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Multi-Objective Optimization of Fuel Consumption and NO_x Emissions using a Stochastic Reactor Model

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Introduction

Highly fuel-efficient Diesel engines, combined with effective exhaust after-treatment systems, enable an economic and low-emission operation of heavy-duty vehicles. The challenge of its development arises from the present engine complexity, which is expected to increase even more in the future. This work presents a methodology to utilize the zero-dimensional (0D) direct injection (DI) stochastic reactor model (SRM) for multi-objective Diesel engine parameter optimization to reduce fuel consumption and NO_x emissions. To reduce the computational cost of the 0D SRM simulations the reaction-progress-variable-based tabulation strategy of Matrisciano et al. is applied [1].

Optimization Process and Tabulated Chemistry

The 0D DI-SRM is based on a probability density function approach for reactive flows [2, 3, 4]. A modified Euclidean Minimum Spanning Tree (EMST) mixing model is used [5, 6], which accounts for locality in the particle mixing process only for mixture fraction. The 0D DI-SRM incorporates a phenomenological turbulence model to calculate the scalar mixing time based on turbulent kinetic energy and dissipation [6].

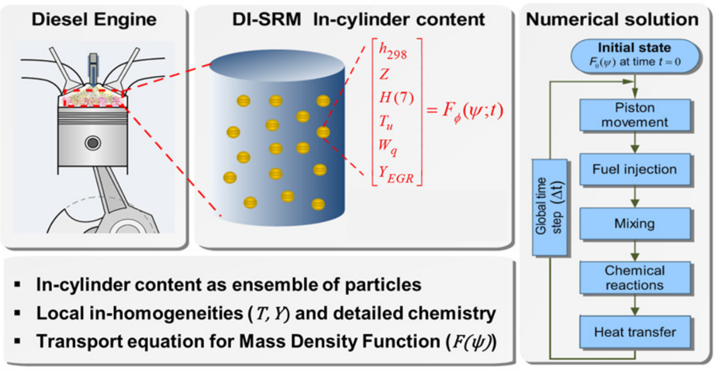

Figure 1: 0D SRM with tabulated chemistry for direct injection Diesel engines.

The surrogate is composed of 25% α-methylnaphtalene and 75% n-decane in mass percent. The Diesel detailed chemistry from the LOGEfuel package [8] is pre-compiled in a look-up table depending on temperature, pressure, equivalence ratio and EGR (see Table 1). During the simulation the chemistry sources are retrieved from the look-up table based on the current thermodynamic conditions and the reaction progress variable.

Table 1: Combustion chemistry table specifications.

	Range	Steps
Temperature	250 – 1600 K	25 K
Pressure	1 - 200 bar	2.5 bar
Equivalence ratio	0.2 – 4.0	0.2
EGR	0 – 50%	10%

The FAST Non-dominated Sorting Genetic Algorithm (NSGA-II) and the Uniform Latin Hypercube (ULHC) space filler algorithm with 1500 designs are used for optimization (see Figure 2).

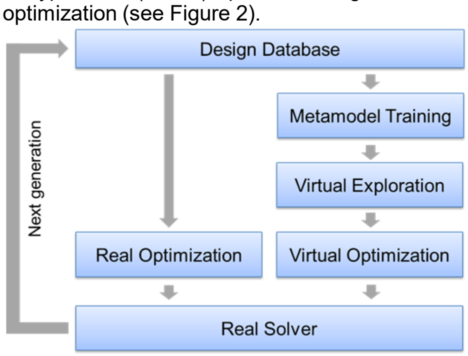

Figure 2: The FAST optimization algorithm combines genetic algorithms and Response Surface Models [6].

Multi-Objective Optimization with 0D DI-SRM

The specific fuel consumption (ISFC) and NO_x emissions (sNO_x) shall be minimized for each operating point by tuning the parameters in Table 2. The constraints are 200bar peak cylinder pressure (PCP) and 1000K turbine inlet temperature (TIT).

Table 2: Optimization parameters.

	Minimum	Maximum
Start of injection (SOI)	-16°CA aTDC	+6°CA aTDC
Injection pressure (p_{rail})	800 bar	2000 bar
Compression Ratio (CR)	15	21
EGR	0%	20%

The optimization results are shown in Figure 3 and Figure 4. The relative change of the given property compared to the base case is depicted in percent. The compression ratio is found to be most effective for improving fuel consumption. Especially part load operating points show the highest potential regarding increased compression ratio. The EGR rate is the most effective parameter to reduce the NO_x emissions for all operating points. Full load operating points show only a minor potential for improving ISFC and sNO_x since they are limited by PCP and TIT.

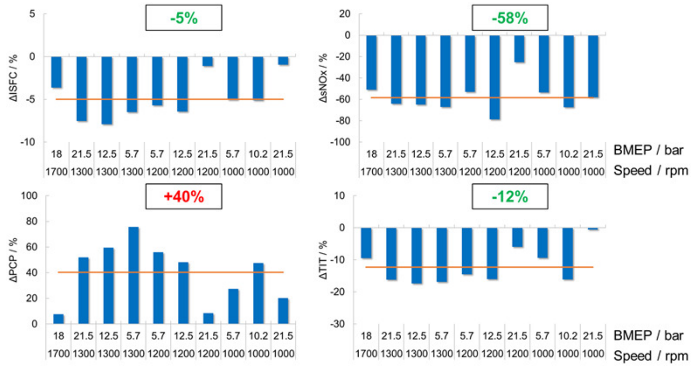

Figure 3: Relative change of ISFC, sNO_x, PCP and TIT after 0D SRM multi-objective optimization.

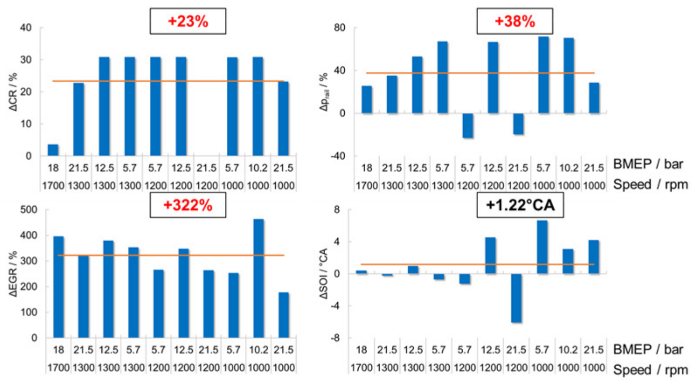

Figure 4: Relative change of CR, p_{rail}, EGR and SOI after 0D SRM multi-objective optimization.

Conclusions

The 0D DI-SRM with tabulated chemistry is successfully applied for a multi-objective optimization of fuel consumption and NO_x emissions in a direct injection Diesel engine. The approach highlighted its strength to account for physical and chemical effects in a 0D model framework with a lesser extent of computational costs. The optimization results show that increasing compression ratio has the highest potential for reducing fuel consumption especially at part load conditions. Increasing the EGR rate is most effective in reducing the NO_x emissions of all operating points. The average optimization time is 30h on three cores of an Intel i7-7820HQ CPU.

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