Combustion simulation for naval diesel engine

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Abstract: - The combustion process that takes place inside of the naval diesel engines is the critical factor for determination of the level of pollution and emissions. The efficiency of such an engine is closely linked of the quality of the combustion process. Based on the Finite Element Analysis, the paper presents a simulation of combustion in the combustion chamber of a diesel engine.

Key-Words: - finite element analysis, naval diesel engines, combustion process

1 Introduction
The combustion process is an important factor for the estimation of the level of pollution and emissions. The efficiency of such an engine is closely linked of the quality of the combustion process. The combustion is the process in any engine functioning when it is delivered the energy via the chemical combustion processes; hence the importance of this phase is the most important in the cycle of the engine, all the technical and economical parameters heavily depending on it. The combustion process is important but, equally, complex. There are a lot of parameters involved in it, highly dependent on the conditions of combustion, and, as a consequence, the combustion process is not easy to be mastered and investigated. All the unknowns related to the combustion chemistry and the conditions for ignition and propagation of flames are still cornerstones for all the simulations and models developed in time. Furthermore there are many unknowns regarding the injection, evaporation and mixing (air-fuel) processes.

Via numerical models/simulations, the behavior of the marine engines and propulsion systems is easy to be done, more economical, allowing various design solutions and optimization studies.

In the present paper, Finite Element Analysis (FEA) was applied to a complex and interdisciplinary theme, pertaining on the simulation of the combustion in the combustion chamber of a diesel engine, the most important parameters of this process being deduced.

2 Theoretical background
The inlet process described using the first law of thermodynamics states for an open system, the continuity equation and the equations of the pressure of steady flow from orifices.

These equations were solved using different approaches in the equation flow and thermodynamics constants. Finally the pressure $p_{in}$ and temperature $T_{in}$ are obtained at theoretical end of the inlet process:

$$p_{in} = \frac{P_a}{\sigma} \left[ 1 - \frac{n^2}{1800} \frac{RT}{n - 1} \left( \frac{\varepsilon - \mu \rho}{\varepsilon - 1} \right)^{n - 1} \right]$$

$$T_{in} = \frac{T_s}{p} \frac{P_{in}}{P_s} \varepsilon - 1 \left[ 1 + \frac{\rho P_{out} T_s V_s}{P_{in} (\varepsilon - 1) \theta n_{s, out}} \right] \left[ \varepsilon + (n_s - 1) (\varepsilon - 1) \theta - \frac{P_{out}}{P_{in} P_s} \right]$$

$T_s$, $P_s$ - inlet air parameters,
$T_{out}$, $P_{out}$ - exhaust gas parameters,
$\varepsilon$ -- compression ratio,
$\theta$ --ratio of temperature increase,
$\rho$ -- scavenge coefficient,
$\phi$ -- debit and velocity coefficient flow in inlet valve,
$fn_{s, V_s}$ - ratio of section time and piston displacement,
$n_s$ -- isentropic index,
$n$ -- speed engine,

The compression process may be calculated using the first law of thermodynamics for a closed system. In order to calculate the state changes $p$ and $T$ it is subdivided the stroke volume into a number of intervals of small volume change and equate the correlation at the beginning and end of each interval using the first law of thermodynamics. The smaller the volume change in the interval the more accurate the calculation.

It is considered a small change in
volume $dV = V_{j+1} - V_j$. It can be applied the first law in the form:

$$dQ = \Delta E + dW$$  

(3)

where $dQ$ is the heat transfer to the cylinder walls. If the cylinder wall temperature is $T_w$ and the exposed surface area is $A$ then the heat transfer is:

$$\frac{dQ}{dt} = \alpha_c A(T_{w,j} - T_s) + \alpha_r A(T_{r,j} - T_s) \left[ \frac{j}{s} \right]$$

(4)

$$dQ = \left[ \alpha_c A(T_{w,j} - T_s) + \alpha_r A(T_{r,j} - T_s) \right] \frac{1}{6n} d\alpha \quad [j]$$

$\alpha_c$ -- convective heat transfer coefficient,
$\alpha_r$ -- radiative heat transfer coefficient.

### 3 Numerical simulation

The naval engines have specific characteristics and their functioning is quite different in comparison with the normal diesel engines. The numerical models developed until now use as theoretical basis, the zero-dimensional thermodynamic models capable to describe globally the phenomena within the marine diesel engines, the result being a lack of the significant detail.

The simulation of the combustion started with the definition of the parameters used in the numerical simulation with a short introduction on the processes forerunning the combustion as the admission, the compression, targeting a general frame for the combustion process.

The attention is shifted on defining the FEA concepts used in modeling the fluid mechanics, along with the general equations of flow and heat exchange for ideal and real fluids, the types of finite elements used in the paperwork, the possible models of materials fully mathematically described, and the treatment of the boundary conditions.

The numerical simulation has as a departure point a real engine, Caterpillar, type 3606, given in the figure below:

![Fig. 1 The diesel engine Caterpillar, type 3606](image)

### 4 Work results and validation

The simulation is conducted in 2D (Bidimensional) approach, the FEA net (grid) is presented and then all the results beginning with the pressure in the combustion chamber, velocities, diffusion coefficients, heat conductivity, Prandl number, entropy, enthalpy, internal energy, mass fractions. Some of the results are shown in the below figures:

![Fig. 2 Static pressures in the combustion chamber](image)
Fig. 3 Dynamic pressures in the combustion chamber

Fig. 4 Velocities distribution in the combustion chamber

Fig. 5 Temperatures distribution in the combustion chamber

Fig. 6 Prandtl number distribution in the combustion chamber

Fig. 7 Entropy distribution in the combustion chamber

Fig. 8 $C_{16}H_{30}$ mass fraction distribution in the combustion chamber

Fig. 9 $CO_2$ mass fraction distribution in the combustion chamber

Fig. 10 $H_2O$ mass fraction distribution in the combustion chamber
The results were validated by comparing them with the exiting databases and work of other authors concerning the same area of interest.

For the future works, there are recommended an extensive approach in which the processes preceding and afterwards of combustion in the engine cycle, may be treated in the FEA-CFD approach, an intensive direction where the combustion chamber may be modeled in the 3D (tridimensional approach) with the explicit simulation of mixed phases as fuel droplets which are evolving in the combustion chamber.

5 Conclusions
The original code is an useful tool in the early design stage necessary to the prediction of the running parameters and performance indicators of direct injection compression ignition engine. The precision of calculus depends on initial data and can be improved if we set up properly these data for the specified engine. Even the numerical results have a satisfactory precision it is not possible to select immediately the final constructive solution. We can make only global evaluations and indicate the optimisation directions that must be followed because the code contain many simplified hypothesis, empirical constants in the mathematical expressions of the model and minimum initial parameters (good for design stage but insufficiently for a final optimum solution). The present theoretical approaches offers good solutions for nominal regime and only satisfactory solutions for other regimes. This observation underlines that some initial parameters are not constant and are not optimum for the partial engine rates.

The Wiebe functions combustion model is more flexible than the fuel rate combustion model and offer a higher precision. This flexibility and the precision of this model is base on larger number of constants that must be set up as initial data. The constants calibration is a very difficult task instead. The fuel rate combustion model has a smaller number of constants and it offer a quickly solution but the precision is lower.

References: