TURBO DIESEL 5 – THE NEW SIMULATOR
FOR MARITIME ENGINEERING TRAINING

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Abstract

The specialized diesel engine simulator named Turbo Diesel 5 is the subject of this paper. The mathematical model simulates an engine operation under various conditions and introduces various defects. This model has been implemented in a software, which is used for teaching of the relation between the diesel engine technical state and its operating parameters. The software can be also used for the maintenance strategy teaching. The most popular marine diesel engine faults like a faulty fuel injector, a leaky cylinder, a worn fuel pump, the broken piston rings, a dirty turbocharger, a dirty air filter, a dirty air cooler (and many others) were simulated. Each fault can be simulated in the certain range which can be observed in the practical operation of marine diesel engines. Not only faults, but also the improper adjustment of the fuel injection advance angle were simulated. First the single faults were simulated and their influence on the NOx emission was analyzed. The simulation research has shown that the interaction of several typical engine faults can cause the NO_x emission far above the emission limit defined by IMO MARPOL convention. It has been also observed that the simulation of multiple mixed faults gives in many cases the different results that the simple multiplication of the single faults simulation.

Keywords: *engine room simulators, marine diesel engines, NO_x emission*

1. Introduction

STCW 2010 has introduced several significant enhancements in management level training when compared with its previous version – STCW 1995 [7]. The requirement for the maintenance planning, repair planning and non-destructive examination have been added together with the requirement that the appropriate simulator training should be used for examination and assessment. The majority of the existing engine room simulators currently available on the market are aimed principally at operational training, even if some of them include the tools and means for management analysis as well. The availability of the indicator diagrams and the possibility of the multiple fault simulation is are rarely combined with the choice of the appropriate maintenance and repair so the management level trainees have usually have no chance to plan and apply different maintenance strategies. Exceptionally, the trainees have the possibility of choosing not only the proper, but also the cost effective, maintenance strategy and most of them are not aware of the additional cost caused by the improper technical state including also environment pollution.

MARPOL convention on the other hand, especially its Annex VI [2, 4], introduces the new higher requirements not only for SO_x and NO_x emission but also for greenhouse gas emission. Under the

"NO$_x$ Technical Code", the ship operator is responsible for in-use compliance which means that not only the adequate training but also the assessment methods for the chief and second engineers have to be provided.

Bearing in mind all abovementioned requirements, the new diesel engine simulator named Turbo Diesel 5 has been developed. This simulator is based on its earlier version 4 [5, 6], which has been successfully used for many years by numerous maritime training centres, academies and owners.

2. Simulator Model

The model simulates the engine operation under selected initial conditions (for example: torque, revolution speed, ambient air pressure) and the variable technical state (Tab. 1). The model will react naturally under almost any combination of factors, but sometimes the engine operation will be impossible. Faults introduced by the user or by the computer will lead to a progressive deterioration in system conditions if maintenance action is not taken at an appropriate stage.

Tab. 1. Diesel engine fault simulations available in Turbo Diesel 5

Simulation Name	Units	Min. Value	Max. Value
Injection advance angle change	deg	10	26
Fuel effective quantity decrease	%	0	20
Gas leak through the piston rings or valves	%	0	20
Injector nozzle cross section change	%	80	120
Decrease of the air filter cross section	%	0	40
Air blower - decrease of the air flow efficiency	%	0	4,5
Air cooler - decrease of the cross section at air side	%	0	40
Decrease of the exhaust duct cross section	%	0	40
Gas turbine – decrease of the cross section at gas side	%	0	4,5
Decrease of the water flow in the air cooler	%	0	20
Decrease of combustion chamber cooling efficiency	%	0	20
Cooling water temp. change at inlet to the engine	°C	40	80
Engine friction coefficient increase	%	0	40
Increase of the pressure drop at the oil filter	MPa	0	0,2
Lub. oil temp change at inlet to the engine	°C	30	70
Ambient air temperature change	°C	20	60
Ambient air pressure change	hPa	950	1050

Great care has been paid to the mathematical modelling of the fuel injection and the combustion process (Fig. 1) [5]. In general, the technique is to solve the governing equations of state and of conservation of energy and mass on a step-by-step basis, using small crank angle increments (2 degrees). The calculation sequence invariably divides itself into two major portions, for closed and open period, starting with assumed trapped conditions of the cylinder charge at the beginning of compression. The stable values of these conditions are obtained only after several successive cycles have been evaluated.

The air flow rate through a turbocharged diesel engine has been simulated as a function of the engine speed, compressor delivery air density and the pressure difference between intake and manifolds during the period of a valve overlap. The digitized turbocharger characteristic has been used in order to simulate its operation. Making suitable simplifying assumptions concerning the

diesel cycle, as well as for a compressor and turbine efficiency, it is possible to construct curves of specific power for engine, compressor and turbine as a function of a boost pressure. Such a mathematical modelling, based on the details of the diesel engine and the compressor map, has made possible the determination of the operating points for both an engine and a turbocharger.
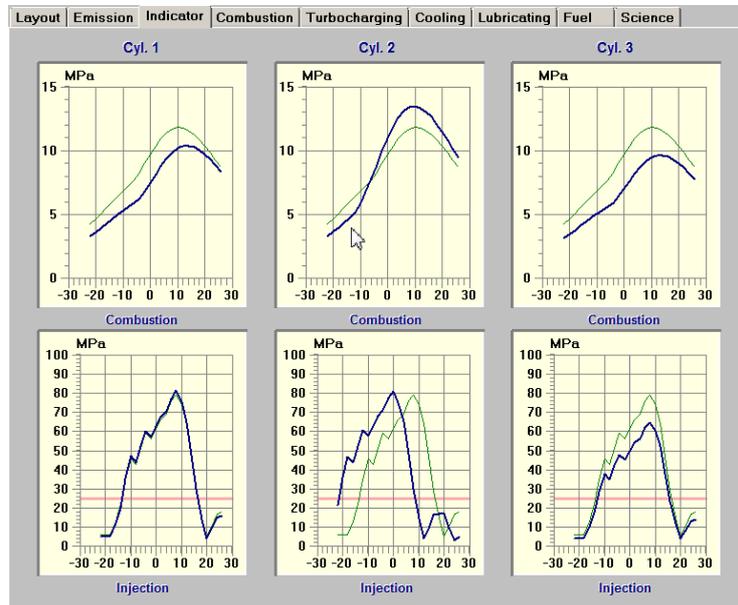
Fig. 1 The example of the combustion and injection diagrams calculated for the different faults
(medium speed diesel engine Sulzer3AL25)

Special attention has been paid to the digital simulation of an exhaust gas emission including the concentration of O_2, CO_2, CO, SO_2 and NO_x (Fig. 2) [1, 2, 3]. The mathematical model was validated during the tests at the actual diesel engine in the laboratory, but the actual model illustrates how the single faults and the multiple mixed faults influence the exhaust emission. The numerous additional combustion parameters like the maximum combustion temperature, air/ fuel ratio and even the thermal load can be presented on request in order to make the relation between engine technical state and the caused environment pollution more readable und understandable.
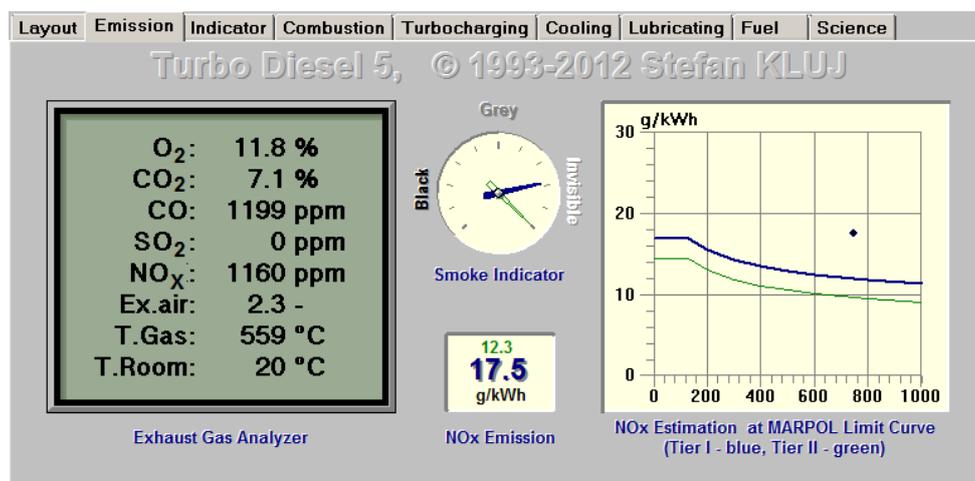
Fig. 2 The example of the exhaust gas content simulation
and its immediate evaluation in reference to MARPOL

3. Operation Modes

Turbo Diesel 5 has three operation modes:

Evaluation mode (default): the trainee can freely change the technical state of the engine elements as well as the engine load and operation conditions. This includes the possibility of inspecting the present technical state of the engine elements. This mode can be used for testing the relation between the engine operation conditions or the technical state on one side and the engine operation parameters on the other side. The evaluation mode is necessary at an early stage of the engine operation education.

Live Run mode: Changes in the engine technical state are simulated automatically "in the background" by the computer. The trainee can only perform maintenance and repair activity and change the engine speed, but he cannot control directly the present technical state. The maintenance tasks have their conventional prices and all these expenses will be taken into account later while calculating the final results. The duration of successful diesel operations renders the player certain incomes; so the final result is actually the difference between the global income and the global cost. The final result will depend also on the cost of all necessary (but required) maintenance. The Live Run is very useful for ~~the~~ management level assessment.

Replay Run mode: The Live Run when finished can be saved on a disk. The saved Run can be re-played in Run Replay mode. The user can navigate between the single run steps using the set of recorder-like keys. The main purpose of this mode is for debriefing and student error discussion. This can be useful both with and without an instructor's assistance, but an instructor can usually better comment on all errors by the student reported automatically in this mode.

The Live Run mode is most interesting for the maritime training because the operator has to act as the qualified user against the computer with its dangerous situations, faults, etc. The trainee can freely inspect all the available engine parameters, perform maintenance and repair and change the engine speed. Each maintenance and repair has its specific price (in US $) which the engineer has 'to pay' and which has to be deducted from the total income (Fig. 3).
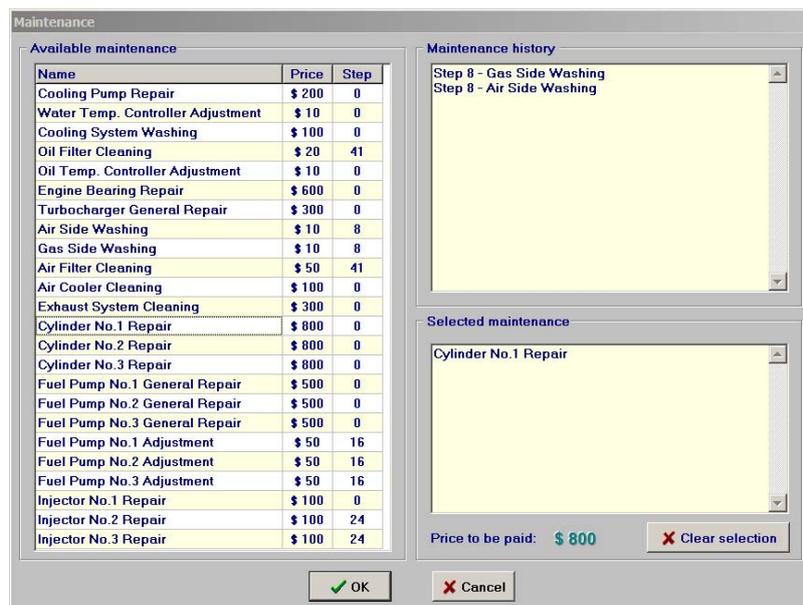
Fig. 3 The choice of available maintenance and repair with their prices

The present status of the Live Run can be seen in the Summary window where the following information (Fig. 4) is presented together with other data.

Fig. 4 The example of the Live Run current status

- *Current Income* field shows Live Run Step number multiplied by a Income in a single Live Run Step which is by default $ 200/day but can be changed any time by a person with the full rights (instructor) in Options | Preferences dialog window. Increasing Step Income causes that all Live Runs will be easier, decreasing it causes that they are more difficult (not recommended).
- *Cost of Applied Maintenance* is the sum of the applied maintenance cost till now. This cost depends only on the kind of applied maintenance (and its quantity). The cost of each maintenance cannot be changed.

- *Cost of Necessary Maintenance* shows the cost of all maintenance which should be applied right now and it depends only on the current technical state.

- *Additional Fuel Cost* is a cost of the additional fuel (i.e. over the normal consumption) burned since the beginning of a Live Run. This value depends on the MDO Fuel Cost which can be changed in Options | Preferences dialog window.

- *Additional NOx Emission* displays the additional NOx in kg caused only by the improper engine technical state since the beginning of Live Run. This value cannot be changed.

- *NOx Emission Fine* is calculated by multiplying the Additional NOx Emission (in tons) by NOx Emission Fine in $/t. The NOx Emission Fine per ton can be customized in Options | Preferences dialog window.

- *Emergency Stop Fine* is calculated by multiplying the number of emergency stops (since the beginning of Live Run) by the Emergency Stop Fine per single stop which can be edited in Options | Preferences dialog window.

- *Current Profit* is calculated as follows. The Current Income minus Cost of Applied Maintenance minus Cost of Additional Maintenance minus NOx Emission Fine minus Emergency Stop Fine.

- *Current Score* shows the relation of the Current Profit to Current Income shown in %. The Current Score must be higher than 60% in order to pass the assessment.

The current Live Run results (Fig. 5) will be saved automatically in the file and can be viewed or printed on request. The result shows also the evaluation of completed (premature or unnecessary) maintenance and required maintenance. This feature enables very precise debriefing of the Live Run and learning about proper engine operation depending on its technical state.
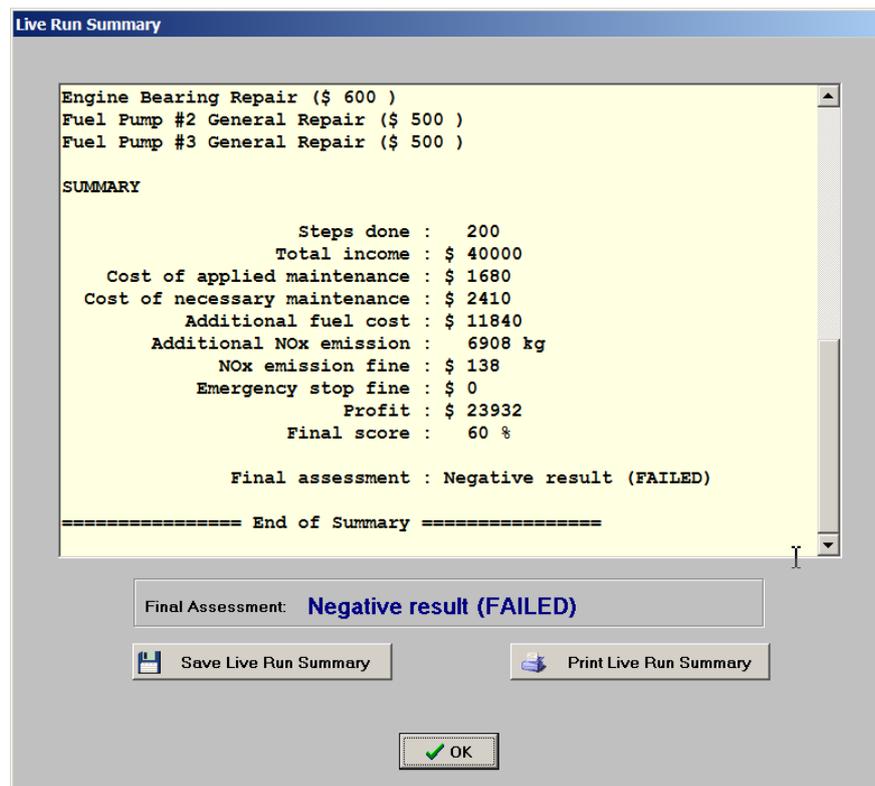
Fig. 5 The example of Live Run results.

4. Mixed Faults Simulation

Turbo Diesel 5 offers the possibility to observe the influence of mixed engine faults on numerous operational parameters. As an example, the influence of the single and multiple (mixed) engine faults on NO_x emission will be discussed. Fig. 6 shows, how does NO_x emission and concentration in the exhaust gases depend on the injection advance angle. It is easy to conclude

that the recommended by an engine producer injection timing (18 deg before TDC) offers the lowest NO$_x$ emission.
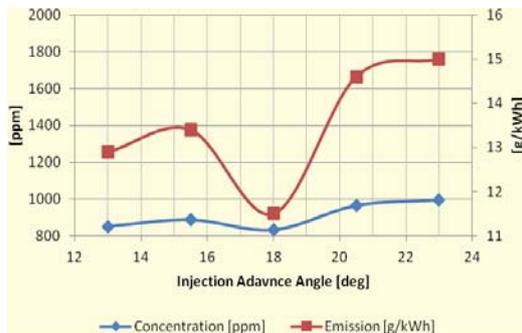
Fig. 6. NOx emission and concentration as a function of an injection advance angle
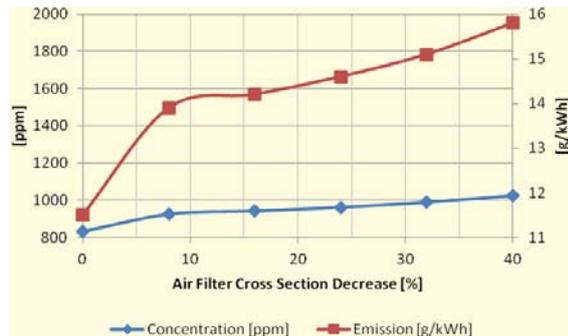
Fig.7. NOx emission and concentration as a function of an air filter cross section decrease

On the other hand, the air filter cross section decrease which simulates the dirty air filer causes a decreased air flow through the engine, lower air/fuel ratio and the significant increase of NO$_x$ emission (Fig. 7) what it is well known from the literature [2, 3, 8].
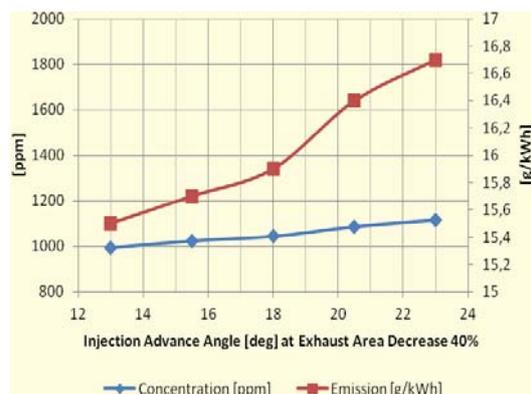
Fig. 8. NOx emission and concentration as a function an injection advance angle and dirty exhaust
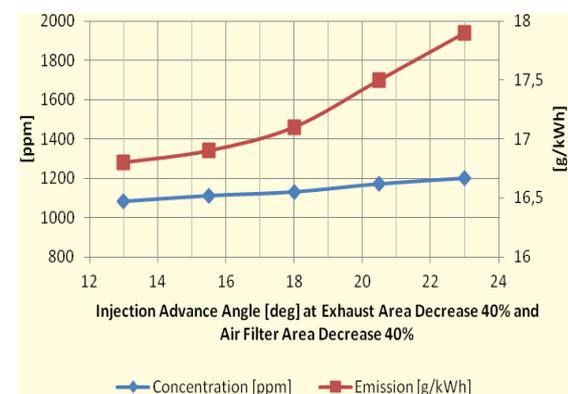
Fig. 9. NOx emission and concentration as a function of an injection advance angle, dirty exhaust and dirty air filter

When the dirty exhaust duct is simulated and the injection advance angle is changed (Fig. 8) the lack of an air dominates the influence of the optimal injection timing and the total NO$_x$ emission is higher than when both single faults are simulated. The emission is much higher and far above even the MARPOL - Tier I limits when the third fault i.e. dirty air filer simulation is mixed in (Fig. 9). The above described observations imply the need to care of the turbocharging system cleanliness as an important measure to prevent the environment pollution by NO$_x$ emission. On the other hand, when the proper flow of the turbocharging air is provided, it is necessary take care about the injection adjustment as an effective measure of the environment protection.

5. Conclusion

The presented simulator, based on the mathematical model of the high power, medium speed, four stroke diesel engine, is particularly suited for management level training, providing the instructors with a powerful teaching tool and the trainees with an increased understanding of the relation between the engine technical state and its operating parameters. The possibility to test the engineer's diagnostic knowledge and to try out the different maintenance strategies is another

feature of this simulator. It is especially important that the assessment rules are based on the financial results of the engine operation, the fuel costs and the cumulated NO_x emission.

This kind of a simulator offers not only the training in marine diagnostics and maintenance strategy but also increases the awareness of the environment pollution problems caused by the diesel engine technical state.

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