“Mircea cel Batran” Naval Academy Scientific Bulletin, Volume XIV – 2011 – Issue 1
Published by “Mircea cel Batran” Naval Academy Press, Constanta, Romania

MODEL SIMULATION OF HIGH POWER DIESEL ENGINE EXHAUST GAS POLLUTANTS

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Abstract: *This paper tried to simulate the combustion inside the marine diesel engine using the newest computer methods and technologies with the result of a diverse and rich palette of solutions, extremely useful for the study and prediction of complex phenomena of the fuel combustion.*
Keywords*: high power marine diesel engine, combustion, finite element analysis, chemical reaction, non-premixed constituents, multiple species*

1. INTRODUCTION

The simulation of the processes inside the marine engines was a permanent subject of study for the specialists. The complexity of all the associated phenomena and their strong correlation make out of this a very difficult task. Once with the emerging of modern computer technologies, mainly the computers with high computer power essentially contributed to the development of combustion models but not only. Therefore in the last decades, the computer simulations and models grow exponentially. Simultaneously, complex calculus algorithms appeared and developed which permitted solving complex differential equations systems of modelled phenomena, thus the central point of the research activity migrated from the purely experimental sphere to the one of theoretical and applicative activities. The complexity of the resulting models and how they performed, permitted today the leap from the studies which merely estimated the behaviour of such system to the prediction of their behaviour, being a powerful tool for any research activity.

The numerical simulation is based on some theoretical hypothesis which allow obtain the numerical model closely simulating the real processes inside the engine. This involves two stages:

- physical modelling which identifies the system particular traits by considering a hierarchy in the importance of the phenomena which describes the behaviour of the real system, with the result of an equations system more or less complex depending on the nature of the study and the grade of detail,
- mathematical modelling is the next stage which, by meaning of certain modifications done over the equation system, permits to have finally, some calculus procedures which may be implemented for issuing solutions with the smallest amount of computer effort, and within a certain precision domain.

The paperwork is a tridimensional modelling of the geometry of the combustion chamber and the CFD (Computational Fluid Dynamics) net/grid of the finite elements involved and tridimensional simulation of the thermo-chemical behaviour of the combustion process and calculating the interesting parameters and the distribution of the mass fraction for the burning by-products.

2. SIMULATION. DESCRIPTION. RESULTS

The theoretical background describes the thermo-physical-chemical processes taking place into the combustion chamber. The mathematical models of pollutants combustion by-products in the marine propulsion systems are presented, along with the models for thermal inhomogeneous motor fluids. There are detailed the influence of the heat transfer over the fluid’s components defining the transfer influence factors for the study of the heat exchange between fluid and the combustion chamber’s walls. A special attention was given to define and describe the chemical equilibrium into the burned gases, their composition being described via the thermodynamic functions. Then, a thorough theoretical review for the thermo dynamical models is detailed along with the general equations for the dynamics of gases and defining the irreversible processes by the meaning of a rich bibliographical material. There are described the mathematical models in order to define the gaseous mixtures and, then it is presented the turbulent flow which is one of the basic hypothesis of the model developed in the present paperwork.

The discrete phase of the model in the paperwork was thoroughly investigated on its theoretical aspects, comprising many mathematical details and, also, the combustion thermodynamics receive a special treatment being its importance in our simulation. Equally important, it was deemed to be the chemical kinetics and the ignition theory with many details regarding the mathematical description of the main mechanisms and models for the oxidation reactions. The flame propagation is described mathematically and there are defined the mathematical aspects of the diffusive combustion.

The fluids mechanics receive a special attention in the work, where it is mathematically defined the mass transfer equations, the energy and momentum conservation equations, being in the end deduced the general equation for laminar and turbulent flows. The core of the paperwork is the numerical simulation of the considered model. The simulation had as departure point a real naval diesel engine Wartsila type 6L26 used for the propulsion of the small and medium ships given in the following figure:

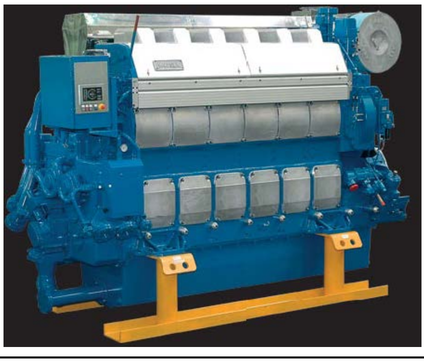


Fig. 1: The diesel engine Wartsila 6L26

Having as lead axis the theoretical description on the mathematical basis, the next stage was developed based on the Finite Element Analysis (FEA) model for the combustion of the non-premixed constituents. The main hypothesis in this approach is that the fuel and the air (oxidizer) enter in the combustion area non-premixed, this hypothesis being well enough near to the real situation. In certain simplified situations, the entire thermo-chemistry of this type of the process may be described using one single parameter: *f*, which is the mass fraction of substance of burnt and unburnt fuel out of the all species in the mixture. This hypothesis is realistic enough for the atoms of the combustion mixture pass through the chemical reactions from one type of molecule to another. Therefore the combustion process is enormously simplified being reduced to a mere mixing process. Once the mixture done, the combustion chemistry may be modelled in : equilibrium or near-equilibrium situations by meaning of the laminar flamelet.In the next section, there are shown the FEA principles for modelling the flame for the non-premixed mixtures, the turbulent flame being considered comprised out of multiple small laminar flamelets, the last ones are computed using detailed chemical mechanisms coupled with a experimental database, also involving stochastic methods.

Another “forced station” in the development of the simulation model is the droplet model definition (discrete phase). They are modelled using the Lagrange reference system, the droplets being considered spherical in shape and they are dispersed in the continuous phase (air) changing mass and heated with it.

Finally, there are given the results obtained by using commercial software, some of these results are given in the following figures

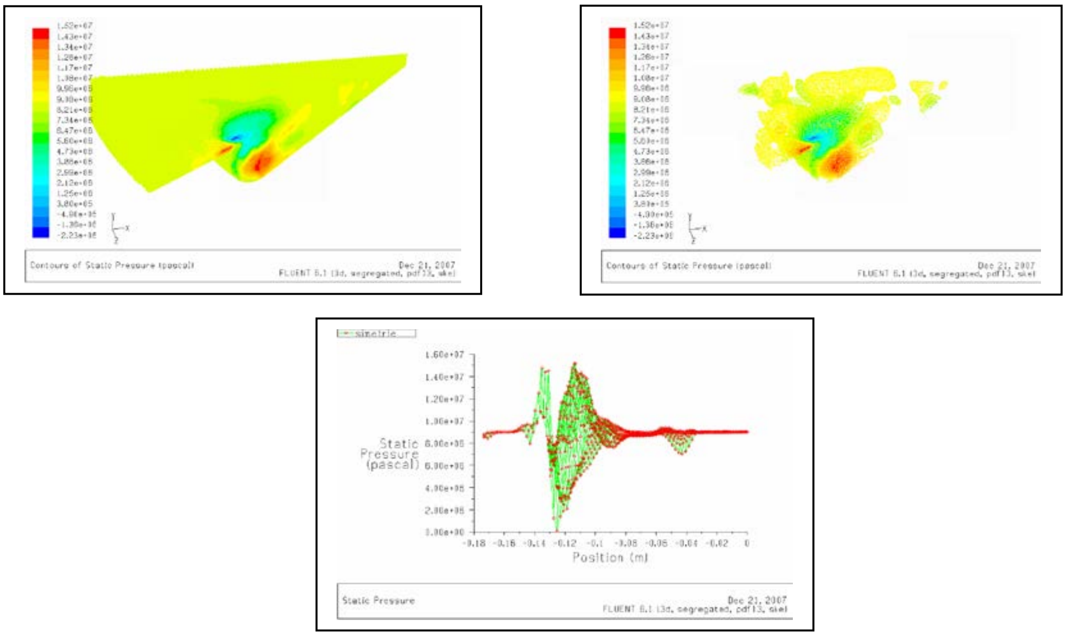
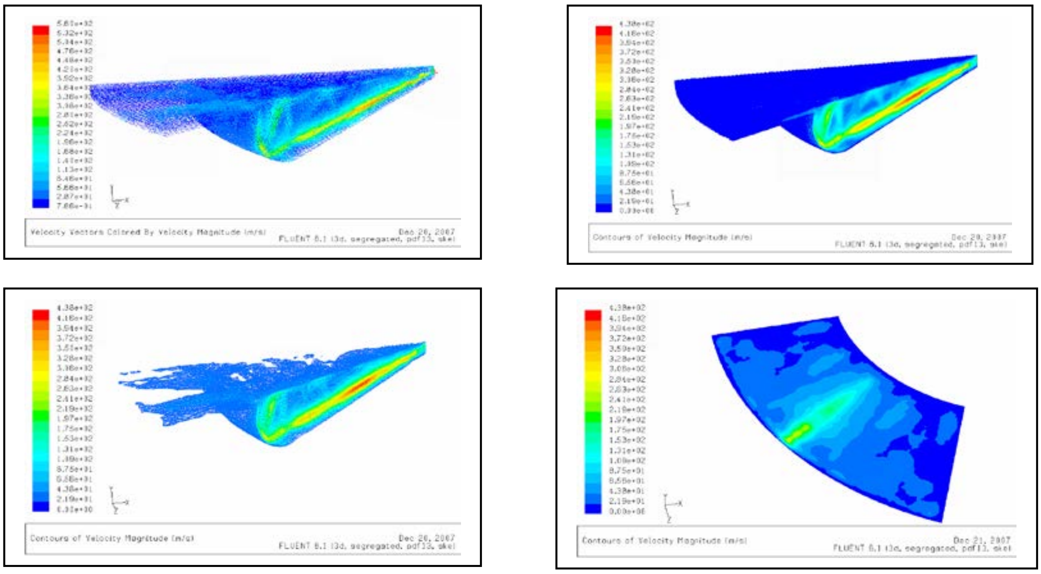


Fig. 2: Static pressure distribution in the combustion chamber



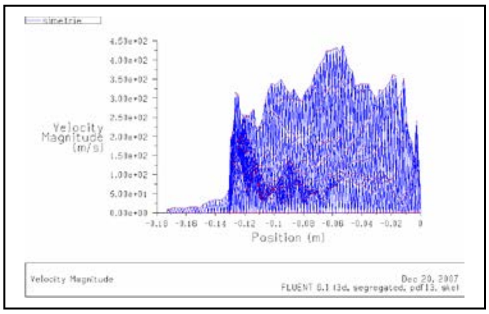


Fig. 3: Speed distribution in the combustion chamber

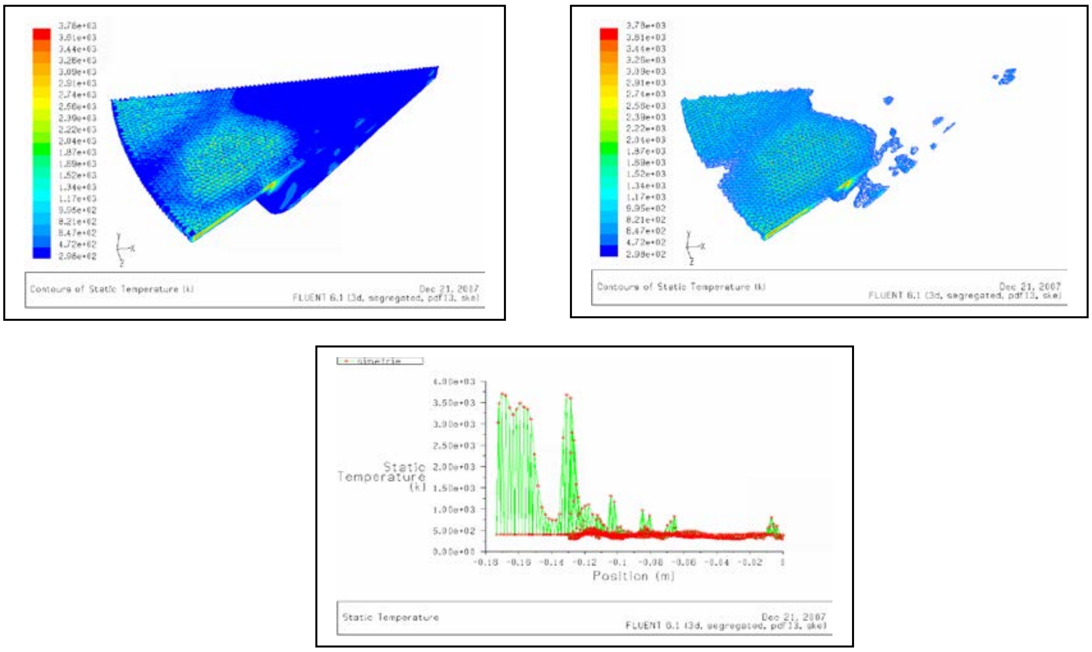


Fig. 4: Temperature's distribution in the combustion chamber

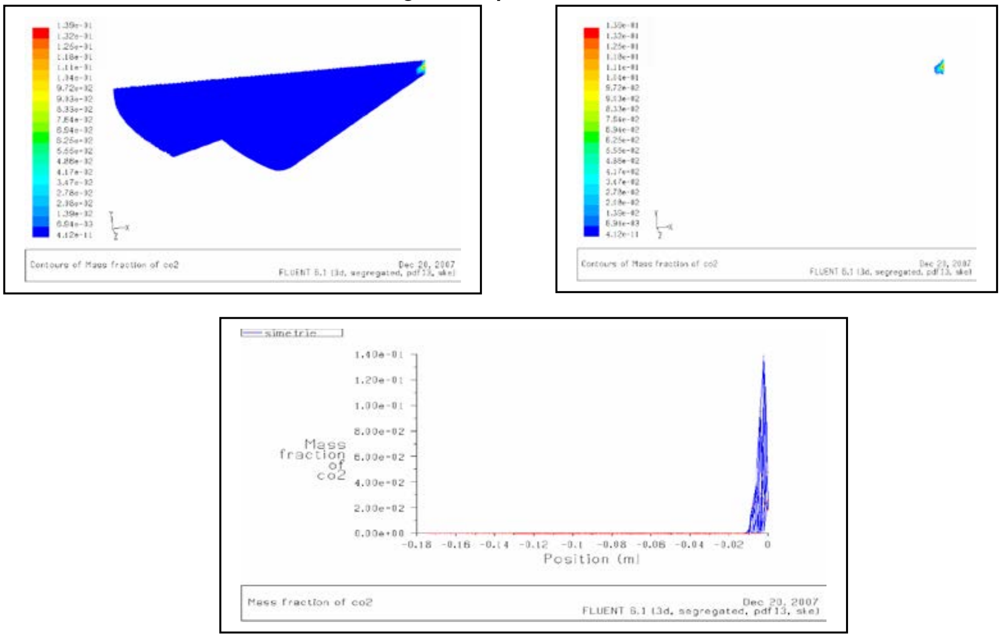


Fig. 5: CO_2 mass fraction distribution in the combustion chamber

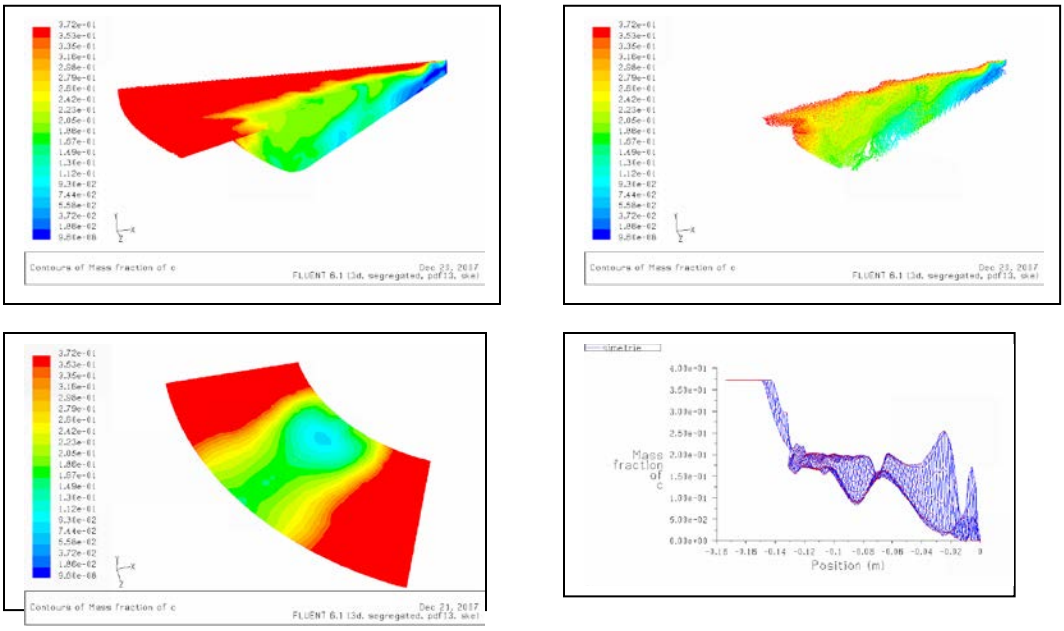


Fig. 6: C mass fraction distribution in the combustion chamber

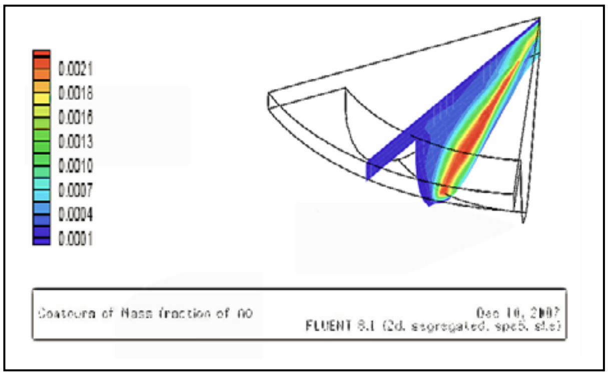


Fig. 7: NOx mass fraction distribution in the combustion chamber

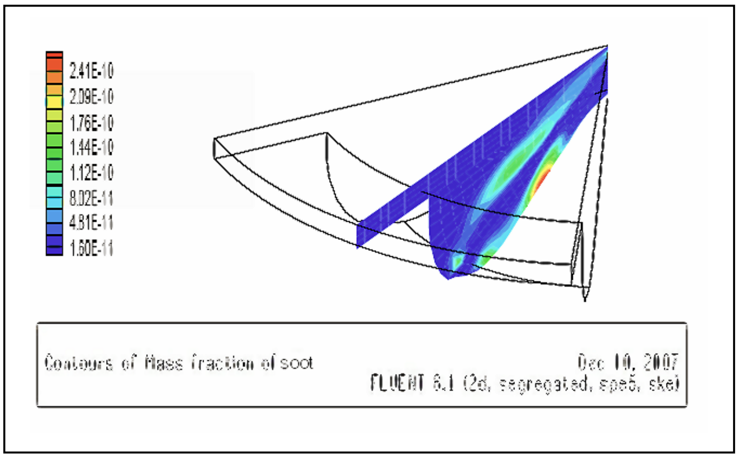


Fig. 8: Sooth mass fraction distribution in the combustion chamber

3. CONCLUSIONS

Validation of the simulation results were made by comparing them with the exiting databases and work of other authors concerning the same area of interest.

The main author personal contributions within this paper are as follows:

- the present paper contributes to the theoretical systematization of the area of interest bringing into attention a thoroughly inventory of the thermodynamic description of the phenomena which take place in the combustion process into the marine diesel engines;
- the paper contributes to the in depth multidimensional combustion models description along with the interdisciplinary phenomenology taking place in the combustion models;
- the present paperwork contributes to the FEA modelling for the combustion chemistry in the non-premixed mixtures approach considered;
- the CFD (Computational Fluid Dynamics) model was issued for the combustion area and a rich palette of results interesting for any researcher of the process were deduced as: pressures, temperatures, velocities, densities, viscosities, distribution of Prandtl number, entropy, enthalpy, total energy, turbulence intensity, vorticity, reaction rates, mass fractions, molar concentration of species.

Some possible directions for the future works are:

- the FEA-CFD study of the processes taking place up side of the combustion chamber (admission process, evacuation etc.) being recommendable to be so treated also the turbo-compressors,
- the study of the fluid-structure interaction and deducing the main toughness requirements for the engine.

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