user story

SAE 2010 World Congress — Recognized as an SAE Industry Innovator

diesel engine optimisation

"virtual cylinder" optimisation in terms of design constraints and regulated emissions

With access to an increasing portfolio of technologies capable of contributing to mitigating exhaust gas emissions from modern diesel engines, identifying the optimal combination to meet exhaust gas emission regulations for a particular load at a specific speed is a multidimensional challenge.

For example, this might be optimising the injection timing, split ratio, EGR composition etc. In this context, conventional modelling tools are either not robust enough (1D models) or too computationally expensive (3D CFD), to provide informed solutions over wide ranges of operation. Hence, the natural response from engine developers has been to increase experimental activities in these areas which can cost thousands of dollars per engine per day.

Due to the multidimensional element, experimental activities are lengthy and expensive thus a number of cmcl innovations' customers employ srm suite to facilitate DoE (Design of Experiments) and to gain further insight into the interaction of the many components within the system. These efforts have proven to cut required experimental activities and overall project costs.

THE CHALLENGE

Identify minimum exhaust gas emissions for a load-speed point

THE SOLUTION

Using the srm suite software to simulate diesel fuelled combustion and emissions

THE RESULTS

- The distribution of soot particles were shown to evolve during the cylinder over time
- The EGR composition is critical to the soot formation process
- Trapped soot particles grow in size in subsequent cycles

THE CHALLENGE

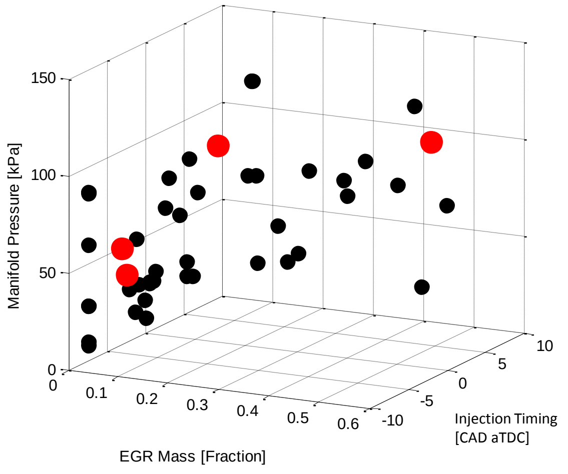
As an example, to obtain the lowest emissions possible within safe engine operating limits at a load of 65kPa BMEP at 1500 rpm in a diesel fuelled engine

THE SOLUTION

The srm suite combustion software was validated in terms of pressure profiles and exhaust gas emissions against 46 operating points to build a "virtual cylinder".

This "virtual cylinder" was employed to carry out a parametric study to identify key interacting processes over variations of boost pressure, EGR rate and injection timing. Various combination of these control variables were analysed to identify the optimal operating point.

user story



This diagram shows the 46 experimental operating points, those marked red were employed in the parameterisation and those marked black employed in a blind test.

BUILDING A "VIRTUAL ENGINE CYLINDER"

•Experimental data

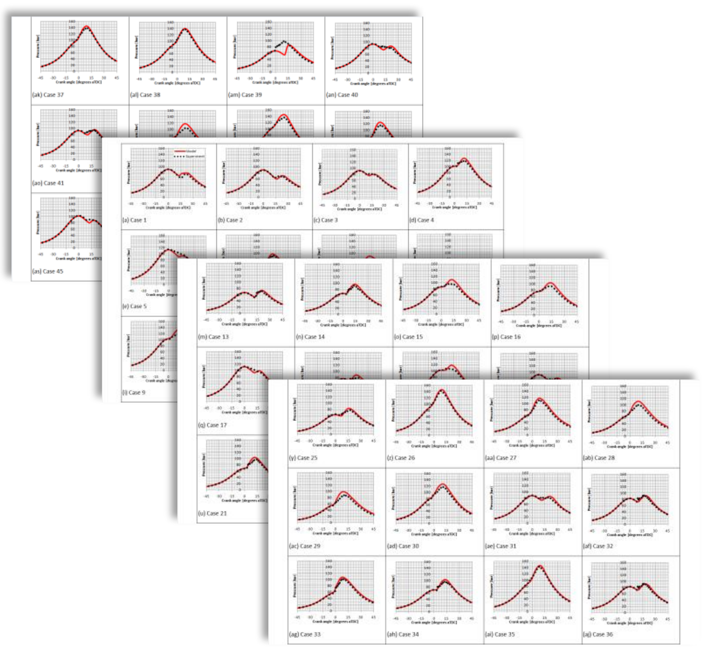
Experimental data was obtained from a diesel fuelled modified Perkins® 1000 series engine with high pressure common rail fuel injection system. Various sweeps examining engine performance in terms of exhaust gas emissions were carried out.

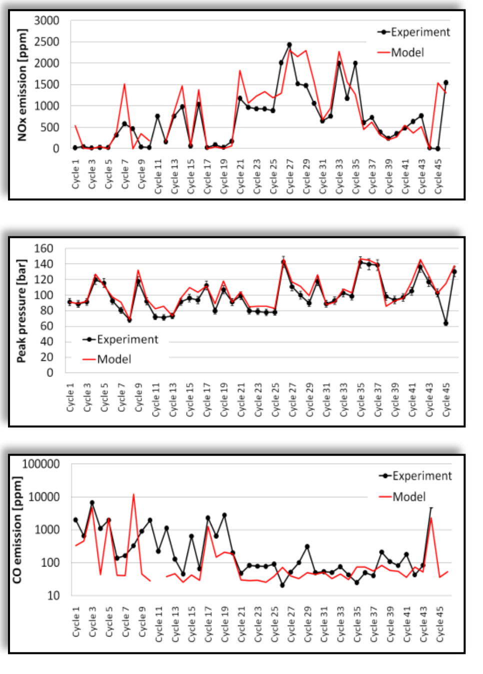
•Model parameterisation

A single set of model parameters were obtained by optimisation to mimic p-CAD and exhaust gas emissions at four operating points marked in red (left). **Each cycle simulation was completed in less than 45 seconds on a standard desktop PC.**

•Blind benchmarking

The single set of model parameters were employed in a blind test for the remaining 42 operating points. Results presented below show that the model successfully predicted engine performance in terms of pressure profiles and exhaust gas emissions when compared to experiments over a range of boost pressures, injection timings and EGR rates. The "predictive" performance of the model was considered suitable to be employed in further analysis of the data.

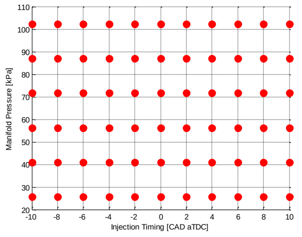


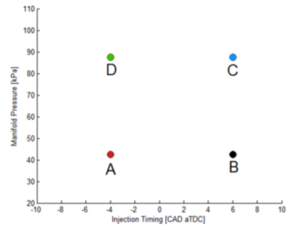


Sample of the results of the model vs. experiment benchmarking testing: Presented are examples of pressure-crank angle data, exhaust gas emissions and peak pressure over the 46 operating points.

cmcl innovations
e-mail: enquiries@cmclinnovations.com web: www.cmclinnovations.com

user story





Above right: The 88 operating points at 30% EGR. In increments of Ignition timing and boost pressure. Total computational time for this exercise was 66 minutes.

Above left: The four representative cycles used in further analysis and shown below.

Below far right: Pressure profiles of four representative cycles

Below: Local temperature and local equivalence ratio for the in-cylinder mixture during the four representative cycles at 5, 10, 15, 20 and 30 CAD aTDC.

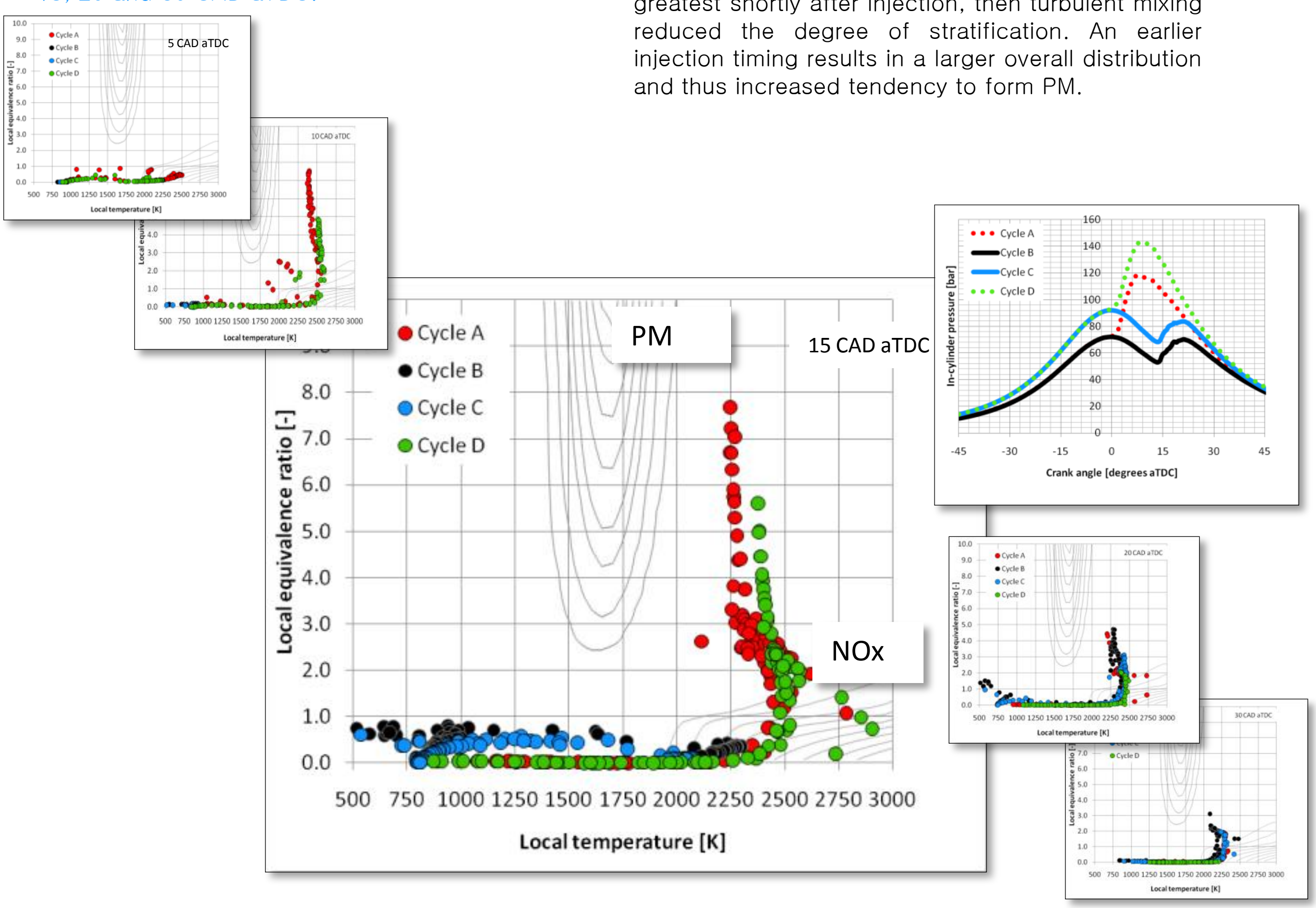
SIMPLIFYING THE ANALYSIS

•Multi-dimensional space simplified

During engine testing because of limited time and budget, it was not possible to incrementally map out the full matrix. As such to identify the trends and understand the key processes within the data requires interpolation. Due to relatively low computational cost this exercise was carried out using the validated “virtual cylinder”. To simplify visualisation of the data, a constant EGR of 30% was adopted and simulations run over a grid of 88 points. Total computational time for this exercise was around 1 hour.

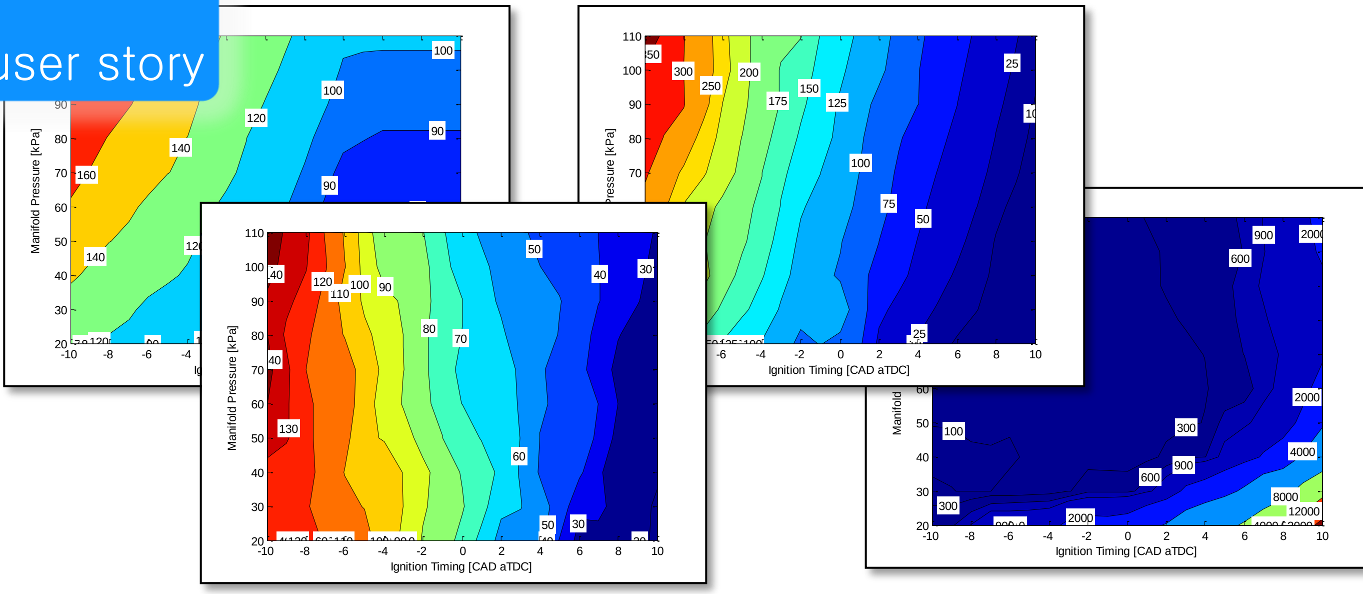
• Four representative cycles

To examine the dominating physical processes during mixture preparation, combustion and emissions formation, four representative cycles were selected. The local in-cylinder temperatures and equivalence ratios showed how varying injection timing and boost pressure impacted significantly on these distributions. As can be observed in the diagrams, the variation in temperatures and local equivalence ratio proved greatest shortly after injection, then turbulent mixing reduced the degree of stratification. An earlier injection timing results in a larger overall distribution and thus increased tendency to form PM.



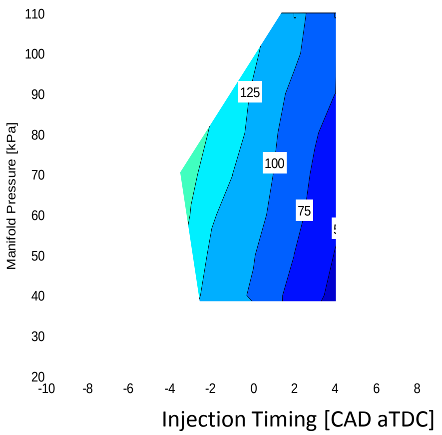
cmcl <>
innovations
e-mail: enquiries@cmclinnovations.com web: www.cmclinnovations.com

user story



Above: Peak pressure, knock limit, NOx emissions and CO emissions

Below: Feasible safe operating regime for minimal emissions



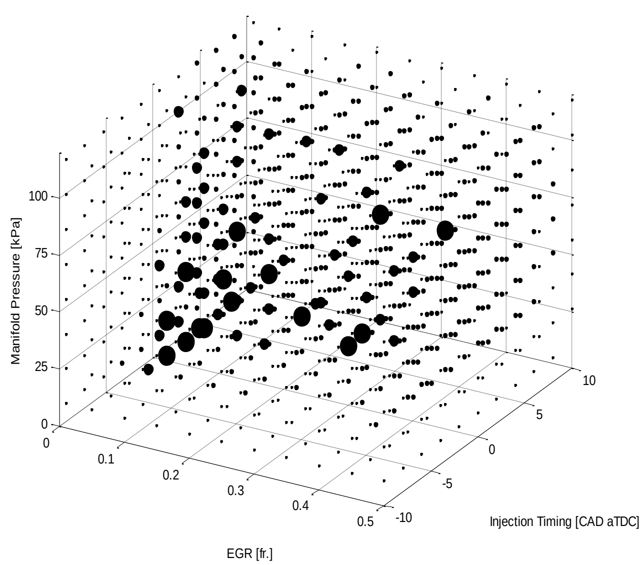
OPTIMISATION

•Identifying engineering constraints and avoiding excessive emissions

Constraints were defined on maximum peak pressure, knock limit, engine harshness etc. as well as avoiding regimes of excessive exhaust gas emissions.

•Finding the optima within the matrix

The analysis was carried out across the full range of EGR rates, boost pressures and injection timings. Emissions were analysed in terms of all regulated emissions including PM, the safe operating, low-emission optima is presented in the 3D diagram below.



This diagram shows the overall matrix, the larger the black dot, the closer to the optimal operating point. The regime at 10% EGR with relatively low boosting was decided to be the optima.

APPLICATION AREAS

•Diesel engines

•Optimisation

•Boosting

•EGR

•Emissions simulations

PRODUCTS USED

•srm suite

•Reduced chemistry sub-model

cmcl innovations

e-mail: enquiries@cmclinnovations.com web: www.cmclinnovations.com