge air manifold.

The experiment

The experiment has been carried out with engine and subsystems in optimal condition. The operation of the EGR was considered as the single difference on three specific load modes of the engine on 52%, 61% and 71%. The fuel used was very low sulfur heavy fuel oil (VLSHFO) with 0,5% sulfur content. The results obtained are present in table 1.

Table 1. Results obtained

EGR operation	Engine Load	Engine speed	Engine Efficiency	TC RPM	Specific fuel consumption	CO_2	NOx
ON/OFF	%	rpm	%	krpm	g/kWh	kg/h	g/kWh
ON	71	85	47,566	14,2383	170,171	8377,18	5,78052
OFF	71	85	48,5644	17,0587	166,438	8199,21	27,8522
ON	61	81	48,0848	13,4581	167,687	7045,95	6,29964
OFF	61	81	48,1329	15,9025	167,906	7086,03	22,4942
ON	52	77	47,1871	12,8242	171,311	6160,98	3,77951
OFF	52	77	47,7112	14,8828	169,417	6092,46	17,5853

EGR operation – turbocharger performance analysis

With the high pressure EGR in operation, a significant amount of exhaust gases are directed not through the turbine side of the turbocharger. Although the exhaust manifold pressure is kept similar to the normal operating mode (without EGR), the amount of gases reduced consequently reduces the energy transfer to the turbine.

The turbine operates in less efficient mode and thus the entire efficiency of the turbocharger is reduced followed by the charge air and the entire combustion process deterioration leading to an increase of CO_2 emissions.

With EGR in operation, the turbine reduces its speed. Figure (2) presents the relative RPM (%) of the turbocharger in switched on and off modes of the EGR system. For all the figures presented the green color is used for EGR – OFF and the red color for the EGR – ON state.

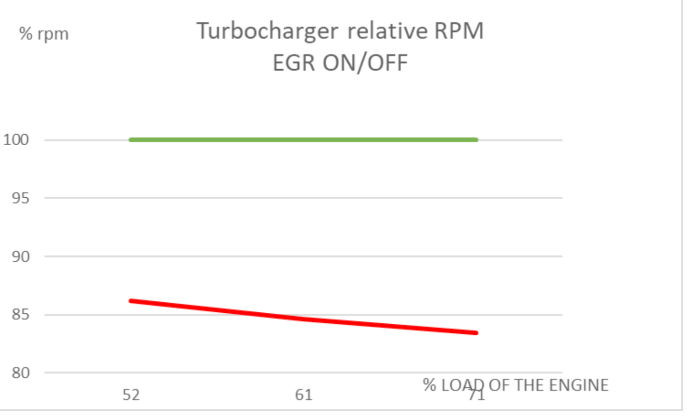

Figure 2. Turbocharger relative RPM

The bigger RPM drop in the high load mode can be explained with the turbine characteristics which in the high load mode suffer extensively from lack of gases. On the lower loads the turbine is generally less efficient and the difference in the amount of gases does not have such big influence on its performance. Here the solution could be to utilize a turbocharger with profiled highly efficient mode on lower loads. Figure (3) presents the efficiency of the engine.

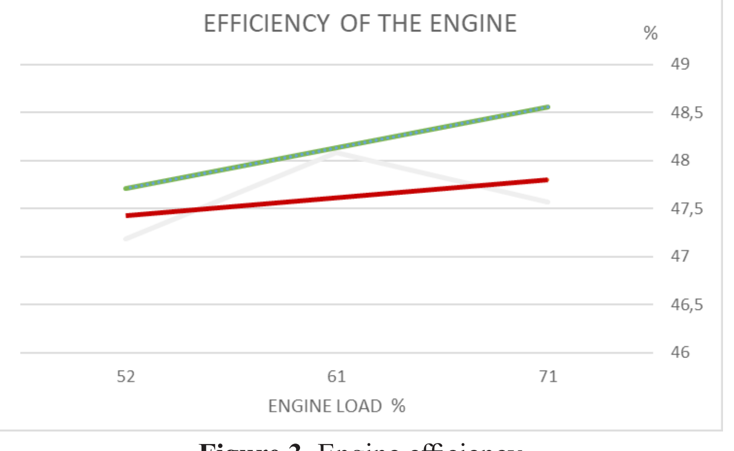

Figure 3. Engine efficiency

On the high load it can be considered a difference in the performance above 1%, which in turn can be calculated as additional fuel consumption (fig.4) and increased emissions of CO_2 (fig.5).

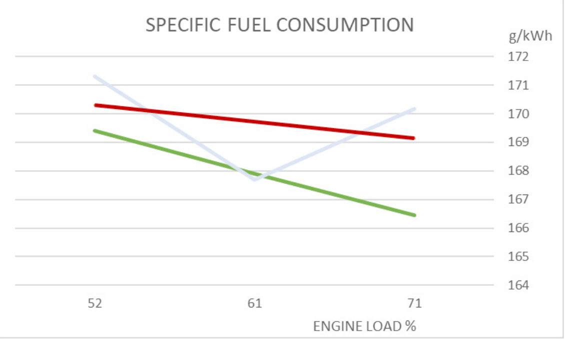

Figure 4. Specific fuel consumption

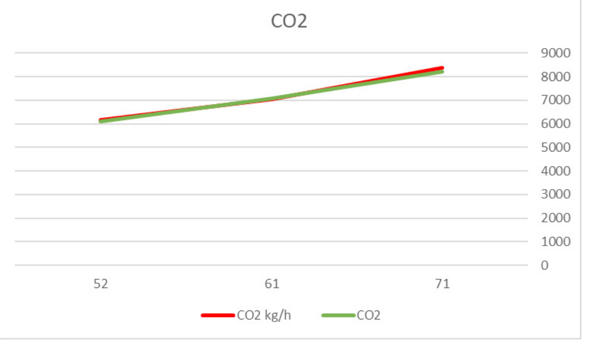

Figure 5. Emissions of CO_2

In the meantime, the significant drop in the NOx emissions is considered to be due to the reduced amount of oxygen in the scavenge reciever (fig. 6). Consequently, it can be determined that the high temperature NOx formation is avoided.

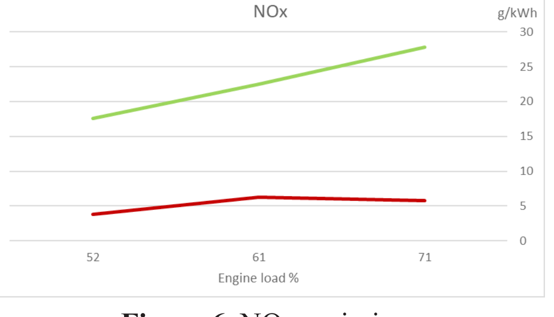

Figure 6. NOx emissions

Conclusions

– The results from the executed experiment tend to be close to the results shown by one of the manufacturers related to the fuel consumption increase[4)]. Further in the marine practice the extent of the influence of the EGR systems on the engine efficiency would be confirmed by field readings.

– The EGR system contributes a prospective way for emission reduction of the marine engine operation. With the EGR technology further development, a considerable reduction in the engine NOx emissions could be achieved.

– The experiment conducted shows the following: The EGR system worsens the engine parameters which is highly visible on the higher load ranges; The EGR system increases the CO_2 emissions as it is more sensible on the high load ranges.

– The EGR system worsens the performance indicators on fuel consumption and engine efficiency, while reducing the NOx formation. On the higher loads the differences of the efficiency increases and the EGR worsens the performance to a higher extent than the lower load.

– For multiple turbocharger engines, the mode of EGR operation matching could be accomplished by turbocharger cut-out systems. The cut-out is utilized in EGR-on mode while the gases are not enough. The by-pass matching relies on releasing the excessive gases in EGR-off mode with a smaller turbocharger installed on the engine.

– For existing ships with single turbochargers, it might be not feasible to install the EGR system without additional matching equipment like exhaust gas bypass and replacement of the existing turbocharger or variable geometry nozzle ring for the turbine side.

– For new buildings, the set up of the supercharging system must be considered in order to achieve the best performance in both modes of the EGR – on and off. That depends on the number and capacity of the present turbochargers.

– For retrofits, attention must be paid to the matching issue with the existing turbochargers with the EGR system additionally to the specific auxiliary equipment necessary to be installed in the engine room – additional coolers, scrubbers, pumps and piping systems.

NOTES

1. MAN B&W Exhaust gas recirculation operation manual, MAN Energy Solutions. Copenhagen, Denmark (2018)
2. Winterthur Gas & Diesel Ltd., Marine Installation Manual X62DF-2.1, 2021
3. Wintertur Gas & Diesel, iCER Installation Guideline, 2021.
4. MAN B&W Two-stroke Marine Engines Emission Project Guide for Marpol Annex VI Regulations, MAN Diesel and turbo, Copenhagen, Denmark, (2017)

REFERENCES

Bakalov, I., 2019. Engine room simulators – ways and tactics for achieving safety in the marine boiler room. *Knowledge – International Journal* **31** [3 June].

Codan, E., Wüthrich, J. 2013. *Turbocharging solutions for EGR on large diesel engines*. ABB Turbo Systems Ltd, Baden: Switzerland.

Yanguo Zhang, Qinghai Li, Hui Zhou, 2016. Chapter 1 – Theoretical Foundation and Basic Properties of Thermal Radiation. In: Yanguo Zhang, Qinghai Li, Hui Zhou, eds. *Theory and Calculation of Heat Transfer in Furnaces*. Academic Press, 1 – 43. ISBN 9780128009666.

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