Phenomenological Combustion Modeling for Optimization of Large 2-stroke Marine Engines under both Diesel and Dual Fuel Operating Conditions

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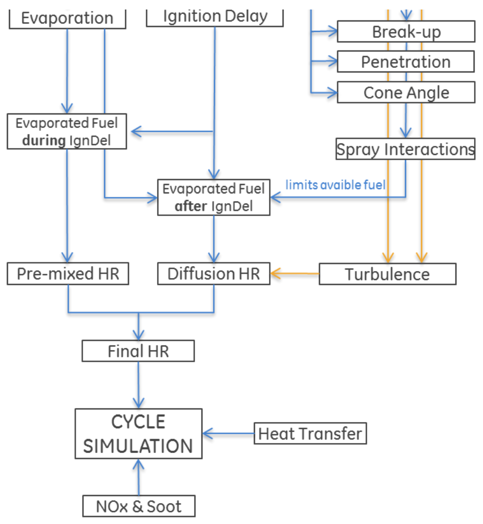
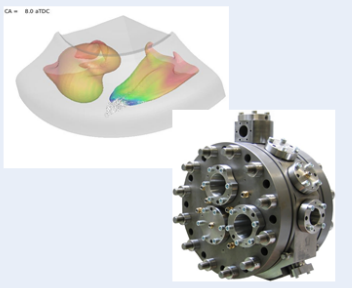
The main goal of the present thesis is a comprehensive assessment of phenomenological aspects of combustion in large low speed uniflow scavenged 2-stroke marine engines and the identification of generally valid concepts for describing diesel and dual fuel combustion in such engines. This comprises the development of quasi-dimensional, physics-based and fast running combustion modeling methodology in order to enable engine performance analysis and optimization under both steady state and transient operation conditions.

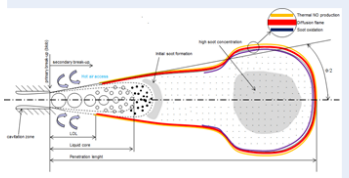
DIESEL MODEL FORMULATION

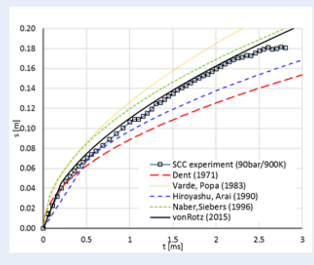


Diesel Spray Morphology

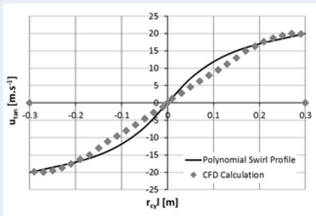
Definition of spray penetration and dispersion by correlations calibrated and validated with CFD and SCC (spray combustion chamber) experiments





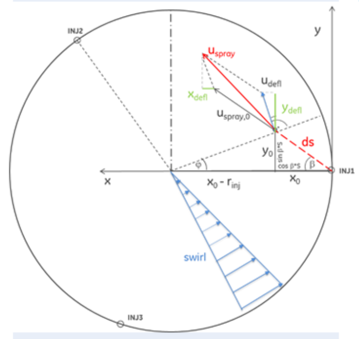


Spray Interactions



In cylinder swirl profile is defined by a polynomial correlation & validated with CFD

Spray history and interactions are captured by a quasi-dimensional model based on nozzle geometry, flow conditions or number of injectors

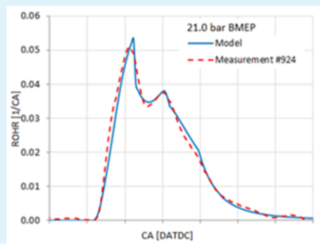


Turbulence and Combustion

The turbulence model relies on the k-ε formulation for 1D homogenous and isotropic turbulence derived from kinetic energy of the injection spray, density variations, swirl motion and dissipation.

$$\frac{dk}{dt} = \left(\frac{dk}{dt}\right)_{density} + \left(\frac{dk}{dt}\right)_{swirl} + \left(\frac{dk}{dt}\right)_{inj} - \varepsilon$$

Both premixed and diffusion combustion rate adopts the time scale approach. Whereas the premixed time scale relates to the ignition delay the diffusion time scale is derived from turbulent intensity and characteristic lenght scale.

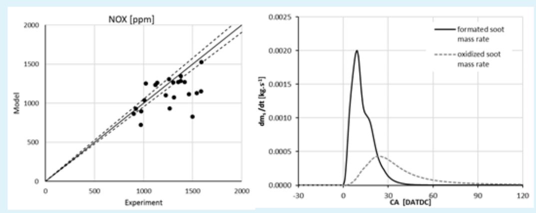


$$\frac{dm_{f,b,diff}}{dt} = C_{diff}\frac{1}{\tau_T} m_{f,u,diff}$$

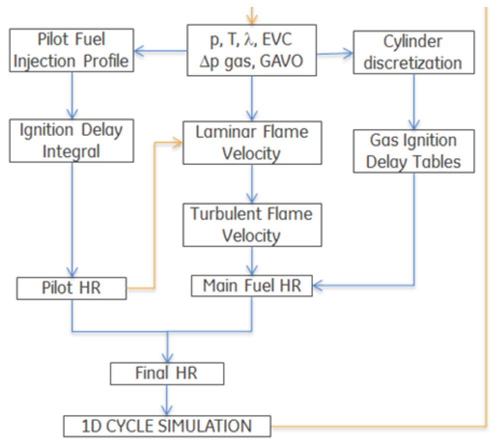
$$\frac{dm_{f,b,prem}}{dt} = C_{prem}\frac{1}{\tau_{ign}} m_{f,u,prem}$$

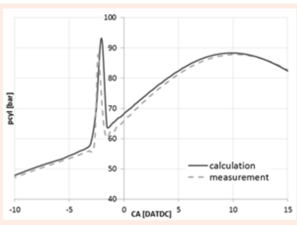
Emission Formation

Using common extended Zeldovic mechanism for NO formation. Phenomenology is employed for soot formation and oxidation



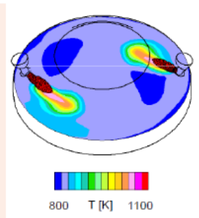
DUAL FUEL MODEL FORMULATION



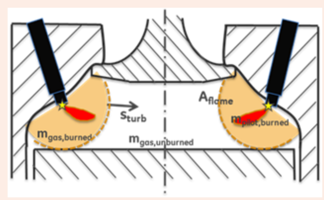


Pilot Diffusion Combustion

Pilot combustion computed analog to the main diesel combustion. Propagation into the main chamber and interaction with the gas-air mixture validated by CFD.



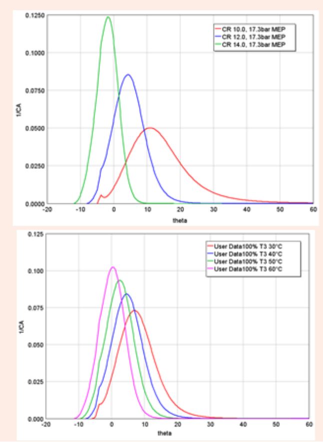
Combustion Model



Flame area propagation modeled according to to the combustion space geometry and link to the combustion pregress variable

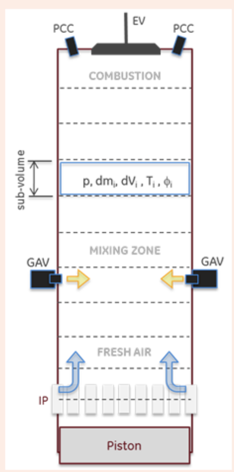
$$A_{fl} = 4 \cdot \pi \cdot r_{fl}^2 \frac{1}{12} \cdot (1 - x_b)$$

Model calibration and validation against engineexperimental data



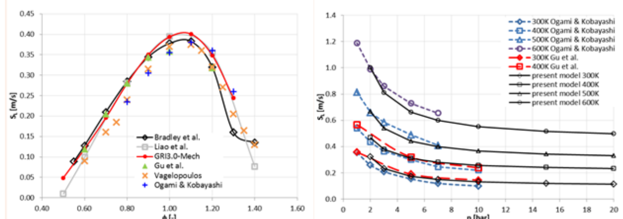
Ignition Delay

Common ignition integral approach considering average in-cylinder conditions not generic due to spacial differences in temperature and concentrations. Concept based on tabulated ignition delay data and cylinder discretization utilized instead.



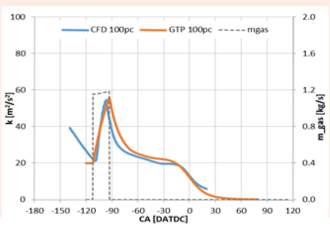
Turbulence Model and Flame Propagation

Laminar flame velocity correlation developed and validated by available experiments and detailed chemical kinetics based calculation.



1D turbulence model defined for determining the turbulent flame speed employing the k-ε model

$$\frac{dk}{dt} = \frac{3}{2}k\frac{1}{\rho}\frac{d\rho}{dt} + \frac{1}{2}\frac{dm_g}{dt}u_g^2\frac{1}{m_{cyl}} - C_{diss}\cdot\frac{1}{l_i}k^{\frac{3}{2}}$$



Following the thesis objectives phenomenological aspects of combustion in large low speed 2-stroke marine engines with respect to both diesel and dual fuel combustion were thoroughly assessed on the basis of results of extensive experimental investigations as well as detailed CFD simulations. The key findings from this assessment were employed for developing models describing combustion phenomenology on the basis of various submodels relevant to spray morphology, mixture formation, ignition delay, turbulence, spray interactions or premixed flame velocity. Regarding key performance figures, the modeling methodology has shown good level of accuracy and predictivity.

Author's Publications and Work

1. Cernik, F., Macek, J., Dahnz, C., and Hensel, S., "Dual Fuel Combustion Model for a Large Low-Speed 2-Stroke Engine," SAE Technical Paper 2016-01-0770, 2016.
2. Cernik, F., "Integrated 1D Simulation for a Large Low-Speed 2-Stroke Marine Engine", Proceedings GT-Suite Users Conference, 2015.
3. Author's research work related to the dual fuel combustion concept development for large 2-stroke engines has contributed to the "Marine Engine of The Year" award for X-DF engines at the Marine Propulsion Awards 2017.