

**MARITIME UNIVERSITY OF CONSTANTA  
FACULTY OF NAVAL ELECTROMECHANICS  
DEPARTMENT OF MECHANICAL ENGINEERING**

# **DOCTORATE DISSERTATION**

**REASERCHES CONCERNING THE REDUCTION OF  
THE POLLUTANT EMISSIONS THROUGH THE  
USAGE OF INNOVATORY SYSTEMS OF NAVAL  
PROPULSION**

**- ABSTRACT-**

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## **SUMMARY OF THE PhD THESIS**

The protection of the surrounding environment, especially within the more recent years, has become a problem constantly considered by the states and the governments of the world, which are more and more responsible concerning the serious problems that the continuous deterioration of the surrounding environment is posing. The long term effects of the pollution on the surrounding environment, that are generated by the lack of sanctionatory reglementations, have directed the attention of the statesmen upon the necessity of the elaboration of normative acts, meant to be effective in the continuous fight with it.

Maritime transportation generates approximatively 4% of the total of the CO<sub>2</sub> emissions that are produced by human activities, which means that its carbon imprint is almost as big as that of Germany.

The emissions generated by this sector are not yet regulated on international level, but this problem is now within debate of the International Maritime Organization (IMO) and of the limit-Convention of the United Nations concerning the climacteric shifts (CCONUSC).

With regard to the emissions of greenhouse effect gases (GES or GHG – GreenHouse Gases) the maritime transportation is the most ecological means of transportation. Still, it is estimated that, if one does not take measures, the emissions generated by the ships will increase with 150-200% until 2050. In the present, there are approximatively 50 000 commercial ships that transport 90 % of the international cargos, maritime transportation becoming consequently indispensable for the global economy [9].

A report that was published by the Common Center of Research (JRC) of the European Commission gives the first overall appreciation that is comprehensive over the methods of estimation of the quantity of atmospheric emissions generated by the maritime transportation. It presents technological solutions and analyses the strategical options in order to reduce the emissions of carbon dioxide and the atmospheric pollution from within this sector.

The maritime transportation sector constitutes a source of atmospheric pollution. If measures are not taken, the atmospheric pollution along the main maritime arteries will get worse due to a growth of emissions of sulfurous dioxide that is estimated to up to 10-20% within the next two years. The crude oil used as fuel for the ships has a very high sulfur content, that varies within the global mean of 27,000 ppm (parts per million) and 10,000 ppm in the areas of control of the sulfur emissions.

The submitted doctorate dissertation entitled “REASERCHES CONCERNING THE REDUCTION OF THE POLLUTANT EMISSIONS THROUGH THE UTILIZATION OF INNOVATORY NAVAL PROPULSION SYSTEMS” is a complex work that approaches its topic in a holistical manner, managing to capture all the aspects that are linked with the reduction of the pollutant emissions in a ship.

Key words: exhaust emissions, operational measures, innovatory techniques, experimental researches

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In the following lines the approached elements will be briefly presented.

**The first chapter** approaches some elements concerning the national and international legislation of the domain with a stress upon the future tendencies concerning the emissions generated by the maritime transportation.

Next there follows a complex presentation concerning the energy installations utilized on shipboard and a description of the most frequently used systems of naval propulsion.

**The second chapter**, entitled „The actual status in the domain of reduction of exhaust emissions and of making the on board installations more efficient” presents the main technologies of ships emissions reduction, which generally concentrate upon the NO<sub>x</sub> and SO<sub>x</sub> emissions, being regulated at an international level.

The utilization of the mentioned technical solutions of NO<sub>x</sub> and SO<sub>x</sub> reduction have as result the reduction of fuel consumption in engines, and also as effect the reduction of CO<sub>2</sub> emissions from the engine exhaust gases, because the percent of CO<sub>2</sub> emissions is directly proportional with the carbon content in the fuel.

These methods are grouped within three big methods: pre-treatment, primary (or internal methods), and secondary (or methods of post-treatment).

All these methods are presented in detail, with exemplifications referring to the technological strategies of their implementation on ships board.

There are also presented the technologies of reduction of the pollutant emissions through the optimization of the ship propulsion system, through the optimization of the ship body design and through the modification of the texture of the ship living opera.

Within this complex study the human factor has not been forgotten, by presenting the manner of reduction of the pollutant emissions through the utilization of operational measures.

In the end of this chapter there are described the modern propulsion system, as well as the hybrid ones (diesel-electrical) and the ones that utilize regenerating resources.

**The third chapter**, entitled „Elements of numerical modeling of the generating exhaust phenomena and processes” presents the theoretical basis of the modeling of the generating exhaust phenomena and processes.

Their study begins with basic notions, presenting the chemical elements out of which are formed the liquid and gaseous fuels and the equations of the complete and incomplete burning.

Within this study there is presented the manner in which the main components of the burning gases take shape:

- $\text{H}_2\text{O}$  and  $\text{CO}_2$ ;
- hydro carbonates (as for instance:  $\text{CH}_4$ ,  $\text{C}_2\text{H}_2$ ,  $\text{C}_2\text{H}_6$ ,  $\text{C}_2\text{H}_8$ ,  $\text{C}_6\text{H}_6$ ,  $\text{CH}_2$ ,  $\text{CHO}$  etc.);
- carbon monoxide ( $\text{CO}$ );
- nitrogen oxides ( $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{N}_2\text{O}_5$ );
- nitrogen compounds as  $\text{NH}_3$  and  $\text{HCN}$ ;
- sulfuric gases ( $\text{SO}_2$ ,  $\text{OCS}$ ,  $\text{CS}_2$ );
- halo-carbonates ( $\text{CHCl}$  and  $\text{CH}_3\text{Br}$ );
- material particles.

In the end of this chapter the numerical methods of the burning modeling are briefly presented, as well as an example of modeling of the burning and of the flow of combustion gases within a burning chamber of a gas turbine.

The fourth chapter is entitled „**The estimation of the pollutant emissions on shipboard by means of numerical methods**”. With this chapter the personal contributions to the doctoral study begin to be presented.

Two methods of estimation of the gases emissions in a ship are proposed here, methods that are very useful for the crews which are exploiting them.

For the determination and the validation of this method the determinations from the tank type M/T Aristidis ship have been used.

This ship has as a main propulsion engine an engine Wärtsilä DU Sulzer RT Flex 50 – 6 cylinders that develops a maximal power of 9720 kW and has a permanent monitoring system of the pollutant emissions.

The methods we develop here have as starting point the values of the polluting elements from the exhaust gases that are determined at the exit of the ship from the ship yard, in the framework of the acceptance tests.

These values have been introduced within the framework of a matrix in the MATHCAD program. This matrix represents the starting point of two methods:

- **The analytical method** of determining the concentrations of the exhaust gases components, by using a computation program that was realized in MathCAD, and as entrance data the results obtained by measurements being undertaken at the exit of the ship from the ship yard following the application of some correction factors.
- **The graphical method** of determining the concentrations of the exhaust gases components, using variation diagrams of the parameters, in which there are introduced the results of the measurements undertaken at the exit of the ship from the ship yard following the application of some correction factors

**The fifth chapter**, named „Validation and experimental researches regarding the influence of the burning improvement in the internal combustion engines upon the gas emissions” comprises two main steps of the doctoral work.

In the first step the proposed in the prior chapter methods of determining are validated.

It is to this end that the determinations realized on the same M/T Aristidis ship, during the period 01.10.20013 – 27.03.2014 have been used.

By applying the two methods developed within the previous chapter and by comparing their results with the measurements from the above mentioned period, one obtained errors below 1, 5%, fact that validates these methods.

In the second part of the chapter there are presented the results of the experimental studies concerning the effect of the fuel burning improvement in the internal combustion engines upon the gases emissions.

For the experimental determinations two engines with internal combustion of small power have been used: CT 151 (diesel oil four-cycle engine of 1,5KW) and CT152 (fuel four-cycle engine of 1,5KW).





Engine CT 151



Engine CT 152

Within the experimental determinations using the CT 152 engine one used 6 fuel probes. Starting from the standard fuel of 95, with a concentration of 5% bioethanol one has added a dose of 2% bioethanol for the determinations to be undertaken. In total there were 6 types of fuel. One has determined the concentrations of CO, CO<sub>2</sub>, HC, O<sub>2</sub> and NO.

Within the experimental determinations using engine CT 151 one used standard diesel oil mixed with biodiesel (rape oil) using 5 probes: probe 1 had 0% addition of biodiesel, probe 2 had 15% addition, probe 3 - 25%, probe 4 – 50% and probe 5 was constituted of 100% biodiesel. And within these measurements one has determined the concentrations of CO, CO<sub>2</sub>, HC, O<sub>2</sub> and NO.

Following the experimental measurements one may conclude:

- From what was observed within the experiment, one can assert that by improving the fuels burning in the internal combustion engines, through a similar approach with the one that was presented above, it is possible to reduce the level of emissions of some pollutant categories (hydrocarbons and carbon monoxide) on one side and to increase the level of emissions of some other pollutant categories which, it seems, are even more damaging then the first category (nitrogen oxides), on the other side.
- The second conclusion, detached from the variations of the cycle engine output that are determined by the variations of the parameters specific to the fuels, is that the burning efficiency improvement and implicitly the engine output improvement (the development of a higher power with the same fuel consumption) leads to a growth of its economic efficiency, having nevertheless as an indirect effect the growth of the NO<sub>x</sub> pollution.

**Chapter 6**, entitled „Subsequent research directions – operational methods of reduction of the pollutant emissions” presents a viable alternative to the technical solutions of reduction of the pollutant emissions: the operational methods of reduction of the pollutant emissions.

These methods are taken into account within the Annex VI of MARPOL that introduces the concept of energy efficiency of a ship. This energy efficiency is mainly obtained through operational methods.

So, the tendency of variation of the CO<sub>2</sub> emissions must be reduced through these methods and the estimated level of the emissions is the following:

<b>The year</b>	<b>Current emissions (mil. tonnes)</b>	<b>Reduction (mil. tonnes)</b>	<b>Estimated level (mil. tonnes)</b>
<b>2020</b>	1103	152	951
<b>2030</b>	1435	330	1105
<b>2040</b>	1913	615	1299
<b>2050</b>	2615	1013	1602

In the end of the chapter an operational plan for energy efficiency of a ship is presented, that takes into account the following operational aspects:

- The optimization of the draught and of the trim
- The optimization of the ship route according to the meteorological conditions
- The speed reglementation
- The maintainence of the automatic pilot
- The cleaning of the propellour
- The cleaning of the living opera
- The optimisation of the mechanical installations functioning
- The maintenance of the main engine according to its state
- The optimization of the main engine according to the fuel properties
- The ventilations of the storehouses and of the machines compartment

**With regard to the personal contributions, one may point out the following:**

1. A very detailed analysis of the norms and international reglementations within the domain of the polution issued from the area of the maritime industry has been achived. Thusly, one has pointed out the importance that the protection of the marine environment has at the present, underlining the international legislative measures within this domain.
2. A detailed study envisaging the naval energy installations and their particularities has been achived. Tusly there have been presented most of the

propulsion systems used on ship board, starting from the most simple ones, such as the propulsion systems with internal combustion engine directly coupled with the port propeller axis, and finishing with the propulsion systems combined with an internal combustion engine – the turbine that starts both the propeller as well as the electrical power generators.

3. A detailed study concerning the methods of determining the resulting emissions following the exploitation of the naval propulsion systems has been undertaken, starting from the equations of complete and incomplete burning according to the burning pressure and to the composition of the utilised fuel.
4. A very elaborated study has been undertaken regarding the methods and methodologies of reduction of the pollutant emissions on ship board. Thusley there were presented:
  - the technologies of reduction of the emissions of nitrogen oxides,
  - the technologies of reduction of the emissions of carbon dioxide,
  - the technologies of reduction of the emissions of sulphur oxides
5. One has proposed two methods of estimation of the pollutant emissions on ship board, a graphical one and an analytical one. These methods allow the crew to realize in real-time and very fast the level of pollution of the ship they exploit.
6. The methods of determining the pollutant emissions on ship board have been validated by comparing the results obtained through the method previously proposed with the indications from a modern ship board.
7. Two series of experiments have been undertaken, one upon an engine with combustion through spark plug and the other upon a diesel engine. In the framework of these experiments one has looked for determining the manner in which the burning improvement affects the pollutant emissions. So, one has increased the concentration of biofuel by using bioethanol and respectively biodiesel, fact that lead to a burning improvement. After analyzing the pollutant emissions one has noticed the reduction of the emissions of CO and HC at the same time with the growth of CO<sub>2</sub> emissions. This fact is due precisely to the burning improvement and it is a beneficial phenomenon. Unfortunately the determination of the emissions of nitrogen oxides indicates that their level is growing. This effect was also to be expected, as it was depicted in the study regarding the methods of determining the pollutant emissions. The explanation of this phenomenon is that the burning improvement rises the temperature and the pressure in the burning chamber, fact that leads to the presence of some more complex compounds of nitrogen with the oxygen and also to the growth of their concentration in the burning gases. These compounds have a cancerigenic effect, as it is noticed in a number of public studies. A conclusion of this study is that at this moment, from a technical point of view, one has reached a limit concerning the level of pollution produced by a ship and the

solutions of reduction of the pollutant emissions must be looked for in the manner of operating the ship.

8. The present work proposes a plan of reduction of the pollutant emissions of the ship through operational methods.