SAE NAPLES
An SAE International Section

ICE2015

12th International Conference on Engines & Vehicles

September 13 - 17, 2015 @ Capri, Napoli

abstracts

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ICE2015

12th International Conference on Engines & Vehicles

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ICE2015

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Combustion In Spark Ignition Engines	**Christine Mounaime Rousselle** *University of Orleans (France)* **Jamie Turner** *University of Bath (UK)*
Combustion in Compression Ignition Engines	**Marcis Jansons** *Wayne State University-MI (USA)* **Amin Velji** *Karlsruhe Institute of Technology (Germany)*
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Fuels and Lubricants

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Fuel Injection and Sprays: Modeling	**Michele Battistoni** *University of Perugia (Italy)* **Mario Trujllo** *ERC University of Wisconsin-Madison (USA)*
Fuel Injection and Sprays: Experiments	**Louis-Marie Malbec** *IFPN (France)* **Alessandro Montanaro** *Istituto Motori (Italy)* **Josè V. Pastor** *CMT - Universitat Politècnica de Valencia (Spain)*
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Fuel and Additive Effects on Engine Systems	**Peter Hutchins** *Infineum (UK)*
Automotive Engine Oils	**Richard Pearson** *British Petroleum (UK)*

Exhaust Aftertreatment and Emissions

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Particle Emissions from Combustion Sources	**Silvana Di Iorio** *Istituto Motori (Italy)* **Imad Khalek** *Southwest Research Institute (USA)*
Gaseous Engine Emissions	**Benjamin Shade** *Tenneco (USA)* **Michael Travel** *Aramco Services Company (USA)*

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Hybrid and Electric Powertrains

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Advanced Fuel Cell Vehicle Applications	**Cesare Pianese** *University of Salerno (Italy)*
Advanced Battery Technologies	**Jim Miller** *Argonne National Laboratory (USA)* **Simona Onori** *Clemson (USA)*
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Controls for Hybrids and Electric Powertrains	**Per Tunestal** *University of Lund (Sweden)* **Giorgio Martini** *Joint Research Centre-Ispra (Italy)*

Preface

With growing concerns about natural resources and environmental protection and restoration, one of the major automotive issues worldwide is that of fuel economy and emissions. The primary objective of automotive manufacturers is to design vehicles that are highly fuel-efficient and cause considerably less air pollution. In order to achieve these goals, new Internal Combustion Engine and Hybrid-Electric Vehicle technologies are being developed.

ICE2015, the 12th International Conference on Engine & Vehicles, has been organized by Argonne National Laboratory and Istituto Motori – National Research Council of Italy (CNR), and SAENA, Italian Section of SAE International, to provide the ideal scenario for a comprehensive interaction among research, academia, and industry institutions that are actively involved in the engines and vehicles field.

To encourage extensive discussions about new results and research approaches on engines, vehicles and propulsion devices in general, 150 papers from about 30 countries have been selected after a meticulous review process according to the SAE International standards. These contributions cover a wide variety of topics, from advanced internal combustion engines to alternative powertrains, from conventional to alternative fuels, from innovative experimental diagnostics to the newest numerical methodologies for modeling, simulation and control. In addition, experts in these topics have been invited to deliver plenary lectures on the state of art and future development trends for the disciplines associated with the ICE2015 conference.

Donald G. Hillebrand and Bianca M. Vaglieco

Plenary Lectures

Toyota Fuel Cell Vehicle: achievements and challenges

Isotta Cerri

Toyota Motor Europe (Belgium)

Hydrogen Fuel Cell Vehicles are zero-emissions vehicles that represent a viable solution to energy and climate change issues; hydrogen can in fact be generated by different energy sources.

Toyota started the development of fuel cell technologies in 1992; after several model changes and ‘limited market’ introduction experience, in December 2014 Toyota launched a hydrogen fuel cell vehicle (Mirai) that in addition to a very attractive drivability features a cruising range of more than 500km, a cold-start capability at -30degC and about 3 minutes refuelling time.

The system uses in-house made components such as the fuel cell stack, the fuel cell boost converter, and the high-pressure hydrogen tanks.

With a maximum power of 114 kW the Toyota fuel cell stack achieves a volumetric power density of 3.1 kW/L thanks to the design and manufacturing of a unique separator consisting of 3D fine mesh flow channels and an internal water circulation system that eliminate the use of any external humidifiers.

A new more compact, high-efficiency, high-capacity converter has been developed to boost the generated power to 650 volts, thereby downsizing the fuel cell stack and reducing the system costs.

Tanks with a three-layer structure made of carbon fibre-reinforced plastic are used to store hydrogen at the very high pressure of 70 MPa at a world-leading 5.7 wt% hydrogen storage capacity (mass of stored hydrogen / mass of empty tank).

Toyota is now looking at the future planning to increase the production of the Mirai in line with the high vehicle demand and solve the next technology challenges to be able enter a mass scale production market at the advancement of a widespread hydrogen infrastructure.

Towards High Efficiency Engine – THE engine

Bengt Johansson

Lund University (Sweden)

The internal combustion engine has great potential for high fuel efficiency. The ideal otto and diesel cycles can easily achieve more than 70% thermodynamic efficiency. The problems come when those cycles should be implemented in a real engine. Extreme peak pressure during the cycle will call for a very robust engine structure that in turn will increase friction and hence reduce mechanical efficiency. A very high compression ratio also increase the surface to volume ratio and promote heat losses, taking away much of the benefits from the theoretical cycle.

The presentation will start with a standard SI engine and it's efficiency as a function of load. Then a high compression ratio SI with be introduced and compared with the same engine operated in HCCI mode. The four efficiencies of SI as well as HCCI will be discussed and variations like HCCI with negative valve overlap and higher mean piston speed will be shown.

A next step is the results with Partially Premixed Combustion. With PPC the indicated efficiency was shown to be up to 57%, thus 10% up from the best HCCI engine of 47%. However, to get the very high efficiency a high dilution level is needed. This is a challenge for the gas management system and hence gas exchange and mechanical efficiencies can suffer.

The final part of the presentation is giving an engine concept that can enable the conditions for PPC combustion but with much improved gas exchange and mechanical efficiency. It enables an effective compression ratio in excess of 60:1 but with much less cylinder surface area. The concept also enables low friction and hence high mechanical efficiency. The basic concept will be explained and initial simulation results will be presented.

Vehicle Electrification Increases Efficiency and Consumption Sensitivity

Henning R.A. Lohse-Busch
Argonne National Laboratory (USA)

The recent powertrain electrification trend contributes to significant vehicle efficiency improvements. As the powertrain efficiency increases, the impact of auxiliary loads on consumption becomes larger. The impact of driving style on energy consumption is also amplified as efficiency increases. As a result the consumption and the potential electric driving range that individual consumers will experience may vary considerably compared to their expectations set by standardized tests. This plenary lecture will summarize the vehicle efficiency correlation to electrification and quantify the impact of driving style, ambient temperature with climate control and auxiliary loads on advanced powertrains. As advances in vehicle efficiencies are made, we need to prepare the consumer for larger variation in consumption in the real world.

Combustion System Design and Development Process for Modern Automotive Diesel Engines

Alberto Vassallo
GM Powertrain Europe (Italy)

In modern automotive diesel engines, the requirements on the combustion system have become very tightening, due to an aggressive combination of pollutant emission, fuel economy, NVH and fun-to-drive targets. Coupled to ever-faster product development schedules, this poses high priority in devising an effective process for the design and development of new combustion systems. Since most of the design choices occur very early in the engine development phase, it is of high importance to have reliable analytical tools capable to predict the performance of each component and of the overall system itself, prior than the actual hardware is available for testing.

The present keynote describes the Combustion System Design and Development Process devised and deployed by General Motors for the new diesel engine families being release to the market. The analytical tools definition, their interaction, and their verification based on prototype hardware testing will be discussed. Also, state-of-the-art experimental techniques will be reviewed for the better understanding of in-cylinder unsteady combustion processes.

The talk will conclude with an overview about the most innovative areas under investigation and what the next steps could be in this continuous improvement process.

Overcoming HCCI Technology Barriers: Management of Fuel Variability and In-cylinder Thermal Environment

Zoran Filipi
Clemson University (USA)

While turbocharging and downsizing dominates the near-term gasoline engine trends, Homogeneous Charge Compression Engine (HCCI) is one of the promising mid-term technologies for achieving the US 2025 CAFE standards and future European vehicle CO2 emission limits. The HCCI concept has been already proven in the laboratory, but complex controls, limited operating range and sensitivity to real-world variabilities remain a challenge. Autoignition, combustion, and low-end operating stability in an HCCI engine critically depend on the interplay between the in-cylinder thermal environment and chemical kinetics, and this presentation addresses both. Variability in pump gasoline composition is one source of uncertainty and therefore a barrier to HCCI introduction, and this study characterizes the impact of the Research Octane Number, Sensitivity (RON-MON), fraction of Aromatics and Olefins on autoignition, operating limits and fuel consumption. Blending with Ethanol and a possibility to improve accuracy of the autoignition quality predictions are discussed as well. Next, research addresses the impact of thermal barrier coatings (TBC) on the HCCI engine, and design of an engineered coating that will produce the most desirable effects on thermal efficiency, combustion efficiency and emissions of UBHC and CO. Extending the low-load limit of HCCI operation due to more stable combustion will produce additional positive impact on vehicle fuel economy. Techniques for generating deep insight into mechanisms and magnitude of the effects on in-cylinder processes are discussed, as well as desirable coating physical properties and plasma spray techniques for achieving them. Single-cylinder research engine with direct injection of gasoline fuel and re-induction of residual enables systematic investigations and quantitative assessments.

Heavy Duty Diesel Engines Technology Roadmap: Review of last decade technical developments and possibilities to achieve a high brake thermal efficiency in the near future

Gilles Hardy

CNH Industrial (Switzerland)

For the last decade, the HD Diesel engine industry has focused primarily its development on ATS in order to achieve the required emissions legislations. As a result, NOx and PM have been reduced by a factor 10 over a very demanding transient cycle. Discussions between industries and government bodies are under way to regulate CO2 emissions. Depending upon the new regulation limits, new combustion strategies, further hardware optimisation/control and additional aggregates will have to be developed with a proven controllability and reliability while OBD-requirements will have to be fulfilled. And above all the overall impact on transport costs should not increase, therefore tough challenges lie ahead the industry.

Thermal Efficiency Enhancement of Gasoline Engine

Kenichiro Ikeya

Honda R&D Co.,Ltd. - Automobile R&D Center (Japan)

Recent years have brought growing calls for automobiles with better fuel economy and lower emissions in order to protect the environment and reduce CO2, which is considered a cause of global warming. The regulation values are also tending to grow more demanding year by year. On the other hand, the use of electric vehicles (EVs) and other such electrification technologies to address these issues is increasing. For the time being, however, conventional automobiles powered solely by internal combustion engines and hybrid vehicles that combine those engines with electric motors are expected to make up the mainstream, so increasing the thermal efficiency of internal combustion engines will also continue to be important. The maximum brake thermal efficiency of automobile gasoline engines is presently around 39%. The upcoming issue for internal combustion engines will be to raise that brake thermal efficiency to 45% or more.

The study to achieve 45% of brake thermal efficiency under conditions of stoichiometric air-fuel ratio and 91 RON (Research Octane Number) gasoline fuel was carried out.

As a result of this study on single cylinder engine, a brake thermal efficiency of 45% was achieved at an engine speed of 2000 rpm, BMEP 800kPa and EGR rate above 35% with a S/B ratio of 1.5, a compression ratio of 17, an effective compression ratio of 12.5, high energy ignition and high tumble flow port.

As a result of this study on 4 cylinder engine, it was needed the firing order arranged intake manifold, and the supercharger which has high efficiency and wide range performance.

Bosch Diesel Systems beyond Fuel Injection & Exhaust Gas Treatment: Air System and Hybridization

Joachim Paul, M. Wüst et al.

Diesel Systems, Robert Bosch GmbH (Germany)

R. Busch et al.

Bosch Mahle Turbo Systems (Germany)

Over the last decades Diesel-powered vehicles have gained an important share of the European pass car market by proving both an outstanding increase of driving performance and at the same time a significant reduction of pollutant emissions. This was mainly achieved by introduction of continuously more advanced technologies related to fuel injection, air and exhaust gas after-treatment systems. E.g. particulate emissions were cut back to a minimum with the introduction of diesel particulate filters. With the upcoming EU6 exhaust regulation the nitrogen-oxide emissions will be further reduced, in many cases applying an efficient NOx exhaust gas after-treatment system as SCR.

Robert Bosch Diesel Systems has strongly contributed to this technological progress as a system supplier of advanced fuel injection systems like common rail and exhaust gas sensors and after-treatment systems like adBlue dosing systems. These systems comprise both the hardware components and the related optimized control and operating strategies integrated in the electronic control units.

However, in the years to come the requirements for passenger-car diesel power-trains will become even more demanding in various regards.

On the one hand, current discussions are focusing on the registration of pollutant emissions produced under real driving conditions (RDE, real driving emissions). Compared to the currently applicable European type approval driving cycle for passenger cars future test cycles will include higher requirements regarding power output and transient operations.

On the other hand, CO2 emissions must be significantly further reduced for all passenger cars. For this purpose, the efficiency of diesel engine must be increased by improvements not only in fuel injection but also in air system performance and may be complemented by various approaches of hybridization.

Robert Bosch GmbH is running comprehensive studies on the optimization of the complete Diesel engine power-trains. The aim of these studies is to develop scalable engine-control functions resulting in the efficient and optimum matching of the Diesel combustion system components, as to be presented here the turbo charging system (worked out in close cooperation with Bosch Mahle Turbo Systems) and possible hybridization concepts for future applications.

X-ray Diagnostics for Fuel Injection and Sprays

Christopher F. Powell
Energy Systems Division, Argonne National Laboratory (USA)

X-ray diagnostics have the potential to make quantitative measurements in environments where optical diagnostics are difficult, particularly inside opaque materials and in highly scattering multiphase flows. The high brightness and increasing availability of synchrotron x-ray sources has made these diagnostics feasible, and enabled their application to a range of challenges for fuel injection. This presentation will describe the measurements which are possible using synchrotron x-ray sources and their application to fuel injection and sprays.

Four diagnostics will be described in detail. X-ray radiography provides quantitative measurements of density in variable density flows. Radiography has been used to measure the time-resolved density in the near-nozzle region of fuel injection sprays and also in cavitating flow fields, environments that are highly scattering in the visible wavelengths. These measurements enable quantitative, unambiguous comparison with computational predictions, and have been used for the development and validation of flow models both inside and outside the nozzle.

X-ray phase-contrast imaging is used to visualize multiphase flows with high spatial and temporal resolution. Because it utilizes x-rays of a more penetrating wavelength, phase contrast imaging allows visualization of components inside operating injectors, and can even image regions of cavitating flow inside steel injection nozzles.

X-ray fluorescence spectroscopy shows significant promise to study mixing in single-phase and multiphase flows. Because it is sensitive to the identity of atomic elements, it allows mixing between different fluids to be tracked quantitatively. Fluorescence has been used to study the mixing of impinging jets, and to understand the influence of dissolved gases on cavitating flows.

Small angle x-ray scattering is a powerful technique to examine small-scale particles in flows. It allows one to measure the total surface area inside the volume probed by the x-ray beam. Combining such measurements with the spray density measured using radiography allows calculation of the Sauter Mean Diameter. This measurement can be performed even in the region of the spray very close to the nozzle, where other diagnostics fail. This measurement provides clues about the morphology of the spray as it first emerges from the nozzle, and has been used to validate computational predictions of near-nozzle spray breakup.C

Engine Modeling and Diagnostics

Engine Combustion

Fuels and Lubricants

Exhaust Aftertreatment and Emissions

New Engines, Components, Actuators, & Sensors

Hybrid and Electric Powertrains

An ICE Map Generation Tool Applied to the Evaluation of the Impact of Downsizing on Hybrid Vehicle Consumption

Guillaume Alix, Jean-Charles Dabadie, and Gregory Font
IFP Energies Nouvelles

Legal constraints concerning CO2 emissions have made the improvement of light duty vehicle efficiency mandatory. In result, vehicle powertrain and its development have become increasingly complex, requiring the ability to assess rapidly the effect of several technological solutions, such as hybridization or internal combustion engine (or ICE) downsizing, on vehicle CO2 emissions. In this respect, simulation is nowadays a common way to estimate a vehicle's fuel consumption on a given driving cycle. This estimation can be done with the knowledge of vehicle main characteristics, its transmission ratio and efficiency and its internal combustion engine fuel consumption map. While vehicle and transmission parameters are relatively easy to know, the ICE consumption map has to be obtained through either test bench measurements or computation. Experimental measurement gives the most precise data but proves to be a too much time consuming and costly procedure for decision support concerning ICE design. In this respect, numerical tools are more adapted, especially when multiple engine architectures need to be assessed. This paper presents a numerical tool for the generation of an ICE fuel consumption map, and illustrates its application by studying the influence of engine downsizing on the fuel consumption of a given hybrid vehicle.

Modeling Waves in ICE Ducts: Comparison of 1D and Low Order Models

Farouq Meddahi, Christian Fleck, and Stefan Grodde

Robert Bosch GmbH

Alain Charlet and Yann Chamaillard

Universite D'Orleans

The paper presents a comparative study of various models used to estimate gas dynamics in internal combustion engine (ICE) ducts. 1D models provide a sufficient accuracy, but they are still not implementable on current ECUs. On the other hand, low order models can be real-time but their lack of accuracy and high calibration cost are still a challenging problem.

This work aims at presenting a comparison of currently used gas dynamics models to predict transient phenomena in engine ducts. It emphasizes on 1D and low order models. To test under engine-like conditions, the intake path of a virtual engine implemented in GT-Power and a production two cylinder engine are used.

Results show a contrast in the performance of the different models, which gives the possibility to evaluate the various approaches. Based on this assessment and depending on the application in hand, the models can be chosen properly to estimate the gas dynamics in internal combustion engine ducts.

Modelling and Simulation of General Path Centrifugal Pendulum Vibration Absorbers

Emiliano Vitaliani, Daniele Di Rocco, and Martin Sopouch

AVL LIST GmbH

The aim of this paper is the study of the Centrifugal Pendulum Vibration Absorber (CPVA) dynamic behavior, with the background of improved vibration isolation and damping quality through a wide range of operating speeds. The CPVAs are passive devices, which are used in rotating machinery to reduce the torsional vibration without decreasing performance. After a first use of these damping systems in the field of aeronautics, nowadays CPVAs are employed also in railway and automotive applications. In principle, the CPVA is a mass, mounted on a rotor, which moves along a defined path relative to the rotor itself, driven by centrifugal effects and by the rotor's torsional vibrations. The advantage that such absorbers provide is the capability to counteract torsional vibrations arising with frequencies proportional to the mean operating speed. This is in particular the case with Internal Combustion Engines (ICE) where the induced vibrations are caused by the combustions process. The above-mentioned feature is obtained thanks to the tuning of the absorber on the specific ICE vibration order, obtained by means of its geometric characteristics. The main goal of this work is to model and simulate different types of CPVAs, where simple vibration models can be implemented for first investigations. Special attention has been given to CPVAs modelled with circular, cycloidal and epicycloidal paths, using a general-path equation system approach. The CPVA unit performance has been analyzed by means of an n_{th} order sine-signal torque. In this simulation environment, the paper aims to highlight the capabilities of absorbing vibrations of CVPAs, emphasizing the configurations with cycloidal and epicycloidal paths where the vibrations of the designated order can be reduced to a level very close to zero, for a major part of the ICE speed range. Furthermore the present work provides a simulation approach as basis for CPVA parameters optimization.

The Dual Flame Model (DFM) : A Phenomenological 0D Diesel Combustion Model to Predict Pollutant Emissions

Jordan Rudloff, Alessio Dulbecco, and Gregory Font
IFP Energies Nouvelles

IFP Energies nouvelles (IFPEN) has a large experience in the development of engine simulation platforms. During the last decade, the Dual Flame Model (DFM), a physical 0-dimensional (0D) combustion model designed for Diesel applications, was developed and continuously improved. The DFM formalism allows to represent quite precisely the in-cylinder combustion process scenario, by accounting for the first order relevant physics impacting fuel oxidation. First of all, this allows to account for the impact of engine actuators on combustion (e.g. injection systems performing complex injection strategies, Low Pressure and High Pressure EGR loops,…) and then to describe the pollutant emissions formation processes, being chemical kinetics strongly dependent on the in-cylinder thermochemical conditions.

The aim of this communication is to present the potential of using the DFM model in the different stages of a Diesel engine development process for pollutant emissions optimization. For this, a new automatic multi-step calibration approach developed at IFPEN will be detailed and its potential will be illustrated thanks to several applications. In a second time, the representativeness of the DFM combustion process description and its potential to predict pollutant emissions to single-parameter variations of engine control actuators will be investigated. To do that, an original model evaluation methodology based on DOE (Design Of Experiments) is presented. Accordingly, the physical response of the DFM, obtained by post-processing the results of the virtual DOE database is compared to the one given by an experimental mirror-DOE database. This permits to validate from one side the physical bases of the DFM and to put in evidence the axes of improvement of the model.

Comparison between Internal and External EGR Performance on a Heavy Duty Diesel Engine by Means of a Refined 1D Fluid-Dynamic Engine Model

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The potential of internal EGR (iEGR) and external EGR (eEGR) in reducing the engine-out NOx emissions in a heavy-duty diesel engine has been investigated by means of a refined 1D fluid-dynamic engine model developed in the GT-Power environment. The engine is equipped with Variable Valve Actuation (VVA) and Variable Geometry Turbocharger (VGT) systems. The activity was carried out in the frame of the CORE Collaborative Project of the European Community, VII FP. The engine model integrates an innovative 0D predictive combustion algorithm for the simulation of the HRR (heat release rate) based on the accumulated fuel mass approach and a multi-zone thermodynamic model for the simulation of the in-cylinder temperatures. NOx emissions are calculated by means of the Zeldovich thermal and prompt mechanisms. As a first step, the model has been calibrated and assessed on the basis of experimental tests carried out on four characteristic operating conditions within the WHSC (World Harmonized Stationary Cycle). The considered engine points have been used to identify the optimal engine parameters on the basis of a DoE approach. As a second step, sweeps simulations centered on the previously considered operating points have been run for iEGR and eEGR in order to study the effects of these latter on combustion and NOx formation processes at steady-state conditions. Finally, a ramp from the WHTC (World Harmonized Transient Cycle) has been reproduced with both iEGR and eEGR modes and the engine performance have been compared in terms of fuel consumption, combustion and NOx emissions.

Development of a Reduced-Order Design/Optimization Tool for Automotive Engines Using Massively Parallel Computing

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Design and optimization of automotive engines present unique challenges on account of the large design space and conflicting constraints. A notable example of such a problem is optimizing the fuel consumption and reducing emissions over the drive cycle of an automotive engine. There are over twenty design variables (including operating conditions and geometry) for the above-mentioned problem. Conducting design, analyses, and optimization studies over such a large parametric space presents a serious computational challenge. The large design parameter space precludes the use of detailed numerical or experimental investigations. Physics-based reduced-order models can be used effectively in the design and optimization of such problems. Since a typical drive cycle is represented by 1500 to 2000 sample data points (engine cycles), it is essential to develop fast and robust computations so that the entire engine cycle computation is done close to real-time speeds (on the order of 100-150 milliseconds). Harnessing the power of high-performance computing, it is possible to perform optimization of automotive drive cycles using massively parallel computations. In this work, we discuss the development of a parallel fast and robust reduced-order modeling tool to compute integrated quantities such as fuel consumption and emissions (NO and CO) over a range of engine drive cycles. As an illustrative example, we perform a massively parallel simulation consisting of 4096 synthetic drive cycles, representative of a fleet of cars. The impact of parameters such as humidity, initial cylinder pressure, inlet air temperature, and residual gas fraction on the performance and emission are presented.

Development of a Template Model and Simulation Approach for Quantifying the Effect of WLTP Introduction on Light Duty Vehicle CO_2 Emissions and Fuel Consumption

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The paper describes the development of a modelling approach to simulate the effect of the new Worldwide harmonized Light duty Test Procedure (WLTP) on the certified CO_2 emissions of light duty vehicles. The European fleet has been divided into a number of segments based on specific vehicle characteristics and technologies. Representative vehicles for each segment were selected. A test protocol has been developed in order to generate the necessary data for the validation of the vehicle simulation models. In order to minimize the sources of uncertainty and the effects of flexibilities, a reference "template model" was developed to be used in the study. Subsequently, vehicle models were developed using AVL Cruise simulation software based on the above mentioned template model. The various components and sub-modules of the models, as well as their input parameters, have been defined with the support of the respective OEMs. Specific strategies have been defined for the implementation of individual technologies affecting fuel consumption such as Start-stop, Brake Energy Recuperation, and Variable Valve Actuation etc. Each vehicle model was validated comparing simulations with measurements for both WLTP and NEDC, achieving accuracies better than 2.5% on the absolute end values for each cycle, and better than 2 g CO_2/km on the difference between the two cycles with respect to the measurements. Finally, a first quantification of the effect of WLTP introduction on CO_2 emissions and fuel consumption of the specific vehicles is attempted.

Knock and Cycle by Cycle Analysis of a High Performance V12 Spark Ignition Engine. Part 1: Experimental Data and Correlations Assessment

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In this paper, a high performance V12 spark-ignition engine is experimentally investigated at test-bench in order to fully characterize its behavior in terms of both average parameters, cycle-by-cycle variations and knock tendency, for different operating conditions. In particular, for each considered operating point, a spark advance sweep is actuated, starting from a knock-free calibration, up to intense knock operation. Sequences of 300 consecutive pressure cycles are measured for each cylinder, together with the main overall engine performance, including fuel flow, torque, and fuel consumption. Acquired data are statistically analyzed to derive the distributions of main indicated parameters, in order to find proper correlations with ensemble-averaged quantities. In particular, the Coefficient of Variation (CoV) of IMEP and of the in-cylinder peak pressure (p_{max}) are correlated to the average combustion phasing and duration (MFB_{50} and $\Delta\theta_b$), with a good coefficient of determination. In addition, a high-pass-filtering technique is used to derive the cycle-by-cycle scattering of the Maximum Amplitude of Pressure Oscillation (MAPO) index. A similar statistical analysis is carried out to derive the log-normal distributions of the MAPO index and a methodology to asses a proper knock threshold is applied to identify the presence of knocking combustion. The above data represent the prerequisites for the implementation and validation of an advanced 1D model, described in Part 2, taking into account cycle-by-cycle variations, and finally aiming to identify the knock-limited spark advance on a completely theoretical basis.

Knock and Cycle by Cycle Analysis of a High Performance V12 Spark Ignition Engine. Part 2: 1D Combustion and Knock Modeling

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The results of the experimental analyses, described in Part 1, are here employed to build up an innovative numerical approach for the 1D modeling of combustion, cycle-by-cycle variations and knock of a high performance 12-cylinder spark-ignition engine. The whole engine is schematized in detail in a 1D framework simulation, developed in the GT-Power™ environment. Proper "in-house developed" sub-models are used to describe the combustion process, turbulence phenomenon, cycle-by-cycle variations (CCV) and knock occurrence. In particular, the knock onset is evaluated by a chemical kinetic scheme for a toluene reference fuel, able to detect the presence of auto-ignition reactions in the end-gas zone. In a first stage, the engine model is validated in terms of overall performance parameter and ensemble averaged pressure cycles, for various full and part load operating points and spark timings. Then, the correlation regarding the maximum in-cylinder pressure distribution developed in Part 1 is here applied to predict representative *faster-then-average* and *slower-than-average* cycles, miming the effects of the experimentally observed CCV. A proper knock index is introduced and evaluated with reference to the above *faster-than-average* cycle. An automatic procedure is implemented to identify the Knock Limited Spark Advance (KLSA), based on the same threshold level utilized in the experimental knock analysis of Part 1. The numerical and experimental KLSA presents an excellent agreement, denoting the accuracy of the proposed combustion and knock modeling.

Analysis of Crank Angle Resolved In-Cylinder Combustion Modeling for Real Time Diesel Engine Simulations

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Mainly due to environmental regulation, future Engine Control Unit (ECU) will be equipped with in-cylinder pressure sensors. The introduction of this innovative solution has increased the number of involved variables, requiring an unceasing improvement in the modeling approaches and in the computational capabilities of Engine Control Unit (ECU). Hardware in the Loop (HIL) test system therefore has to provide in-cylinder pressure in real time from an adequate model. This paper describes a synthesis of our study targeted to the development of in-cylinder crank angle combustion model excluding look up tables, dedicated to HIL test bench. The main objective of the present paper is a comprehensive analysis of a reduced combustion model, applied to a direct injection Diesel engine at varying engine operating range, including single injection and multi injection strategies. The developed model has required an important identification step to calibrate the parameters of the combustion model based on single and double Wiebe function. The difficulty to derive one calibrated model for all engine operations is discussed. This study allows to develop two calibrated combustion models one applied to high engine speeds and the other to low and medium engine speeds. The global model is able to run within one crank angle degree required by real time simulations. The precision of the model is analyzed by comparing in-cylinder pressure traces and ignition delay times at varying engine operating conditions.

A 1D Model for Diesel Sprays under Reacting Conditions

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In this paper, a new 1D combustion model is presented. It is expected to combine good predictive capacities with a contained CPU time, and could be used for engine design. It relies on a eulerian approach, based on Musculus 1D transient spray model. The latter has been extended to model vaporizing, reacting sprays. The general features of the model are first presented. Then various sub models (spray angle and dilatation, vaporization, thermodynamic properties) are detailed. Chemical kinetics are described with a global scheme to keep computational time low.

The spray discretization (mesh) and angle model are first discussed through a sensitivity analysis.

The model results are then compared to experiments from ECN data base (SANDIA) realized in constant volume bombs, for both inert and reacting cases. Some detailed analysis of model results are performed, including comparisons of vaporizing and non-vaporizing cases, as well as inert and reacting cases. Finally some parametric studies are presented, involving the injection pressure, fuel temperature, ambient density, temperature and O_2 concentration. The evolutions of spray vapor penetration, liquid length, lift-off length and ignition delay are studied, as well as bomb pressure evolutions. Quantitative and qualitative agreements are discussed.

Determination of the Kinetic Parameters for the Soot Combustion through a Dynamic Numerical Procedure

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We present an experimental and modelling methodology developed at LGRE research laboratory to characterize soot oxidation in the presence of different atmospheres (NO_2, NO_2/O_2), simulating passive regeneration which occur in a Diesel Particulate Filter (DPF). Based on this methodology which aims at deriving the kinetic parameters for soot combustion, the thermal reactivity of different soot has been studied and compared. Soot were produced from a prototype Liebherr engine and on an engine dynamometer at R&D Moteurs company, under two engine cycles and for two different fuels. Small soot masses (15-30mg) were deposited on the quartz frit of the reactor and submitted to a gas flow (NO_2 or NO_2/O_2), under different temperatures. The mole fractions of NO_2, NO, CO_2 and CO at the reactor outflow were measured by infrared analyzers. The soot oxidation rate and the sample remaining mass were deduced from CO/CO_2 emissions.

In order to determine the intrinsic kinetic parameters for soot combustion, we improved a model already built at LGRE and consisting of a coupled system of five partial differential equations which describe the spatial or the temporal evolutions of the gas mole fractions (NO_2, CO, CO_2 and NO) and of the sample mass. The numerical resolution of this model involves an optimization procedure which determines the best kinetic constants of this model comparing the experimental and the computed (at the reactor outflow) mass loss rates and gas mole densities at different temperatures.

Application of Willans Line Method for Internal Combustion Engines Scalability towards the Design and Optimization of Eco-Innovation Solutions

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Main aim of this paper was to exploit the well-known Willans line method in a twofold manner: indeed, beyond the usual identification of Willans line parameters to enable internal combustion engine scaling, it is also proposed to infer further information from identified parameters and correlations, particularly aiming at characterizing mechanical and frictional losses of different engine technologies. The above objectives were pursued relying on extended experimental performance data, which were gathered on different engine families, including turbo-charged Diesel and naturally aspirated gasoline engines. The matching between Willans line scaled performance and experimental ones was extensively tested, thus allowing to reliably proceed to the subsequent objective of characterizing mechanical losses on the basis of identified Willans parameters. This latter task was accomplished by comparing Willans derived losses to those estimated via the Bishop model, extensively adopted in the related literature to predict such a key performance variable. The comparisons highlight the usefulness of Willans line-based estimation of mechanical losses as a function of engine speed, thus also contributing to adding new exploitation means to a key methodology for optimal design of advanced automotive propulsion systems, in view of prospective diffusion of optimally sized and cost-effective solutions for the reduction of CO_2 emissions, including hybridization devices.

Enhanced Multi-Zone Model for Medium Pressure Injection Spray and Fuel-Wall Impingement in Light-Duty Diesel Engines

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Nowadays the high competition reached by the automotive market forces Original Equipment Manufacturers (OEMs) towards innovative solutions. Strict emission standards and fuel economy targets make the work hard to be accomplished. Therefore modern engines feature complex architecture and embed new devices for Exhaust Gas Recirculation (EGR), turbocharging (e.g. multi-stage compressors), gas after-treatment (e.g. the Selective Catalyst Reduction (SCR)) and fuel injection (either high or low pressure). In this context the Engine Management System (EMS) plays a fundamental role to optimize engine operation. The paper deals with fuel spray and combustion simulation by a multi-zone phenomenological model aimed at the steady-state optimal tuning of the injection pattern. The fuel spray model simulates the fuel-air mixture formation, the in-cylinder gas mixture evolution and accounts for fuel-wall impingement, which usually occurs in case of low-medium injection pressure or advanced injection timing. This feature is fundamental to investigate a wide range of injection timing, as that applied for advanced combustion concepts (i.e. Premixed Charge Compression Ignition (PCCI)). In the model the jet core is divided into many parcels in order to describe the thermal gradient and the chemical composition within the combustion chamber, fundamental to estimate NO_x and soot emissions. The impingement of the spray on cylinder walls is modeled by a zero-dimensional approach simulating dynamics and evaporation of the fuel film with two different semi-empirical models. Model parameters identification and validation have been carried out vs. experimental data measured at the engine test stand on a light-duty Diesel engine, equipped with a Magneti Marelli prototype medium pressure injection system based on a solenoid direct actuation injector.

Study of Pressure Losses of Unsteady Compressible Flows in Three- Way Junctions

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The aim of this paper is to extend the evaluation of the accuracy of published 1-D pressure loss coefficients which are used in 1-D g as dynamics models, in unsteady compressible flows propagating in the exhaust pulses in manifolds. These pressure loss coefficients were derived from the conservation of linear momentum over finite control volumes based on assumptions including steady flow. The objectives of this work were to evaluate the accuracy of the pressure loss coefficients over the type of flows generated by engine-like pressure pulses propagating in a range of three-pipe junctions. The evaluation was performed by reference to results from unsteady, compressible, 3-D Reynolds-averaged computational fluid dynamic (CFD - open source software OpenFOAM) simulations. Two of the junction branches represented the exhaust pipes from two cylinders and the remaining was the outlet pipe. All pipes had a diameter of 25mm with length ratio 1:2 between inlet and outlet. Y junctions of 30° and 60° degrees and a T junction of 60° were tested with a blow-down 1.8bar isothermal pulse at 45Hz as the inlet boundary condition. The results have shown that the temporal pressure loss ‘signal’, as calculated between stations 5 diameters away of each of the junction ends, has also the shape of a pulse. The discrepancies observed with the 1D model occur at the beginning of the pulse and during the deceleration phase for all three geometries tested. For the Y30° discrepancies also occurred in the intermediate regions leading to less satisfactory results.

Soot Source Term Tabulation Strategy for Diesel Engine Simulations with SRM

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In this work a soot source term tabulation strategy for soot predictions under Diesel engine conditions within the zero-dimensional Direct Injection Stochastic Reactor Model (DI-SRM) framework is presented. The DI-SRM accounts for detailed chemistry, in-homogeneities in the combustion chamber and turbulence-chemistry interactions. The existing implementation [1] was extended with a framework facilitating the use of tabulated soot source terms. The implementation allows now for using soot source terms provided by an online chemistry calculation, and for the use of a pre-calculated flamelet soot source term library. Diesel engine calculations were performed using the same detailed kinetic soot model in both configurations. The chemical mechanism for n-heptane used in this work is taken from Zeuch et al. [2] and consists of 121 species and 973 reactions including PAH and thermal NO chemistry. The engine case presented in [1] is used also for this work. The case is a single-injection part-load passenger car Diesel engine with 27 % EGR fueled with regular Diesel fuel. The two different approaches are analyzed and a detailed comparison is presented for the different soot processes globally and in the mixture fraction space. The contribution of the work presented in this paper is that a method which allows for a direct comparison of soot source terms - calculated online or retrieved from a flamelet table - without any change in the simulation setup has been developed within the SRM framework. It is a unique tool for model development. Our analysis supports our previous conclusion [1] that flamelet soot source terms libraries can be used for multi-dimensional modeling of soot formation in Diesel engines.

Investigation on the Potential of Quantitatively Predicting CCV in DI-SI Engines by Using a One-Dimensional CFD Physical Modeling Approach: Focus on Charge Dilution and In-Cylinder Aerodynamics Intensity

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Increasingly restrictive emission standards and CO_2 targets drive the need for innovative engine architectures that satisfy the design constraints in terms of performance, emissions and drivability. Downsizing is one major trend for Spark-Ignition (SI) engines. For downsized SI engines, the increased boost levels and compression ratios may lead to a higher propensity of abnormal combustions. Thus increased levels of Exhaust Gas Recirculation (EGR) are used in order to limit the appearance of knock and super-knock. The drawback of high EGR rates is the increased tendency for Cycle-to-Cycle Variations (CCV) it engenders. A possible way to reduce CCV could be the generation of an increased in-cylinder turbulence to accelerate the combustion process. To manage all these aspects, 1D simulators are increasingly used. Accordingly, adapted modeling approaches must be developed to deal with all the relevant physics impacting combustion and pollutant emissions formation. In this study, a CCV modeling approach for system simulation integrated into the 12 gas CFM1D combustion model has been used to reproduce CCV in a downsized Direct Injection (DI) - SI single cylinder engine. The CCV model was developed by integrating physical understanding gained from 3D CFD based on a Large-Eddy Simulation (LES) approach. The experimental database includes a complete engine map, single-parameter variations of dilution rate as well as standard and increased aerodynamics operating conditions. Once the CCV model was calibrated, it was applied to simulate CCV over the complete experimental database and showed a good reproduction of experimental observations. As a result of using a physics based CCV model, it was possible to acquire some understanding of the reasons for the observed combustion variability from the performed simulations. Finally, with the perspective of using the model for engine control applications, its potential to run in Real Time (RT) was evaluated.

Spark Ignition Engine Simulation Using a Flamelet Based Combustion Model

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Three-dimensional Computational Fluid Dynamics (CFD) has become an integral part in analysing engine in-cylinder processes since it provides detailed information on the flow and combustion, which helps to find design improvements during the development of modern engine concepts. The predictive capability of simulation tools depends largely on the accuracy, fidelity and robustness of the various models used, in particular concerning turbulence and combustion. In this study, a flamelet model with a physics based closure for the progress variable dissipation rate is applied for the first time to a spark ignited IC engine. The predictive capabilities of the proposed approach are studied for one operating condition of a gasoline port fuel injected single-cylinder, four-stroke spark ignited full-metal engine running at 3,500 RPM close to full load (10 bar BMEP) at stoichiometric conditions. The combustion model employs pre-calculated unstrained laminar flamelet libraries parametrised by the reaction progress variable, its variance, the unburnt mixture temperature and pressure. The look-up tables are generated using both a skeletal (29 species and 49 reactions) and a detailed (1,389 species and 5,935 reactions) mechanisms for iso-octane - air combustion to study the influence of chemical kinetics. A simple“energy deposition” approach has been adopted as a first step to model spark ignition and its impact on the results is discussed. The sensitivities of the results to the calculation of the unburnt mixture temperature and the temperature increment used in the look-up table are also investigated. The predicted pressure variations show fair agreement in view of the first application of the model to IC engines and a comparison of this result with those

obtained using the level-set approach is discussed. Despite the observed sensitivities to the ignition treatment, the unburnt mixture temperature calculation and the chemical kinetics, this first application shows considerable promise of the proposed flamelet approach to model premixed combustion in IC engines.

LES Modelling of Spark-Ignition Cycle-to-Cycle Variability on a Highly Downsized DISI Engine

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The paper reports an activity aiming at characterizing cycle-to-cycle variability (CCV) of the spark-ignition (SI) process in a high performance engine. The numerical simulation of spark-ignition and of early flame kernel evolution are major challenges, mainly due to the time scales of the spark discharge process and to the reduced spatial scales of flame kernel. Typical mesh resolutions are insufficient to resolve the process and a dedicated treatment has to be provided at a subgrid level if the ignition process is to be properly modelled. The focus of this work is on the recent ISSIM-LES (Imposed Stretch Spark-Ignition Model) ignition model, which is based on an extension of the flame surface density (FSD) transport equation for a dedicated flame kernel treatment at subgrid scales. The FSD equation is solved immediately after spark discharge. The interaction of the flame kernel with the flow field is fully accounted for since spark formation and a transition is provided from ignition to propagation phase. The comparison is carried out with the AKTIM-Euler ignition model in terms of flame interaction with the flow field (e.g. arc convection, flame blow-off, flame holder effect). A multiple cycle LES activity provided a set of cycle-resolved conditions for spark-ignition comparisons, and the flame kernel development is carefully analyzed for the two ignition models on a wide range of thermo-physical conditions. Spark-ignition cyclic variability and combustion traces are compared with experiments. Results confirm that the simulated cycle-to-cycle variability increases through the adoption of the ISSIM-LES ignition model.

Measurements of the Intake and In-Cylinder Flow Field to Investigate the Reliability of CFD Steady-State Simulations for Actual Engines

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The design of intake manifolds and valve ports in internal combustion engines is a fundamental aspect of obtaining high volumetric efficiency and originating in-cylinder flows of proper intensity. CFD calculations using the RANS approach may support steady-state flow measurements in the design of intake manifolds, valve passages, and combustion chambers. On the other hand, the geometrical complexity of these engine parts hardly allows to mesh them by means of fully hexahedral grids and the accuracy of computations is strongly compromised.

The paper presents the results of an experimental and numerical study performed on the head of a motorbike high-speed spark ignition engine. The work aims at investigating the reliability of CFD RANS computations performed on polyhedral grids of different size and assessing the mesh size required for accurate computations on such a type of grid.

Discharge flow coefficients of the intake valves, in-cylinder tumble intensity, and static pressure along the surface of intake manifolds have been measured in a discharge flow test rig operating in steady-state conditions. Detailed geometry of actual bell-mouth inlet, intake ports and valves, combustion chamber roof, and cylinder wall has been obtained by using a reverse engineering technique. The geometry is used to build a CFD model which allowed to simulate the steady flow field measured during the experiments for several values of valve lift.

Image Processing for Early Flame Characterization and Initialization of Flamelet Models of Combustion in a GDI Engine

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Ignition and flame inception are well recognised as affecting performance and stable operation of spark ignition engines. The very early stage of combustion is indeed the main source of cycle-to-cycle variability, in particular in gasoline direct injection (GDI) engines, where mixture formation may lead to non-homogenous air-to-fuel distributions, especially under some speed and load conditions. From a numerical perspective, 3D modelling of combustion within Reynolds Averaged Navier Stokes (RANS) approaches is not sufficient to provide reliable information about cyclic variability, unless proper changes in the initial conditions of the flow transport equations are considered. Combustion models based on the flamelet concept prove being particularly suitable for the simulation of the energy conversion process in internal combustion engines, due to their low computational cost. These models include a transport equation for the flame surface density, which needs proper initialization. A flame collocation is indeed to be properly made when starting the calculations, often just based on the user's skill and without resorting to any quantitative data derived from experiments. However, the way to define initial conditions for cyclic variability prediction is often based on just statistical considerations. This work aims at exploiting information derived from images collected in a single cylinder 4-stroke GDI engine to properly collocate the flame at the start of the combustion calculation. The considered engine is optically accessible through a wide fused-silica window fixed on the piston crown having a Bowditch design. Image processing methodologies are applied to evaluate local and integral luminous intensity, and flame morphology parameters. The collected data allows improving the numerical simulation and gaining hints about the main parameters defining the engine cyclic variability.

Numerical Study on the Multiple Injection Strategy in Diesel Engines using a Modified 2-D Flamelet Model

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The flamelet model is a widely used combustion model that demonstrates a good prediction of non-premixed combustion. In this model, the chemical time scales are considered to be smaller compared to those of the turbulence, which allows the heat and mass transfer equation to be decoupled from the flow equation. However, the model's dependency on the mixture fraction limits the combustion analysis to a single injection. To overcome this limitation, a two dimensional flamelet model, which uses two mixture fraction variables, was introduced to represent the non-premixed combustion of multiple injections. However, the model's computational time drastically increased due to the expansion of the solution domain. Thus, a modified 2-D flamelet model was introduced to reduce the computational time of the two dimensional flamelet model. In this model, the 2-D flamelet equations were only solved near the stoichiometric region; the other regions were changed to those of the steady-state 1-D flamelet solution if they were ignited. The objective of this study is to extend the modified 2-D flamelet model to three or more injection strategies without increasing the computational costs. A few multiple injection strategies (pilot-pilot-main/pilot-pilot-main-post) were applied to a multi-cylinder engine. Two operating conditions (1500/4, 1500/6, [rpm/bar]) were tested, and the simulation results of the pressure and the HRR using the modified 2-D flamelet model were compared with the experimental data. Lastly, the combustion and emission characteristics of each injection strategy were determined, and the model demonstrated a good agreement with the experimental results.

CFD Analysis of the Effects of Fuel Composition and Injection Strategy on Mixture Preparation and Fuel Deposit Formation in a GDI Engine

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In spark-ignited direct-injected engines, the formation of fuel pools on the piston is one of the major promoters of unburnt hydrocarbons and soot: in order to comply with the increasingly stringent emission regulations (EU6 and forthcoming), it is therefore necessary to limit fuel deposit formation. The combined use of advanced experimental techniques and detailed 3D-CFD simulations can help to understand the mechanisms driving fuel pool formation. In the paper, a combined experimental and numerical characterization of pool formation in a GDI engine is carried out to investigate and understand the complex interplay of all the mentioned factors. In particular, a low-load low-rpm engine operation is investigated for different ignition phasing, and the impact of both fuel formulation and instantaneous piston temperature variations in the CFD analyses are evaluated. The investigated engine operation shows some interesting features which are suited to deeply investigate the interplay between fuel film formation, mixing and soot. In particular, the relatively low wall temperature and low injection pressure allow the fuel to form deposits and then slowly evaporate, with possible presence of liquid fuel at the time of ignition. The simultaneous presence of slow fuel evaporation, reduced turbulence and presence of liquid fuel leads to the formation of extremely rich mixture pockets (with equivalence ratios well above 5) which are the major promoters for soot inception.

Four different start of injection (hereafter SOI) values are analyzed, for which tailpipe Soot concentration measurements are available. For one SOI value, two different injection profiles are also evaluated. In particular, the analyses focus on the formation of fuel pads on the combustion chamber walls and on the

mixture stratification, and a correlation between these two factors and the tailpipe soot level is found.

The proposed methodology proves to be able to capture the Soot trend for the different SOI values without simulating the combustion process; it is therefore promising since it avoids the need for a dedicated calibration of the combustion model parameters and provides reasonable results (at least in terms of trends) with limited computational resources.

Partially Stratified Charge Natural Gas Combustion: The Impact of Uncertainties on LES Modeling

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The aim of this work is to carry out statistical analyses on simulated results obtained from large eddy simulations (LES) to characterize spark-ignited combustion process in a partially premixed natural gas mixture in a constant volume combustion chamber (CVCC). Inhomogeneity in fuel concentration was introduced through a fuel jet comprising up to 0.6 per cent of the total fuel mass, in the vicinity of the spark ignition gap. The numerical data were validated against experimental measurements, in particular, in terms of jet penetration and spread, flame front propagation and overall pressure trace. Perturbations in key flow parameters, namely inlet velocity, initial velocity field, and turbulent kinetic energy, were also introduced to evaluate their influence on the combustion event. A total of 12 simulations were conducted. The results show how the perturbations affect flame front propagation, although the ensemble average shows that the position of the flame front can still be reasonably predicted with a single simulation. It has been also highlighted the role of turbulence in the evolution of the combustion process. This demonstrates the accuracy of LES in simulating such combustion process, a key step towards its application on more complex problems such as direct injection engines.

Analysis of the Mixture Formation at Partial Load Operating Condition: The Effect of the Throttle Valve Rotational Direction

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In the next incoming future the necessity of reducing the raw emissions leads to the challenge of an increment of the thermal engine efficiency. In particular it is necessary to increase the engine efficiency not only at full load but also at partial load condit ions. In the open literature very few technical papers are available on the partial load conditions analysis. In the present paper the analysis of the effect of the throttle valve rotational direction on the mixture formation is analyzed. The engine was a PFI 4-valves motorcycle engine. The throttle valve opening angle was 17.2°, which lays between the very partial load and the partial load condition. The CFD code adopted for the analysis was the FIRE AVL code v. 2013.2. The exhaust, intake and compression phases till TDC were simulated: inlet/outlet boundary conditions from 1D simulations were imposed. The injection system operation was experimentally investigated in terms of spray shape and drop sizing and veloci ty for a proper tuning of the numerical model. The injection process was modelled and the final results in terms of mixture compositi on and turbulence level at the ignition time were investigated. The aim of the paper was to deeply analyze the dynamic effect of the throttle valve position on the engine behavior. The wallfilm effect on the effective mixture formation process was considered by means a new methodological approach.

The wallfilm thickness and its dynamics affect the final mixture formation process and the level of the mixture index at the ignition time close to the spark plug. It is also necessary to consider that, even though the CFD simulations were RANS simulations, it could take some days for reaching the converged wallfilm thickness, even 20 or more engine cycles at full load conditions could be

necessary. The research group proposed a new methodological approach for facing this problem within a computational time compatible with industrial applications too.

Dual Fuel Diesel Engine at Variable Operating Conditions: A Numerical and Experimental Study

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The dual-fuel (diesel/natural gas, NG) concept represents a solution to reduce emissions from diesel engines by using natural gas as an alternative fuel. As well known, the dual-fuel technology has the potential to offer significant improvements in the emissions of carbon dioxide from light-duty compression ignition engines. A further important requirement of the DF operation in automotive engines is a satisfactory response in a wide range of load levels. In particular, the part-load levels could present more challenging conditions for an efficient combustion development, due to the poor fuel/air ratio.

Basing on the above assumptions, the authors discuss in this article the results of a combined numerical and experimental study on the effect of different injection timings on performance and pollutant fractions of a common rail diesel engine supplied with natural gas and diesel oil. The study of dual-fuel engines that is carried out in this paper aims at the evaluation of the CFD capability to analyze the main phenomena that characterize this particular technology. Actually, in order to put into evidence the key processes that take place during the dual-fuel operation, say the typical flame propagation throughout the premixed methane-air medium that is activated by the early self-ignition of the diesel fuel, the fluid-dynamic calculations are extremely useful.

The different conditions have been induced by changes in the operating parameter setting; in particular, the tests have been performed by varying the injection timing for a fixed NG ratio, both at full and at part load. Actually, the start of the liquid fuel injection can considerably influence the combustion development and therefore THC and NOx fractions production. The calculations have been validated with the experimental data and a comparison

between diesel and dual fuel diesel/CNG operation has been made, in terms of performance and pollutant levels. A detailed description of the phenomena that govern the engine response at several operating conditions and at different load levels is then provided.

Experimental and Numerical Investigation of the Effect of Split Injections on the Performance of a GDI Engine Under Lean Operation

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Gasoline direct injection (GDI) allows flexible operation of spark ignition engines for reduced fuel consumption and low pollutants emissions. The choice of the best combination of the different parameters that affect the energy conversion process and the environmental impact of a given engine may either resort to experimental characterizations or to computational fluid dynamics (CFD). Under this perspective, present work is aimed at discussing the assessment of a CFD-optimization (CFD-O) procedure for the highest performance of a GDI engine operated lean under both single and double injection strategies realized during compression.

An experimental characterization of a 4-stroke 4-cylinder optically accessible engine, working stratified lean under single injection, is first carried out to collect a set of data necessary for the validation of a properly developed 3D engine model. Homogeneous lean operation is not considered due to the consequent high instability of the engine under study as injection is too much advanced. The 3D engine model is used to explore the main advantages deriving from modulating injection on the engine power output and the main pollutants formation. The model is then exploited to perform an optimization analysis searching for the injection and spark advance synchronization within the working cycle being optimal for the combustion development.

Numerical simulations allow clarifying the effects of multiple injections on the engine power output and the NO and CO emissions, besides offering the way to study the combustion process and the occurrence of the adverse phasing deriving from variations of the spark timing. The obtained results are finally used to drive a further experimental campaign that substantially confirms the main conclusions of the CFD-O, at least qualitatively.

Some Developments in DES Modeling for Engine Flow Simulation

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Scale-resolving turbulence modeling for engine flow simulation has constantly increased its popularity in the last decade. In contrast to classical RANS modeling, LES-like approaches are able to resolve a larger number of unsteady flow features. In principle, this capability allows to accurately predict some of the key parameters involved in the development and optimization of modern engines such as cycle-to-cycle variations in a DI engine. However, since multiple simulated engine cycles are required to extract reliable flow statistics, the spatial and temporal resolution requirements of pure LES still represent a severe limit for its wider application on realistic engine geometries. In this context, Hybrid URANS-LES methodologies can therefore become a potentially attractive option. In fact, their task is to preserve the turbulence scale-resolving in the flow core regions but at a significantly lower computational cost compared to standard LES. In this paper, we present our achievements in the development of an original hybrid simulation method which relies on the Detached Eddy Simulation (DES) concept applied to a reformulated two-equation turbulence model. The resulting method has been implemented in the open-source CFD toolbox OpenFOAM® and initially assessed against a standard freely decaying turbulent flow case with considerations on the numerical schemes optimal choice. Subsequently, the proposed model has been applied on geometries presenting different levels of complexity, mimicking some of the typical flow conditions encountered at an engine intake port. The current numerical predictions have been compared with the available experimental data as well as with previous computational studies performed on the same flow configurations.

Capturing Cyclic Variability in SI Engine with Group Independent Component Analysis

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Data decomposition techniques have become a standard approach for the analysis of 2D imaging data originating from optically accessible internal combustion engines. In particular, the method of Proper Orthogonal Decomposition (POD) has proven to be a valuable tool for the evaluation of cycle-to-cycle variability based on luminous combustion imaging and particle image velocimetry (PIV) measurements. POD basically permits to characterize the dominant structures of the process under consideration. Recently, an alternative procedure based on Independent Component Analysis (ICA) has been introduced in the engine field. Unlike POD, the method of ICA identifies the patterns corresponding to physical processes that are statistically *independent*. In this work, a Group-ICA approach is applied to 2D cycle-resolved images of the luminosity emitted by the combustion process. The analysis is meant to characterize cyclic variability of a port fuel injection spark ignition (PFI SI) engine. For example, any flame front ignited independently by a hot spot is expected to behave independently from the other observed flames. In the Group-ICA approach, image sequences collected synchronically over a number of cycles are grouped together and then analyzed to identify common independent components. These should correspond to the independent phenomena underlying the combustion process at the group level. By this way, a projection is implicitly defined that permits the reconstruction of each member of the group (cycle) through the independent components and their coefficients. The successive analysis of the associated time courses (coefficients), specific for each cycle, permits to capture and discuss differences among cycles.

Spray and Soot Formation Analysis by Means of a Quasi-Dimensional Multizone Model in a Single Cylinder Diesel Engine under Euro 4 Operating Conditions

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An investigation has been carried out on the spray penetration and soot formation processes in a research diesel engine by means of a quasi-dimensional multizone combustion model.

The model integrates a predictive non stationary 1D spray model developed by the Sandia National Laboratory, with a diagnostic multizone thermodynamic model, and is capable of predicting the spray formation, combustion and soot formation processes in the combustion chamber.

The multizone model was used to analyze three operating conditions, i.e., a zero load point (BMEP = 0 bar at 1000 rpm), a medium load point (BMEP = 5 bar at 2000 rpm) and a medium-high load point (BMEP = 10 bar at 2000 rpm). These conditions were experimentally tested in an optical single cylinder engine with the combustion system configuration of a 2.0L Euro4 GM diesel engine for passenger car applications.

The experimental spray tip penetration and spreading angle were evaluated on the basis of images acquired by means of a high-speed CCD camera, while the experimental trend of the in-cylinder soot concentration was derived by means of the two-color pyrometry method.

The acquired experimental data have allowed useful information to be obtained for the assessment of the multizone model. Well-defined trends between some of the model parameters and the engine operating conditions (namely, speed and load) have been found and preliminary correlations have been developed.

Soot Quantification of Single-Hole Diesel Sprays by Means of Extinction Imaging

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A radiation-based 2-color method (2C) and light extinction imaging (LEI) have been performed simultaneously to obtain two-dimensional soot distribution information within a diesel spray flame. All the measurements were conducted in an optically accessible two-stroke engine equipped with a single-hole injector. The fuel used here is a blend of 30% Decane and 70% Hexadecane (in mass). According to previous research, operating conditions with three different flame soot amounts were investigated.

The main purpose of this work is to evaluate the two soot diagnostics techniques, after proper conversion of soot-related values from both methods. All the KL extinction values are lower than the saturation limit. As expected, both techniques show sensitivity with the parametric variation. The soot amount increases with higher ambient gas temperature and lower injection pressure. However, the LEI technique presents more sensitivity to the soot quantity. Differences in the KL value on the spray axis between LEI and 2C increase with higher soot quantity.

Comparison of the Lift-Off Lengths Obtained by Simultaneous OH-LIF and OH* Chemiluminescence Imaging in an Optical Heavy-Duty Diesel Engine

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The presence of OH radicals as a marker of the high temperature reaction region usually has been used to determine the lift-off length (LOL) in diesel engines. Both OH Laser Induced Fluorescence (LIF) and OH* chemiluminescence diagnostics have been widely used in optical engines for measuring the LOL. OH* chemiluminescence is radiation from OH being formed in the exited states (OH*). As a consequence OH* chemiluminescence imaging provides line-of-sight information across the imaged volume. In contrast, OH-LIF provides information on the distribution of radicals present in the energy ground state. The OH-LIF images only show OH distribution in the thin cross-section illuminated by the laser. When both these techniques have been applied in earlier work, it has often been reported that the chemiluminescence measurements result in shorter lift-off lengths than the LIF approach. In order to investigate this discrepancy this work presents a dedicated comparison of the LOL obtained from these two diagnostic techniques. In diesel engines, the cycle-to-cycle variations in lift-off region are usually significant. To avoid misinterpretations caused by these variations simultaneous measurements are needed. The statistical analysis based on our simultaneous data can conclude that the OH-LIF method yields longer LOL than the OH* chemiluminescence method by a smaller sample size and more precisely than non-simultaneous data. This can be partially explained by the 3D geometry and flame axis asymmetry effects. A numerical simulation with OH and OH* distribution was performed for the comparison. It shows a great agreement with the experimental results in this study.

Towards the Development of the In-Cylinder Pressure Measurement Based on the Strain Gauge Technique for Internal Combustion Engines

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A simple, cheap and effective way of measuring the pressure inside the cylinders of internal combustion engines is proposed in this paper. It is well known that the in-cylinder pressure is one of the most significant variables describing the combustion status in internal combustion engines; therefore, if the measured value of the actual pressure in the combustion chamber is used as a feedback variable for closed loop monitoring and control techniques, it will be possible both to improve engine performances and to reduce fuel consumptions and emissions. However, to date such a pressure-based control strategy has been limited by costs, reliability and lifetime of commercially available cylinder pressure sensors.

To overcome these limitations, the present paper proposes a very simple and low cost experimental device for measuring the pressure inside the combustion chamber, developed for engine control and monitoring applications. The sensor exploits the strain measurements of the external walls of engine cylinders, which are indicative of the pressure information during the combustion process. The measurement is carried out by means of strain gauges attached to the external wall of the cylinders inside the water channels of the cylinder block. This location has been selected because it minimizes the temperature variations induced by different loads and engine speeds.

This study presents a feasibility analysis of the system. Preliminary tests were initially conducted on a hydraulic cylinder and subsequently on an internal combustion engine. The analysis shows that the proposed method has the potential to predict the internal cylinder pressure accurately, thus representing an interesting contribution for the development of low-cost engine management systems. The robustness of the proposed solution has the potential to be very high, as the concept is based on strain gauges. Forthcoming experimental

investigations on a fired engine under regular engine operating conditions will aim at assessing the capability of the proposed method over various loads, frequencies and thermal conditions.

Remote Combustion Sensing Methodology for PCCI and Dual-Fuel Combustion Control

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The increasing request for pollutant emissions reduction spawned a great deal of research in the field of innovative combustion methodologies, that allow obtaining a significant reduction both in particulate matter and NOx emissions. Unfortunately, due to their nature, these innovative combustion strategies are very sensitive to in-cylinder thermal conditions. Therefore, in order to obtain a stable combustion, a closed-loop combustion control methodology is needed.

Prior research has demonstrated that a closed-loop combustion control strategy can be based on the real-time analysis of in-cylinder pressure trace, that provides important information about the combustion process, such as Start (SOC) and Center of combustion (CA50), pressure peak location and torque delivered by each cylinder. Nevertheless, cylinder pressure sensors on-board installation is still uncommon, due to problems related to unsatisfactory measurement long term reliability and cost.

In order to overcome the issues related to in-cylinder pressure measurement, this paper demonstrates that the indicated quantities used in closed-loop control strategies can be accurately estimated using low-cost reliable sensors, such as accelerometers or crankshaft speed sensors. In this paper, an overall methodology for indicated quantities estimation has been applied both to PCCI and Dual-Fuel combustion. These innovative combustion methodologies have been performed using a light-duty Common-Rail Diesel engine. The algorithms proved to be suitable for real-time indicated quantities estimation in both cases.

Electric Feed Pump Simulation and Control for Fuel Saving and System Cost Reduction

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Current market drivers for automotive and light commercial engines and powertrain systems are mainly the new CO2 emission regulations all over the world and the pollutant emission reduction in the emerging markets, at minimal system cost. For both reasons, the adoption of a regulated electric low pressure fuel pump is very advantageous for electronically controlled diesel systems, customized for the emerging markets. Usually, the fuel delivery from the feed pump is performed at the maximum flow rate and a pressure regulator discharges the exceeding fuel amount either from the rail or upstream the high pressure pump.

Therefore, at part load, the electric feed pump flow is higher than the request for engine power generation. For the purpose of this paper, the low pressure fuel pump is controlled for fuel delivery according to the engine request (reduced fuel consumption), thus avoiding the use of a pressure regulator valve (reduced cost). The development of the system was carried out with an SIL approach, by simulating the performance of the ECU control on a validated plant model, thus also reducing the costs related to engine testing. The performance of the rail pressure control was compared to the state-of-the-art systems. A sensitivity analysis to system parameters dispersion was also carried out, to verify the feasibility on actual system and the constraints. Then, the control was tested at the engine bench for a preliminary tuning and evaluation of the fuel saving.

Assessment of the Influence of GDI Injection System Parameters on Soot Emission and Combustion Stability through a Numerical and Experimental Approach

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The next steps of the current European and US legislation, EURO 6c and LEV III, and the incoming new test cycles will impose more severe restrictions on pollutant emissions for Gasoline Direct Injection (GDI) engines. In particular, soot emission limits will represent a challenge for the development of this kind of engine concept, if injection and after-treatment systems costs are to be minimized at the same time. The paper illustrates the results obtained by means of a numerical and experimental approach, in terms of soot emissions and combustion stability assessment and control, especially during catalyst-heating conditions, where the main soot quantity in the test cycle is produced. A number of injector configurations has been designed by means of a CAD geometrical analysis, considering the main effects of the spray target on wall impingement. The numerical CFD simulation has helped the definition of the injection system and of its control settings for a given operating condition, in terms of start of injection, injection pressure and number of pulses per stroke. Engine test bench experiments have finally been used to validate the numerical results, and to further optimize the injection system calibration in order to minimize soot emissions, while respecting combustion stability constraints. The main results are presented in the paper.

Cylinder Pressure-Based Closed Loop Combustion Control: A Valid Support to Fulfill Current and Future Requirements of Diesel Powertrain Systems

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The strategies adopted to control the combustion in Diesel applications play a key role when dealing with current and future requirements of automotive market for Diesel powertrain systems. The traditional “open loop” control approach aims to achieve a desired combustion behaviour by indirect manipulation of the system boundary conditions (e.g. fresh air mass, fuel injection). On the contrary, the direct measurement of the combustion process, e.g. by means of in-cylinder pressure sensor, offers the possibility to achieve the same target “quasi” automatically all over the vehicle lifetime in widely different operating conditions.

Beside the traditional combustion control in closed loop (i.e. based on inner torque and/or combustion timing), the exploitation of in-cylinder pressure signal offers a variety of possible further applications, e.g. smart detection of Diesel fuel quality variation, control of combustion noise, modeling engine exhaust emission (e.g. NO_x). Such advanced cylinder pressure-based control concepts can support the development of Diesel powertrain systems, taking into account recent trends characterized by an increasing system complexity, additional degrees of freedom related to e.g. real world driving emissions (RDE) procedure or penetration of opening markets, as well as an increasing attention paid by modern OEMs towards the development efficiency (time/costs optimization).

In this contribution an overview about the on-going development activities is given and the deriving benefits are illustrated with the support of experimental results.

Simultaneous Control of Combustion Timing and Ignition Delay in Multi-Cylinder Partially Premixed Combustion

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In low-temperature combustion concepts such as partially premixed combustion, the ignition delay should be large enough in order to ensure sufficient fuel and air mixing before the start of combustion. It is also necessary that the combustion timing is sufficiently well phased for high thermal efficiency.

Since the ignition delay and combustion timing are intimately coupled, the decoupling of these two quantities gives rise to an interesting multiple input, multiple output control problem where the control of the air system and the fuel injection system have to be combined. In a multi-cylinder engine this problem becomes underdetermined or uncontrollable with more outputs than inputs.

This article investigates model-based cycle-to-cycle cylinder-individual closed-loop control of the ignition delay and the combustion phasing in a multi-cylinder heavy-duty DI engine running on a gasoline fuel mixture. The controller design of choice was model predictive control (MPC) which is a suitable design for multiple input/output systems with actuator constraints. Ignition delay and combustion phasing were extracted from cooled in-cylinder pressure sensors and controlled by manipulating injection timings, the gas mixture temperature and exhaust-gas recirculation (EGR) ratio using a dual EGR-path system and a fast thermal-management (FTM) system.

Nonlinear MIMO Data-Driven Control Design for the Air and Charging Systems of Diesel Engines

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Emission requirements for diesel engines are becoming increasingly strict, leading to the increase of engine architecture complexity. This evolution requires a more systematic approach in the development of control systems than presently adopted, in order to achieve improved performances and reduction of times and costs in design, implementation and calibration. To this end, large efforts have been devoted in recent years to the application of advanced Model-Based MIMO control systems.

In the present paper a new MIMO nonlinear feedback control is proposed, based on an innovative data-driven method, which allows to design the control directly from the experimental data acquired on the plant to be controlled. Thus, the proposed control design does not need the intermediate step of a reliable plant model identification, as required by Model-Based methods. In this way, significant advantages over Model-Based methods can be achieved in terms of times and costs in design and deployment as well as in terms of control performances. The method is applied to the control design for the air and charging systems, using experimental data measured on a four cylinder diesel engine with single stage turbocharger. The performances of the designed controller are evaluated on an accurate nonlinear engine model, showing significant reductions of up to 2.7 times for the intake manifold pressure, up to 2.7 times for the oxygen concentration tracking errors and about 4 times in controller design and calibration efforts with respect to a decoupled-gain-scheduled PID controller typically applied for the air charging system control of diesel engines.

Offline and Real-Time Optimization of EGR Rate and Injection Timing in Diesel Engines

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New methodologies have been developed to optimize EGR rate and injection timing in diesel engines, with the aim of minimizing fuel consumption (FC) and NO_x engine-out emissions.

The approach entails the application of a recently developed control-oriented engine model, which includes the simulation of the heat release rate, of the in-cylinder pressure and brake torque, as well as of the NO_x emission levels. The engine model was coupled with a C-class vehicle model, in order to derive the engine speed and torque demand for several driving cycles, including the NEDC, FTP, AUDC, ARDC and AMDC.

The optimization process was based on the minimization of a target function, which takes into account FC and NO_x emission levels. The selected control variables of the problem are the injection timing of the main pulse and the position of the EGR valve, which have been considered as the most influential engine parameters on both fuel consumption and NO_x emissions. The gear number has also been selected for optimization.

One benchmark tool, which is based on the dynamic programming technique, and one real-time tool, which implements a static optimization method, have been developed for the optimization process. A new mathematical technique has been introduced and applied in order to decrease the computational time of the optimizers to a great extent.

It was verified that the real-time method has the potential of being implemented in the engine control unit (ECU), in order to realize an onboard optimization of the selected engine and vehicle parameters.

Turbocharger Control-Oriented Modeling: Twin-Entry Turbine Issues and Possible Solutions

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The paper presents possible solutions for developing fast and reliable turbocharger models, to be used mainly for control applications. This issue is of particular interest today for SI engines since, due to the search for consistent CO2 reduction, extreme downsizing concepts require highly boosted air charge solutions to compensate for power and torque de-rating. For engines presenting at least four in-line cylinders, twin-entry turbines offer the ability of maximizing the overall energy conversion efficiency, and therefore such solutions are actually widely adopted.

This work presents a critical review of the most promising (and recent) modeling approaches for automotive turbochargers, highlighting the main open issues especially in the field of turbine models, and proposing possible improvements. The main original contribution is then on solving specific issues related to the twin-entry turbine, to develop a control-oriented model able to predict the machine behavior under all possible admission conditions.

The results of this study have been applied to a V8 high-performance GDI engine with twin-entry turbochargers. Experimental data are shown throughout the paper, to demonstrate the benefits of the proposed approach.

Real Time Control of GDI Fuel Injection during Ballistic Operation Mode

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Gasoline direct injection (GDI) combustion with un-throttled lean stratified operation allows to reduce engine toxic emissions and achieve significant benefits in terms of fuel consumption. However, use of gasoline stratified charges can lead to several problems, such as a high cycle-to-cycle variability and increased particle emissions. Use of multiple injection strategies allows to mitigate these problems, but it requires the injection of small fuel amounts forcing the traditional solenoid injectors to work in their “ballistic” region, where the correlation between coil energizing time and injected fuel amount becomes highly not linear.

In the present work a closed-loop control system able to manage the delivery of small quantities of fuel has been introduced. The control system is based on a particular feature found on the coil voltage command signal during the de-energizing phase. On the basis of this feature, the injector needle closing time and then, in turn, the actual amount of fuel injected can be calculated.

Results showed that the proposed control system, through a proper management of ballistic injections, has the potential to increase the minimum fuel injection capabilities of GDI solenoid injectors.

Engine Modeling and Diagnostics

Engine Combustion

Fuels and Lubricants

Exhaust Aftertreatment and Emissions

New Engines, Components, Actuators, & Sensors

Hybrid and Electric Powertrains

Relating Knocking Combustions Effects to Measurable Data

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Knocking combustions heavily influence the efficiency of Spark Ignition engines, limiting the compression ratio and sometimes preventing the use of Maximum Brake Torque (MBT) Spark Advance (SA).
A detailed analysis of knocking events can help in improving the engine performance and diagnostic strategies. An effective way is to use advanced 3D Computational Fluid Dynamics (CFD) simulation for the analysis and prediction of the combustion process. The standard 3D CFD approach based on RANS (Reynolds Averaged Navier Stokes) equations allows the analysis of the average engine cycle. However, the knocking phenomenon is heavily affected by the Cycle to Cycle Variation (CCV): the effects of CCV on knocking combustions are then taken into account, maintaining a RANS CFD approach, while representing a complex running condition, where knock intensity changes from cycle to cycle. The focus of the numerical methodology is the statistical evaluation of the local air-to-fuel and turbulence distribution at the spark plugs and their correlation with the variability of the initial stages of combustion.
CFD simulations have been used to reproduce knock effect on the in-cylinder pressure trace. For this purpose, the CFD model has been validated, proving its ability to predict the combustion evolution with respect to SA variations, from non-knocking up to heavy knocking conditions.
The CFD model allowed relating measurable data (i.e., the simulated cylinder pressure signal) to other factors, representative of the phenomena actually taking place during knocking combustions: for each cell used in the CFD simulation, information such as pressure, heat release, etc. are available and can be traced over the angular domain. Furthermore, the analysis refers to hundredths of engine cycles, leading to a comprehensive correlation between standard cylinder pressure-based knock indexes and other indexes (only available in a simulation environment), more representative of the actual knock intensity.

Split Injection in a GDI Engine Under Knock Conditions: An Experimental and Numerical Investigation

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Present work investigates both experimentally and numerically the benefits deriving from the use of split injections in increasing the engine power output and reducing the tendency to knock of a gasoline direct injection (GDI) engine.

The here considered system is characterized by an optical access to the combustion chamber. Imaging in the UV-visible range is carried out by means of a high spatial and temporal resolution camera through an endoscopic system and a transparent window placed in the piston head. This last is modified to allow the view of the whole combustion chamber almost until the cylinder walls, to include the so-called eng-gas zones of the mixture, where undesired self-ignition may occur under some circumstances. Optical data are correlated to in-cylinder pressure oscillations on a cycle resolved basis.

The numerical investigation is performed through a properly developed 3D CFD model of the engine under study, which employs a flamelet model for the combustion initiated by the spark plug, and a low-temperature self-ignition model in the zones not yet reached by the flame front.

The difference in the engine behavior if powered under single or double injection strategies and their influence about knocking are discussed.

Split injection reduces engine cycle-by-cycle variability with respect to the single injection case, all the others relevant parameters remaining unchanged. Benefits are also obtained as regards the resistance to knocking. This is a consequence of the different flow fields arising under the two powering modes, which obviously affect the formation of chemical intermediate species in the low temperature regimes preceding self-ignition.

Experimental Investigation on the Influence of Boost on Emissions and Combustion in an SGDI-Engine Operated in Stratified Mode

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Among many techniques used for increasing fuel efficiency of a modern Gasoline Direct-Injected (GDI) engine are boosting and stratified operation. In modern downsized GDI engines, boosting is standard in order to achieve a high power output. Boosted GDI-engines have however mostly been operated in homogenous mode and little is known on the effects of operating a boosted GDI-engine in stratified mode.

This paper presents the influence on combustion, standard emissions and particulate size distribution in a Spray-Guided, Gasoline, Direct-Injected (SGDI), single cylinder, research engine operated with various levels of boost.

The engine was operated in steady state mode at five engine operating points of various load and speed. The engine was boosted with a Roots blower and operated at four levels of boost as well as atmospheric pressure for comparison. The engine was fueled with market gasoline (95 RON) blended with 10% ethanol. The gas motion induced by the engine head was primarily tumble motion but a small amount of swirl. The spark plug and injector was mounted in parallel with the intake valves.

Results indicate that exhaust temperature and NOx emissions decrease with increasing boost. Hydrocarbon emissions increase with increasing boost. The results on particulate emissions indicate that nucleation mode particulates increase with increasing boost. The opposite trend was observed for agglomeration mode particulates which decreased with increasing boost pressure.

Development of Innovative Microwave Plasma Ignition System with Compact Microwave Discharge Igniter

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Extending the lean limit or/and exhaust-gas-recirculation (EGR) limit/s are necessary for improving fuel economy in spark ignition engines. One of the major problems preventing the engine to operate at lean conditions is stable and successful initial ignition kernel formation. A repeatable, stabilized ignition and early flame development are quite important for the subsequent part of the combustion cycle to run smooth without partial burn or cycle misfire. This study aims to develop an innovative plasma ignition system for reciprocating combustion engines with an aim to extend lean limit and for high pressure applications. This ignition system utilizes microwaves to generate plasma as an ignition source. This microwave plasma igniter is much simplified device compared to conventional spark plug. The microwave plasma ignition system consists of microwave oscillator, co-axial cable and microwave discharge igniter (MDI). A semi-conductor device was used as microwave oscillator, a flexible co-axial cable transmitted the microwaves from microwave oscillator to MDI, and MDI acts as an ignition source. This microwave ignition system generates non-thermal plasma and allows the control of plasma lifetime, plasma intensity with changing microwave oscillation pulse pattern. The MDI can be applied to multi-point ignition to achieve higher thermal efficiency by improving not only ignition performance, but also faster combustion and knock reduction.

In this study, plasma generation and ignition performance of MDI were investigated in constant volume chamber at high ambient pressure of 6 MPa. The results indicated that MDI can generate plasma under much high ambient pressures up to 6 MPa in both air and CO_2 as ambient gases. The combustion performance of MDI was compared with commercial spark plug in constant volume combustion chamber by Schlieren technique, and in single cylinder optical engine. Preliminary results suggested that MDI delivered similar performance with spark plug.

Butanol-Diesel Blend Spray Combustion Investigation by UV-Visible Flame Emission in a Prototype Single Cylinder Compression Ignition Engine

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The paper reports the results of an experimental investigation carried out in a prototype optically accessible compression ignition engine fuelled with different blends of commercial diesel and n-butanol. Thermodynamic analysis and exhaust gas measurements were supported by optical investigations performed through a wide optical access to the combustion chamber. UV-visible digital imaging and 2D chemiluminescence were applied to characterize the combustion process in terms of spatial and temporal occurrence of auto-ignition, flame propagation, soot and OH evolution.

The paper illustrates the results of the spray combustion for diesel and n-butanol-diesel blends at 20% and 40% volume fraction, exploring a single and double injection strategy (pilot+main) from a common rail multi-jet injection system. Tests were performed setting a pilot+main strategy with a fixed dwell time and different starts of injection. For the diesel case, the whole amount of injected fuel and injection pressure were set at 22 mg/str and 80 MPa corresponding to a medium load regime for an automotive light duty diesel engine. The fuel amount for the butanol-diesel blends was changed to get the same chemical energy of the delivered fuel as the reference diesel case (935J/str). The investigation was carried out at two EGR rates, 0% and 50%, corresponding to a concentration of O_2 at intake of 21 and 17%, respectively.

Taking advantages of the higher resistance to auto ignition of the butanol-diesel blends, the results showed a transition from the conventional to a partial premixed combustion for the BU40 in the single injection case. The combined effect of two-stage injection and EGR increased the ignition delay and the switch to the partial premixed combustion was enhanced. Improvement in NOx-soot trade-off was obtained activating the double injection strategy particularly with the butanol blends.

Optical diagnostics allowed to detect and feature the spatial distributions due to the flame luminosity and OH emission at autoignition and to estimate of the lift-off length. A high concentration of OH radicals was detected for all the test cases without EGR that corresponded to an enhanced oxidation phase and a fast soot reduction. Further, the soot oxidation phase resulted more significant for the higher butanol volume fraction in the blends.

Applying Advanced CFD Analysis Tools to Study Differences between Start-of- Main and Start-of-Post Injection Flow, Temperature and Chemistry Fields Due to Combustion of Main-Injected Fuel

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This paper is part of a larger body of experimental and computational work devoted to studying the role of close-coupled post injections on soot reduction in a heavy-duty optical engine. It is a continuation of an earlier computational paper. The goals of the current work are to develop new CFD analysis tools and methods and apply them to gain a more in depth understanding of the different in-cylinder environments into which fuel from main- and post-injections are injected and to study how the in-cylinder flow, thermal and chemical fields are transformed between start of injection timings.

The engine represented in this computational study is a single-cylinder, direct-injection, heavy-duty, low-swirl engine with optical components. It is based on the Cummins N14, has a cylindrical shaped piston bowl and an eight-hole injector that are both centered on the cylinder axis. The fuel used was n-heptane and the engine operating condition was light load at 1200 RPM.

The in-cylinder processes investigated are typical and include fuel injection and the subsequent growth of a largely non-combusting fuel-rich vapor jet, pre-mixed burn followed by sharp reductions in fuel and oxygen concentrations, limited air entrainment that coincides with a transition from pre-mixed burn to mixing-controlled burn, and the end of main-injection, after which many in-cylinder processes tend back toward their pre-injection values. What distinguishes the work is the ability to use the newly developed tools and methods so that the aforementioned in-cylinder processes of interest can be linked in a quantifiable and visual way.

A Feasibility Study of Using Pyrolysis Oil/Butanol Blended Fuel in a DI Diesel Engine

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The vast stores of biomass available worldwide have the potential to displace significant amounts of petroleum fuels. Fast pyrolysis of biomass is one of several possible paths by which we can convert biomass to higher value products. Pyrolysis oil (PO) derived from wood has been regarded as an alternative fuel to be used in diesel engines. However, the use of PO in a diesel engine requires engine modifications due to the low energy density, high acidity, high viscosity, high water content, and low cetane number of PO. The easiest way to adopt PO without engine modifications is blending with other fuels that have a high cetane number. However, PO has poor miscibility with light petroleum fuel oils; the most suitable candidate fuels for direct fuel mixing are alcohol fuels. Early mixing with alcohol fuels has the added benefit of significantly improving the storage and handling properties of the PO.

In this study, the properties of PO were upgraded by blending n-butanol and two cetane enhancements as additives. Blending with n-butanol effectively reduced the viscosity of PO to the proper level for use in conventional diesel engines while suppressing PO polymerization, which would otherwise spontaneously produce gummy polymers. The auto-ignitability of the PO-butanol blended fuel was improved by the addition of the cetane enhancements, polyethylene glycol 400 (PEG 400) and 2-ethylhexyl nitrate (2-EHN). Experimental results showed that stable combustion characteristics were obtained for PO-blended fuels with a maximum PO content of 15 wt%. The combustion of PO-butanol blended fuels produced comparable or less hydrocarbon (HC) and carbon monoxide (CO) emissions than diesel fuel combustion over most of the engine load range. And nitrogen oxides (NOx) emissions for the blended fuel were higher than those of diesel fuel over the entire engine load range of IMEP 0.2-0.8 MPa.

An Experimental Investigation on the Effect of Diluent Addition on Flame Characteristics in a Single Cylinder Optical Diesel Engine

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The present work investigates the effect of low levels CO_2 addition on the combustion characteristics inside a single cylinder optical engine operated under low load conditions. The effects of dilution levels (up to 7.5% mass flow rate CO_2 addition), the number of pilot injections (single or double pilot injections) and injection pressure (25 or 40 MPa), are evaluated towards the direction of achieving a partially premixed combustion (PPC) operation mode. The findings are discussed based on optical measurements and via pressure trace and apparent rate of heat release analyses in a Ricardo Hydra optical light duty diesel engine. The engine was operated under low IMEP levels of the order of 1.6 bar at 1200 rpm and with a CO_2 diluent-enhanced atmosphere resembling an environment of simulated low exhaust gas recirculation (EGR) rates. Flame propagation is captured by means of high speed imaging and OH, CH and C_2 line-of-sight chemiluminescence respectively. Each of the above species is a proxy of a fundamental combustion property; OH* is related to the oxidation zone, CH* to the heat release zone and the flame front, while C_2* is indicative of fuel-rich areas. The combined analyses of the obtained results were made under the perspective of identifying the induced alterations in flame structures and, possibly, combustion modes, and their manifestation at the global in-cylinder conditions. The increase of CO_2 addition results in lower peak pressures and in an overall delay of the combustion process, while also influences the spatial characteristics of reaction and oxidation zones, as well as differentiates the extent of fuel-rich pockets. Multiple injections advance the main combustion event and an increase in injection pressure enhances fuel

evaporation and mixing while spatially confining the observed flame structures. Overall, operation under relatively slightly diluted conditions with more pilot injection events at higher rail pressure appear to enhance mixing, proving thus an indication of lower emission levels.

Experimental Investigation on CNG-Diesel Combustion Modes under Highly Diluted Conditions on a Light Duty Diesel Engine with Focus on Injection Strategy

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In the last decades, emission legislation on pollutant emissions generated by road transportation sector has become the main driving force for internal combustion engine development. Approximately 20% of worldwide emissions of carbon dioxide from fuel combustion come from the transportation sector, and road vehicles contribute up to 80% of those emissions [1].

Light-duty methane gas engines are usually spark-ignited due to similar combustion characteristics for methane gas and gasoline. Since spark ignition requires a low compression ratio to avoid knock problems, gas engines have lower efficiency than diesel engines. A combustion concept that has been successfully applied on large stationary engines and to some extent on heavy-duty engines is dual-fuel combustion, where a compression-ignited diesel pilot injection is used to ignite a homogeneous charge of methane gas and air. This dual-fuel combustion concept is well established for large stationary engines and exists as an after-market solution for heavy-duty engines but does not exist at all for light-duty engines. This concept offers a high degree of flexibility for the engine operation because dual fuel combustion does not require heavy modifications of the original diesel engine architecture so diesel operation could remain unaltered.

This paper presents an initial study of how combustion characteristics in a multi-cylinder dual fuel methane-diesel light duty engine are altered by the injection control strategy adopted on different high substitution ratio operating points under highly diluted conditions (unthrottled). The measurements have been performed under steady state conditions but the impact of injection strategy on transient operation is discussed and analyzed based on emissions and brake thermal efficiency. Results show that high substitution ratios are difficult to operate at low loads regardless the operation mode selected. RCCI or PPCI combustion could be adopted to promote more stable and robust combustion,

although those modes require lower substitution ratios to be achieved. This investigation does not aim for an optimization of the injection parameters in dual fuel combustion mode, but it aims to point out and understand the most relevant characteristics and behaviors of a light duty dual fuel CNG-Diesel engine operating under high substitution ratios.

Potentials of the Miller Cycle on HD Diesel Engines Regarding Performance Increase and Reduction of Emissions

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A variable air path on diesel engines offers further potentials to manage the challenges of engine development - such as reduction of emissions and fuel consumption, as well as performance increase. The Miller cycle is one of the possibilities, which is well known as an effective way to reduce process temperatures and so NO_X emissions. The present paper discusses the potentials of this strategy for heavy duty diesel engines by identifying and analyzing the effects caused.

The investigations were carried out in the upper load range. First the isolated effect of the Miller cycle was analyzed. The results show reduced NO_X emissions, although increased PM and CO emissions were measured. Further, the Miller cycle caused a reduction in peak cylinder pressure. This pressure reserve can be used to combine the Miller cycle with further measures while maintaining the maximum cylinder pressure of the reference operation point. On the one hand, a performance increase of about 10% was achieved. On the other hand, the combination of Miller cycle and increased boost pressure showed great potential to optimize the NO_X-PM trade-off and led to an efficiency rise. To understand the effects caused, the losses of the process were separated and compared with the reference operation point.

The experimental tests were carried out on a single cylinder heavy duty test engine equipped with an in-house developed camless valve actuation system, and operated in a flexible test environment.

The Benefits of High Injection Pressure on Future Heavy Duty Engine Performance

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Diesel fuel injection pressures have increased steadily on heavy duty engines over the last twenty years and pressures as high as 300MPa are now possible. This was driven by the need to control toxic exhaust emissions, in particular particulate emissions using advanced in-cylinder combustion strategies. With the introduction of efficient aftertreatment systems for both particulate and NO_x emissions control there is less demand for in-cylinder emissions control especially considering the drive for improved fuel economy. In this paper we consider the benefit of high fuel injection pressure for a number of emissions control strategies with different balances of in-cylinder and exhaust aftertreatment emissions control. A test program was undertaken on a single cylinder heavy duty research engine installed at the University of Brighton, in collaboration with Ricardo. The engine was fitted with the Delphi F2E fuel injection system capable of 330MPa injection pressure and multiple fuel injections. The engine intake system was configured to give independent control of the intake pressure and EGR rates, achieving rates of up to 50% at high engine loads. The benefit of high injection pressure was investigated under a number of strategies for achieving Euro VI emissions levels. The trade-off of controlling NO_x emissions using EGR rate and aftertreatment on engine performance and Total Cost of Ownership (TCO) was investigated. Finally, the benefit of a simple split injection strategy at high rail pressure was studied.

Lift-Off Length in an Optical Heavy-Duty Diesel Engine: Effects of Swirl and Jet-Jet Interactions

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The influence of jet-flow and jet-jet interactions on the lift-off length of diesel jets are investigated in an optically accessible heavy-duty diesel engine. High-speed OH chemiluminescence imaging technique is employed to capture the transient evolution of the lift-off length up to its stabilization. The engine is operated at 1200 rpm and at a constant load of 5 bar IMEP. Decreasing the inter-jet spacing shortens the liftoff length of the jet. A strong interaction is also observed between the bulk in-cylinder gas temperature and the inter-jet spacing. The in-cylinder swirl level only has a limited influence on the final lift-off length position. Increasing the inter-jet spacing is found to reduce the magnitude of the cycle-to-cycle variations of the lift-off length. The measured lift-off lengths, at their stabilized positions, are combined with a previous database composed of variations of intake air temperature, motored top dead center density, fuel injection pressure, intake oxygen concentration and nozzle diameter. A non-linear regression model based on the power law form proposed by Siebers *et al.* is developed for describing the stabilized lift-off length of diesel jets as function of the ambient in-cylinder conditions, jet-flow and jet-jet interactions. The model has good accuracy. Although it is only validated for this particular engine environment it identifies the parameters that have the dominating effect on the lift-off length.

An Investigation of Radiation Heat Transfer in a Light-Duty Diesel Engine

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In the last two decades engine research has been mainly focused on reducing pollutant emissions. This fact together with growing awareness about the impacts of climate change are leading to an increase in the importance of thermal efficiency over other criteria in the design of internal combustion engines (ICE). In this framework, the heat transfer to the combustion chamber walls can be considered as one of the main sources of indicated efficiency diminution. In particular, in modern direct-injection diesel engines, the radiation emission from soot particles can constitute a significant component of the efficiency losses. Thus, the main of objective of the current research was to evaluate the amount of energy lost to soot radiation relative to the input fuel chemical energy during the combustion event under several representative engine loads and speeds. Moreover, the current research characterized the impact of different engine operating conditions on radiation heat transfer. For this purpose, a combination of theoretical and experimental tools were used. In particular, soot radiation was quantified with a sensor that uses two-color thermometry along with its corresponding simplified radiation model. Experiments were conducted using a 4-cylinder direct-injection light-duty diesel engine fully instrumented with thermocouples. The goal was to calculate the energy balance of the input fuel chemical energy. Results provide a characterization of radiation heat transfer for different engine loads and speeds as well as radiation trends for different engine operating conditions.

Nanostructure Analysis of In-flame Soot Particles under the Influence of Jet-Jet Interactions in a Light-Duty Diesel Engine

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Some soot particles emitted from common-rail diesel engines are so small that can penetrate deep into the human pulmonary system, causing serious health issues. The analysis of nano-scale internal structure of these soot particles sampled from the engine tailpipe has provided useful information about their reactivity and toxicity. However, the variations of carbon fringe structures during complex soot formation/oxidation processes occurring inside the engine cylinder are not fully understood. To fill this gap, this paper presents experimental methods for direct sampling and nanostructure analysis of in-flame soot particles in a working diesel engine. The soot particles are collected onto a lacey carbon-coated grid and then imaged in a high-resolution transmission electron microscope (HR-TEM). The HR-TEM images are post-processed using a Matlab-based code to obtain key nanostructure parameters such as carbon fringe length, fringe-to-fringe separation distance, and fringe tortuosity. Of particular interest is how jet-jet interactions impact the soot nanostructures because a wall-jet head merging with a neighbouring jet head is well known to cause high soot formation due to rich mixtures. The soot sampling was conducted for three different jet configurations including two single jets (Jet A and Jet B) and a double jet (Jet A&B). Results show that soot primary particles from all the jet configurations are comprised of two distinctively different structures of multiple amorphous cores and concentrically-oriented carbon-layer shells. From about 5000 carbon fringes processed for each jet configuration, the Jet A and Jet B samples show nearly identical mean values for the fringe length, separation distance, and fringe tortuosity of 0.955~0.962 nm, 0.398~0.399 nm, and 1.22, respectively. This suggests that jet-to-jet (or hole-to-hole) variations make a minimal impact on the soot nanostructures. The Jet A&B sample also displays similar tortuosity; however, 4% higher fringe separation distance (0.415 nm), which is well outside of the error range, and the increased proportion of highly reactive short carbon

fringes suggest that soot particles formed in the jet-jet interaction region are more pre-mature and reactive than those formed in the single-jet head region.

Characterization of Combustion and Emissions in Light-Duty Diesel Engines Using High-Glycerol-Ethers/Diesel Blends

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In this paper, a detailed analysis of combustion and emissions is carried out on both metal and optical light duty diesel engines equipped with up-to-date combustion architecture. Both engines were fed with glycerol ethers mixture (GEM) in blend (10% and 20% v/v) within a commercial diesel fuel. The engines ran in significant operating points in the NEDC (New European Driving Cycle) emission homologation area.

The results of the experimental campaign on the metal engine show comparable performances between the diesel/GEM blends and the diesel fuel and demonstrate benefits mainly in terms of soot production. The exhaust particles diameters of diesel/GEM blends shift toward smaller dimensions and the total number decreases. Moreover, at lower load conditions, the outputs show a worsening of the unburnt mainly ascribable to the fuel characteristics.

In order to characterize and investigate more deeply on the combustion process when using the diesel/GEM blends additional tests were performed on a diesel engine with similar combustion architecture of the metal engine and with optical access through the piston bowl. The collection of images of the injection and combustion processes allowed to characterize the behaviour of the two tested fuels and to support metal engine results. Optical techniques were applied to detect soot concentration and flame temperature versus crank angle. Moreover, soot formation and oxidation rates helped to understand the evolution of PM emission.

Analysis of Soot Particles in the Cylinder of a Heavy Duty Diesel Engine with High EGR

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When applying high amount of EGR (exhaust gas recirculation) in Partially Premixed Combustion (PPC) using diesel fuel, an increase in soot emission is observed as a penalty. To better understand how EGR affects soot particles in the cylinder, a fast gas sampling technique was used to draw gas samples directly out of the combustion chamber in a Scania D13 heavy duty diesel engine. The samples were characterized on-line using a scanning mobility particle sizer for soot size distributions and an aethalometer for black carbon (soot) mass concentrations. Three EGR rates, 0%, 56% and 64% were applied in the study. It was found that EGR reduces both the soot formation rate and the soot oxidation rate, due to lower flame temperature and a lower availability of oxidizing agents. With higher EGR rates, the peak soot mass concentration decreased. However, the oxidation rate was reduced even more. This led to increased soot mass concentrations with increasing EGR in late expansion and in the exhaust. During the combustion cycle, both particle number concentrations and particle mean diameters initially increased, followed by a decrease after the peak in soot mass. Generally, increasing EGR reduced the in-cylinder particle mean diameter but increased particle number concentrations. Therefore, increased particle number concentrations were the main reason for increased soot mass emissions with increasing EGR.

Influence of Directly Injected Gasoline and Porosity Fraction on the Thermal Properties of HCCI Combustion Chamber Deposits

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The limited operational range of low temperature combustion engines is influenced by near-wall conditions. A major factor is the accumulation and burn-off of combustion chamber deposits. Previous studies have begun to characterize in-situ combustion chamber deposit thermal properties with the end goal of understanding, and subsequently replicating the beneficial effects of CCD on HCCI combustion. Combustion chamber deposit thermal diffusivity was found to differ depending on location within the chamber, with significant initial spatial variations, but a certain level of convergence as equilibrium CCD thickness is reached. A previous study speculatively attributed these spatially dependent CCD diffusivity differences to either local differences in morphology, or interactions with the fuel-air charge in the DI engine. In this work, the influence of directly injected gasoline on CCD thermal diffusivity is measured using the in-situ technique based on fast thermocouple signals. Comparison of measurements under motoring and firing conditions leads to a conclusion that directly injected fuel trapped within CCD porosity has a negligible impact on in-situ thermal diffusivity for cylinder head CCD. An analytical investigation quantifies the sensitivity of CCD diffusivity to absorbed air or fuel, respectively, and indicates that variation in CCD porosity, rather than the presence of fuel in the pores, accounts for thermal diffusivity differences between cylinder head and piston CCD.

Towards Stoichiometric Combustion in HCCI Engines: Effect of Ozone Seeding and Dilution

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Homogeneous Charge Compression Ignition (HCCI) is generally considered as an efficient solution to reduce fuel consumption and meet the pollutant requirements of internal combustion engines. Furthermore, the HCCI combustion strategy delivers drastically reduced levels of NOx and particulate matter, and combined with a post treatment device, low levels of unburned hydrocarbons (HC) and carbon monoxide (CO) can be achieved. However, affordable and widely used three-way catalytic converters require the engine to be run under stoichiometric conditions. Running an HCCI engine under an increased equivalence ratio leads to advanced combustion phasing and an excessive in-cylinder pressure rate that can affect engine operation. The dilution effect of Exhaust Gas Recirculation (EGR) represents a way to delay ignition of the mixture and reduce excessive in-cylinder pressure gradients. However, acting exclusively on dilution in order to control HCCI combustion is problematic and could lead to misfire or unstable combustion characteristics. Recent studies demonstrated that seeding the engine intake with oxidizing chemical species is a promising strategy to achieve combustion control in HCCI engines. Among many oxidizing chemical species, ozone (O_3) is one of the most promising promoters of combustion. Results showed that it enhances combustion and advances the combustion phasing. Moreover, ozone generators have become increasingly compact, making it possible to extend combustion control with ozone to commercial engines. The present work investigates HCCI combustion of iso-octane for lean to stoichiometric conditions and examines the combined effects of ozone and EGR dilution inside the combustion chamber. Experiments showed that dilution counterbalances excessive in-cylinder

pressure due to the high fuel concentration, enabling stoichiometric HCCI combustion of iso-octane. Seeding ozone at the engine intake reduced engine inefficiencies and extended the HCCI engine operating range towards lower temperatures. EGR was also simulated using the main combustion products, H_2O, CO_2 and N_2. Experiments were performed to investigate possible interactions with ozone. Results showed that seeding the intake of the engine with ozone and simultaneously diluting the mixture allowed better control of HCCI combustion of iso-octane.

Analysis of Thermal and Chemical Effects on Negative Valve Overlap Period Energy Recovery for Low-Temperature Gasoline Combustion

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A central challenge for efficient auto-ignition controlled low-temperature gasoline combustion (LTGC) engines has been achieving the combustion phasing needed to reach stable performance over a wide operating regime. The negative valve overlap (NVO) strategy has been explored as a way to improve combustion stability through a combination of charge heating and altered reactivity via a recompression stroke with a pilot fuel injection. The study objective was to analyze the thermal and chemical effects on NVO-period energy recovery. The analysis leveraged experimental gas sampling results obtained from a single-cylinder LTGC engine along with cylinder pressure measurements and custom data reduction methods used to estimate period thermodynamic properties. The engine was fueled by either iso-octane or ethanol, and operated under sweeps of NVO-period oxygen concentration, injection timing, and fueling rate. Gas sampling at the end of the NVO period was performed via a custom dump-valve apparatus, with detailed sample speciation by in-house gas chromatography. The balance of NVO-period input and output energy flows was calculated in terms of fuel energy, work, heat loss, and change in sensible energy. Experiment results were complemented by detailed chemistry single-zone reactor simulations performed at relevant mixing and thermodynamic conditions, with results used to evaluate ignition behavior and expected energy recovery yields.

For the intermediate bulk-gas temperatures present during the NVO period (900-1100 K), weak negative temperature coefficient behavior with iso-octane fueling significantly lengthened ignition delays relative to similar ethanol fueled conditions. Faster ethanol ignition chemistry led to lower recovered fuel intermediate yields relative to similar iso-octane fueled conditions due to more complete fuel oxidation. From the energy analysis it was found that increased NVO-period global equivalence ratio, either from lower NVO-period oxygen concentrations or higher fueling rates, in general led to a greater fraction of net recovered fuel energy and work as heat losses were minimized. These observations were supported by complementary single-zone reactor model results, which further indicated that kinetic time-scales favor chemical energy-consuming exothermic oxidation over slower endothermic reformation. Nonetheless, fuel energy recovery close to the thermodynamic equilibrium solution was achieved for baseline conditions that featured 4% NVO-period oxygen concentration.

Experimental Investigation of a RCCI Combustion Concept with In-Cylinder Blending of Gasoline and Diesel in a Light Duty Engine

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Within this study a dual-fuel concept was experimentally investigated. The utilized fuels were conventional EN228 RON95E10 and EN590 Diesel B7 pump fuels. The engine was a single cylinder Diesel research engine for passenger car application. Except for the installation of the port fuel injection valve, the engine was not modified. The investigated engine load range covered low part load operation of IMEP = 4.3 bar up to IMEP = 14.8 bar at different engine speeds. Investigations with Diesel pilot injection showed that the dual-fuel approach can significantly reduce the soot/NO_x-trade-off, but typically increases the HC- and CO-emissions. At high engine load and gasoline mass fraction, the premixed gasoline/air self-ignited before Diesel fuel was injected.

Reactivity Controlled Compression Ignition (RCCI) was subsequently investigated in a medium load point at IMEP = 6.8 bar. Here, the impact of EGR, gasoline mass fraction and DI injection pressure and timing on emissions and combustion behavior were investigated. Despite elevated HC- and CO-emissions, it was possible to achieve a higher efficiency while simultaneously keeping the engine-out NO_x-emissions below the EU-6.1 level. Moreover, the combustion was almost soot-free and featured reduced noise emission compared to conventional Diesel injection compression ignition (DICI).

Effect of Split Injection on Combustion and Performance of a Biogas-Diesel Fuelled PPCCI Engine

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In this experimental work the effect of double injection of diesel in a biogas-diesel partially premixed charge compression ignition (BDPPCCI) engine was studied. Biogas was inducted along with air while diesel was injected through a common rail system using an open electronic control unit. Experiments were done at a fixed brake mean effective pressure of 2 bar and an intake charge temperature of 40°C. The effect of start of injection (SOI) of first and second injection pulses and also the biogas energy share (BGES) were evaluated. Experiments were also done in the BDPPCCI mode with diesel being injected in a single pulse and in the biogas-diesel dual fuel (BDDF) mode for comparison. The thermal efficiency in the BDPPCCI mode was better with double injection of diesel as compared to single pulse injection due to better combustion phasing. Improved charge homogeneity and reduced wall wetting of diesel lowered the smoke emission levels with split injection. Nitric oxide (NO) and hydrocarbon (HC) emissions were similar between split and single injection in the BDPPCCI mode. Further the BDPPCCI mode was significantly better than the BDDF in terms of NO and HC emissions. However, at high BGES the thermal efficiency with the BDPPCCI mode with single pulse injection was better than the BDDF mode. With split injection this threshold energy share could be lowered and thus the operating range of energy ratios was widened in the BDPPCCI mode.

High-Speed Particle Image Velocimetry Measurement of Partially Premixed Combustion (PPC) in a Light Duty Engine for Different Injection Strategies

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Dantec Dynamics A/S

It has been proven that partially premixed combustion (PPC) has the capability of high combustion efficiency with low soot and NOx emissions, which meet the requirements of increasingly restricted emission regulations. In order to obtain more homogenous combustion and longer ignition delay in PPC, different fuel injection strategies were employed which could affect the fuel air mixing and control the combustion. In the present work, a light duty optical diesel engine was used to conduct high speed particle image velocimetry (PIV) for single, double and triple injections with different timings. A quartz piston and a cylinder liner were installed in the Bowditch configuration to enable optical access. The geometry of the quartz piston crown is based on the standard diesel combustion chamber design for this commercial passenger car engine, including a re-entrant bowl shape. The severe image distortions caused by the optical piston shape are minimized through recordings of reference targets and an image dewarping algorithm. To the authors knowledge this is the first time the flow field inside such realistic re-entrant piston bowl has been mapped through high speed PIV. PRF 70 was used as fuel in these measurements. The in-cylinder flow field was evaluated and investigated with high temporal and spatial resolution to provide additional understanding of the fuel air mixing process. Formation of the vortices and turbulence enhance the air fuel interaction. The vector field of 40 consecutive cycles, mean velocity, and turbulence kinetic energy were calculated and evaluated. All the results based on PIV experiment also provide a quantitative dataset being useful for model validation of the computational fluid dynamics (CFD) simulation of this PPC engine.

Effects of Injection Strategies on Fluid Flow and Turbulence in Partially Premixed Combustion (PPC) in a Light Duty Engine

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Partially premixed combustion (PPC) is used to meet the increasing demands of emission legislation and to improve fuel efficiency. With gasoline fuels, PPC has the advantage of a longer premixed duration of the fuel/air mixture, which prevents soot formation. In addition, the overall combustion stability can be increased with a longer ignition delay, providing proper fuel injection strategies.

In this work, the effects of multiple injections on the generation of in-cylinder turbulence at a single swirl ratio are investigated. High-speed particle image velocimetry (PIV) is conducted in an optical direct-injection (DI) engine to obtain the turbulence structure during fired conditions. Primary reference fuel (PRF) 70 (30% n-heptane and 70% iso-octane) is used as the PPC fuel. In order to maintain the in-cylinder flow as similarly as possible to the flow that would exist in a production engine, the quartz piston retains a realistic bowl geometry. The distortion caused by the complex shape of the optical piston is corrected by an advanced image-dewarping algorithm. The in-cylinder charge motion is evaluated and investigated over a range of crank angles in the compression and expansion strokes in order to understand the turbulence level, especially the late-cycle turbulence.

The results show the spatial and temporal development of the flow-field structures in the piston bowl. The PIV data, obtained in the vertical plan, are used to calculate the ensemble average velocity turbulent kinetic energy (TKE), cycle-resolved turbulence, and mean velocity of the instantaneous fluid motion.

Application of an Ozone Generator to Control the Homogeneous Charge Compression Ignition Combustion Process

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The present investigation examines a new way to control the homogeneous charge compression ignition (HCCI) process. An ozone generator was set up to seed the intake of a single-cylinder engine with low concentrations of ozone. Two kinds of gas supply were tested: an oxygen supply and an air supply; as well as two kinds of injection: a plenum injection and an injection inside one of the intake pipes. The results showed that air can easily be used and that the second injection mode is the best way to achieve an on-road application. Moreover, experiments demonstrated that each combustion parameter such as the phasing, the indicated mean effective pressure and the pollutants can be controlled by varying the capacity of the ozone generator. Then, from experimental results, two dynamic control approaches on the maximum pressure phasing were proposed. A cartography control showed that a fast control of the combustion phasing can be achieved and a closed loop control demonstrated an excellent accuracy. Finally, this investigation demonstrated that an on-road application is achievable and improvements of this new combustion control approach are discussed.

Effect of Hydrogen Fumigation in a Dual Fueled Heavy Duty Engine

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Concerns over the impact of road transport emissions on the climate have led to increased focus on how CO_2 emissions could be reduced from the sector. This is of particular concern in the commercial vehicle sector, where engine downsizing and electrification have limited benefit due to the vehicle duty cycle. In this paper, we present results from an experimental program to investigate the impact of dual fueling a heavy duty engine on hydrogen and diesel. Hydrogen is potentially a zero carbon fuel, if manufactured from renewable energy but could also be manufactured on the vehicle through steam reformation of part of the liquid fuel. This opens a novel pathway for the recovery of waste heat from the exhaust system through the endothermic steam reformation process, improving the overall system efficiency. For these concepts to be viable, it is essential the dual fueled combustion system is both thermally efficient, and does not increase toxic emissions such as NO_x. The test program reported studied the impact of hydrogen injection into the engine intake system with and without Exhaust Gas Recirculation (EGR). The baseline engine was calibrated to achieve Euro VI NO_x emissions with various aftertreatment strategies. The impact of displacing diesel with increased quantities of hydrogen was studied. The results are compared with a conceptual model of the hydrogen - diesel combustion process presented in the paper.

The Performance of Multi-Cylinder Hydrogen / Diesel Dual Fuel Engine

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Hydrogen can be produced by electrolyzation with renewable electricity and the combustion products of hydrogen mixture include no CO, CO2 and hydrocarbons. In this study, engine performance with hydrogen / diesel dual fuel (hydrogen DDF) operation in a multi-cylinder diesel engine is investigated due to clarify advantages and disadvantages of hydrogen DDF operation. Hydrogen DDF operation under several brake power conditions are evaluated by changing a rate of hydrogen to total input energy (H2 rate). As H_2 rate is increased, an amount of diesel fuel is decreased to keep a given torque constant.

When the hydrogen DDF engine is operated with EGR, Exhaust gas components including carbon are improved or suppressed to same level as conventional diesel combustion. In addition, brake thermal efficiency is improved to 40% by increase in H2 rate that advances combustion phasing under higher power condition. On the other hand, NOx emission is much higher than one of conventional diesel engine. Additionally, hydrogen DDF engine operation at higher engine load with high H2 rate is limited by a variability of in-cylinder pressure among each cylinder. Mixing hydrogen and intake air will be encouraged to introduce homogeneous mixture to each cylinder.

Following the result of increase in NOx emission under hydrogen DDF operation, we evaluate the effects of EGR (Exhaust Gas Recirculation) on the performance. Under 40kW power and H2 rate 55% condition. When EGR rate is around 20 %, the emission level of hydrogen DDF engine is at the same level as a mass-production diesel engine for heavy duty vehicles. However, there're still problems on soot emission and cylinder-to-cylinder pressure variation.

Experimental Analysis of a Gasoline PFI-Methane DI Dual Fuel and an Air Assisted Combustion of a Transparent Small Displacement SI Engine

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The use of direct injection (DI) engines allows a more precise control of the air-fuel ratio, an improvement of fuel economy, and a reduction of exhaust emissions thanks to the ultra-lean combustion due to the charge stratification. These effects can be partially obtained also with an optimized Air Direct Injection that permits to increase the turbulence at low speed and load increasing the combustion stability especially in lean condition. In this paper, a gasoline PFI (named G-PFI), gasoline PFI-methane DI dual fuel (named G-MDF) lean combustion were analyzed. The G-MDF configuration was also compared with a gasoline PFI - air DI (named G-A) configuration in order to distinguish the chemical effect of methane from the direct injection physical effect. The tests were carried out in a small displacement PFI/DI SI engine. The experimental investigation was carried out in a transparent small single-cylinder, spark ignition four-stroke engine. It was equipped with the cylinder head of a Direct Injection 244 cc engine. The in-cylinder pressure was measured and the indicated mean effective pressure, IMEP, and its CoV were evaluated. 2D-digital imaging optical measurements were performed to analyze the combustion process with high spatial and temporal resolution. In particular, it allows to follow the flame evolution and evaluate the flame front propagation speed. The CO, CO_2, HC and NOx emissions were characterized at the exhaust by means of gaseous analyzers. The measurements were performed at 2000 rpm PL in steady state condition. The G-MDF as well as the G-A configurations allow improving the vaporization of the heavy gasoline compound and the homogenization of the charge. Moreover, for the G-MDF, the presence of the methane and its chemical interaction with gasoline heavy hydrocarbon enhances a more efficient combustion.

Experimental Evaluation of Compression Ratio Influence on the Performance of a Dual-Fuel Methane-Diesel Light-Duty Engine

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The paper reports an experimental study on the effect of compression ratio variation on the performance and pollutant emissions of a single-cylinder light-duty research diesel engine operating in DF mode.

The architecture of the combustion system as well as the injection system represents the state-of-the-art of the automotive diesel technology. Two pistons with different bowl volume were selected for the experimental campaign, corresponding to two CR values: 16.5 and 14.5. The designs of the piston bowls were carefully performed with the 3D simulation in order to maintain the same air flow structure at the piston top dead center, thus keeping the same in-cylinder flow characteristics versus CR.

The engine tests choice was performed to be representative of actual working conditions of an automotive light-duty diesel engine. Moreover, the test methodology was designed in order to carry out emission and fuel consumption (FC) estimation on New European Driving Cycle (NEDC) test procedure. A proper engine Dual-Fuel calibration was set-up respecting prefixed limits in terms of in-cylinder peak firing pressure, cylinder pressure rise, IMEP cycle-to-cycle variation, and gaseous emissions.

The results evidence a significant impact of CR on the THC level (mainly CH_4), as well as on the combustion efficiency. Benefits on combustion noise and full load performance in DF mode can be attained reducing the CR. The results also show a great potential on the CO_2 reduction beyond a NG substitution rate of 50%. Moreover, the study indicates that such limit could be overcome with specific combustion system design as well as a proper engine calibration.

Combustion Analysis of Dual Fuel Operation in Single Cylinder Research Engine Fuelled with Methane and Diesel

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In the present activity, dual fuel operation was investigated in a single cylinder research engine. Methane was injected in the intake manifold while the diesel was delivered via the standard injector directly into the engine. The aim is to study the effect of increasing methane concentration at constant injected diesel amount on both pollutant emissions and combustion evolution in an optically accessible engine. Emissions are in line with those previously published by other authors, it is noted no PM and constant NOx emissions. Moreover, a decrease of the brake specific CO emissions and an increase of the brake specific THC for the operating condition with the highest premixed ratio was detected. THC was mainly constituted by methane unburned hydrocarbons. Combustion resulted more or less stable. Moreover, via both UV-VIS spectroscopy and digital imaging, the spatial distribution of several species involved in the combustion process was analyzed. In particular, OH radical was recognized via chemiluminescence analysis and its integral intensity from UV digital imaging was compared with the ROHR of the several operating conditions investigated. Ignition delay is not affected by the premixed charge of methane. Moreover, the premixed combustion shows stronger OH radical emission, more than an order of magnitude, increasing the methane quantity in the burning charge.

On the Acoustic Impedance of a Fibreless Sound Absorptive Element

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The acoustic impedance exhibited by a new type of element for noise control, the Micro-Grooved Elements (MGEs), has been widely investigated in this paper.

The MGEs are typically composed of two overlying layers presenting macroscopic slots and a number of micro-grooves on one of the contact surfaces. The micro-grooves result in micro-channels as the layers are assembled to form the element. Similarly to Micro- Perforated Elements (MPEs), the MGEs have been proved to provide effective dissipation of acoustic energy by the means of viscous losses taking place in the micro-channels. However, in contrast to the MPEs, the MGEs use the grooves, instead of the holes, in which the air is forced to pass through. It results in more cost effective elements, which have been found to represent an adequate alternative for fibrous materials, typically present in silencer units.

The design of the MGEs has been largely improved since the year 2012 and a number of configurations, provided with different internal geometries, have been produced during the last three years. For this reason new and more general models are needed, allowing to describe the acoustic behavior of those elements. In this study, the impedance model provided in the paper [1] has been extended and generalized in order to be applicable to a wider variety of MGEs configurations.

The methodology proposed here comprises a systematic investigation on the impedance contribution of all the constituting parts, e.g., inlet/outlet layers and internal micro channels, treated as series impedance. Experimental results have been carried out by extracting the transfer matrix from the 2-port data and by assuming constant particle velocity throughout the elements.

The acoustic impedance of the micro-channels has been studied in detail, since it gives the most important contribution to the global performance of the MGEs.

Therefore, the impedance end corrections of the micro-channels have been determined by interpolating the impedance values of micro-channels with different lengths. Finally, the non-linear impedance contribution and the mutual interactions between the constituting parts have been experimentally evaluated and modeled by using ansatz equations.

Engine Modeling and Diagnostics
Engine Combustion
Fuels and Lubricants
Exhaust Aftertreatment and Emissions
New Engines, Components, Actuators, & Sensors
Hybrid and Electric Powertrains

Aspects of Numerical Modelling of Flash-Boiling Fuel Sprays

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Flash-boiling of sprays may occur when a superheated liquid is discharged into an ambient environment with lower pressure than its saturation pressure. Such conditions normally exist in direct-injection spark-ignition engines operating at low in-cylinder pressures and/or high fuel temperatures. The addition of novel high volatile additives/ fuels may also promote flash-boiling. Fuel flashing plays a significant role in mixture formation by promoting faster breakup and higher fuel evaporation rates compared to non-flashing conditions. Therefore, fundamental understanding of the characteristics of flashing sprays is necessary for the development of more efficient mixture formation. The present computational work focuses on modelling flash-boiling of *n*-Pentane and *iso*-Octane sprays using a Lagrangian particle tracking technique. First an evaporation model for superheated droplets is implemented within the computational framework of STAR-CD, along with a full set of temperature dependent fuel properties. Then the computational tool is used to model the injection of flashing sprays through a six-hole asymmetric injector. The computational results are validated against optical experimental data obtained previously with the same injector by high-speed imaging techniques. The effects of ambient pressure (0.5 and 1.0 bar) and fuel temperature (20-180° C) on the non-flashing and flashing characteristics are examined. Effects of initial droplet size and break-up sub-models are also investigated. The computational methodology is able to reproduce important physical characteristics of flash-boiling sprays like the onset and extent of spray collapse. Based on the current observations, further improvements to the mathematical methodology used for the flash-boiling model are proposed.

Analysis of Averaging Methods for Large Eddy Simulations of Diesel Sprays

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Large Eddy Simulations (LES) provide instantaneous values indispensable to conduct statistical studies of relevant fluctuating quantities for diesel sprays. However, numerous realizations are generally necessary for LES to derive statistically averaged quantities necessary for validation of the numerical framework by means of measurements and for conducting sensitivity studies, leading to extremely high computational efforts. In this context, the aim of this work is to explore and validate alternatives to the simulation of 20-50 single realizations at considerably lower computational costs, by taking advantage of the axisymmetric geometry and the Quasi-Steady-State (QSS) condition of the near nozzle flow at a certain time after start-of-injection (SOI). Three different approaches are proposed and carefully investigated: the first combines ensemble with spatial averaging techniques based on the estimation of the azimuthal integral length scales to assess the maximal number of independent profiles; the second proposes in addition a time averaging technique that relies on the QSS assumption, whereas a third approach merges all the mentioned techniques together. Results show that for axisymmetric constant volume geometries, converged statistics (mean and standard deviation values) can be obtained from one single LES realization with up to 252 statistically independent samples. These results are very promising and could potentially reduce computational costs up to 50 times, allowing for numerical setup optimizations and sensitivity studies at computational efforts comparable to Reynolds-averaged Navier-Stokes (RANS) simulations.

An Erosion Aggressiveness Index (EAI) Based on Pressure Load Estimation Due to Bubble Collapse in Cavitating Flows Within the RANS Solvers

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Despite numerous research efforts, there is no reliable and widely accepted tool for the prediction of erosion prone material surfaces due to collapse of cavitation bubbles. In the present paper an Erosion Aggressiveness Index (EAI) is proposed, based on the pressure loads which develop on the material surface and the material yield stress. EAI depends on parameters of the liquid quality and includes the fourth power of the maximum bubble radius and the bubble size number density distribution. Both the newly proposed EAI and the Cavitation Aggressiveness Index (CAI), which has been previously proposed by the authors based on the total derivative of pressure at locations of bubble collapse ($DP/Dt>0$, $D\alpha/Dt<0$), are computed for a cavitating flow orifice, for which experimental and numerical results on material erosion have been published. The predicted surface area prone to cavitation damage, as shown by the CAI and EAI indexes, is correlated with the experiments. EAI predictions indicate the minimum bubble size above which erosion starts as also its location along the injector wall. The proposed methodology is also tested in an actual Diesel injector, operating under realistic injection cycles and pressure levels for which erosion data are available.

Comparison of a Representative Linear Eddy Model with a Representative Interactive Flamelet Model for Spray Combustion Processes

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To further improve engines in terms of both efficiency and emissions many new combustion concepts are currently being investigated. Examples include homogeneous charge compression ignition (HCCI), stratified charge compression ignition (SCCI), lean stratified premixed combustion, and high levels of exhaust gas recirculation (EGR) in diesel engines. All of these combustion concepts have in common that the typical combustion temperatures are lower than in traditional spark ignition or diesel engines.

To further improve and develop combustion concepts for clean and highly efficient engines, it is necessary to develop new computational tools that can be used to describe and optimize processes in non-standard conditions, such as low temperature combustion. Thus, in the presented study a recently developed model (RILEM: Representative Interactive Linear Eddy Model) for modeling non-premixed combustion, regime-independently, was used to simulate a spray combustion process. RILEM consists of a single representative linear eddy model (LEM) coupled to a 3D CFD solver. All fluid dynamics and scalar field equations are solved in the CFD code, while the turbulent combustion is solved simultaneously in a separate, representative one-dimensional LEM. Parameters and boundary conditions that determine the evolution of the LEM are supplied from the 3D calculation at each time step. The LEM code is then solved for the same time step, providing the 3D CFD code with an update of the composition state. In addition to the modelling strategy, a numerical simulation of a n-heptane spray is presented here. The RILEM output is also compared to calculations for the same case by the RIF (representative interactive flamelet) model.

Modal Analysis as a Design Tool for Dynamical Optimization of Common Rail Fuel Injection Systems

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A challenging task that is required to modern injection systems is represented by the enhanced control of the injected quantities, especially when small injections are considered, such as, pilot and main shots in the context of multiple injections.

The propagation of the pressure waves triggered by the nozzle opening and closure events through the high-pressure hydraulic circuit can influence and alter the performance of the injection apparatus. For this reason, an investigation of the injection system fluid dynamics in the frequency domain has been proposed. A complete lumped parameter model of the high-pressure hydraulic circuit has been applied to perform a modal analysis. The visualization of the main vibration modes of the apparatus allows a detailed and deep comprehension of the system dynamics. Furthermore, the possible resonances, which are induced by the action of the external forcing terms, have been identified. These forcing terms are the pump delivered flow-rate, the leakages through the injector pilot-valve, the injected flow-rate and the pressure control valve operation.

On the basis of the developed methodology, it is possible to design injection systems with an optimized dynamic response. The sensitivity of the modes of vibration to a relevant geometrical parameter of the injection system has been analyzed and discussed in order to illustrate the practical application of the proposed approach.

Soot Formation Modeling of n-dodecane and Diesel Sprays under Engine-Like Conditions

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This work concerns the modelling of soot formation process in diesel spray combustion under engine-like conditions. The key aim is to investigate the soot formation characteristics at different ambient temperatures. Prior to simulating the diesel combustion, numerical models including a revised multi-step soot model is validated by comparing to the experimental data of n-dodecane fuel in which the associated chemistry is better understood. In the diesel spray simulations, a single component n-heptane mechanism and the multi-component Diesel Oil Surrogate (DOS) model are adopted. A newly developed C_{16}-based model which comprises skeletal mechanisms of n-hexadecane, heptamethylnonane, cyclohexane and toluene is also implemented. Comparisons of the results show that the simulated liftoff lengths are reasonably well-matched to the experimental measurement, where the relative differences are retained to below 18%. Only that predicted by the DOS model in the 900 K case is overestimated by approximately 28%. The experimental maximum soot volume fraction (SVF) rises by approximately 7.0 fold as the ambient temperature is raised from 900 K to 1000 K. The ratio calculated by chemical mechanisms without toluene chemistry is approximately two-fold. Improvement is observed when toluene chemistry is considered, producing ratios of greater than 3.7. This can be attributed to the higher amount of soot precursor and surface growth species formed through the toluene oxidation pathways in the 1000 K case. A surrogate model that considers the kinetics of aromatic compounds is hence more promising to improve the prediction of local SVF which is significant to soot radiation modelling.

Enhanced Investigations of High-Performance SI-Engines by Means of 3D-CFD Simulations

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Comparative analyses of a high-performance 4-cylinder DISI-engine and its equivalent single-cylinder research engine were performed by means of fast response 3D-CFD simulations. Both engines have identical geometries of intake and exhaust channels, cylinder head and piston. The used 3D-CFD tool QuickSim was developed at the Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart (FKFS), particularly for the numerical simulation of internal combustion engines (ICE).

A calibration of the air consumption enabled a comparison of in-cylinder processes, including charge motion, mixture formation and combustion. All calculated operating points showed a similar trend. Deviations during the gas exchange phase led to a higher turbulence level and hence combustion velocity for the single-cylinder research engine. This resulted in a slightly higher maximum cylinder pressure and indicated mean effective pressure. Results are presented for a representative full load operating point at 6000 rpm.

Near Nozzle Field Conditions in Diesel Fuel Injector Testing

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The measurement of the rate of fuel injection using a constant volume, fluid filled chamber and measuring the pressure change as a function of time due to the injected fluid (the so called "Zeuch" method) is an industry standard due to its simple theoretical underpinnings. Such a measurement device is useful to determine key timing and quantity parameters for injection system improvements to meet the evolving requirements of emissions, power and economy. This study aims to further the understanding of the nature of cavitation which could occur in the near nozzle region under these specific conditions of liquid into liquid injection using high pressure diesel injectors for heavy duty engines. The motivation for this work is to better understand the temporal signature of the pressure signals that arise in a typical injection cycle.

A preliminary CFD study was performed, using OpenFOAM, with a transient (Large Eddy Simulation -LES), multiphase solver using the homogenous equilibrium model for the compressibility of the liquid/ vapour. The nozzle body was modelled for simplicity without the nozzle needle using a nozzle hole of 200μm diameter and the body pressurised to values typical for common rail engines. Temperature effects were neglected and the wall condition assumed to be adiabatic. The chamber initial static pressure was varied between 10 and 50 bar to reflect typical testing conditions.

Results indicate that vapour formation could occur in areas 10-30mm distant from the nozzle itself. The cavitation was initiated around 100 μs after the jet had started for low ΔP cases and followed the development period required for the formation of vortices associated with the vortex roll up of this jet. These vortices had localised sites, in their core region, below the vapour pressure and were convected downstream of their initial formation location. It was also found that vapour formation could occur at chamber static pressures up to 50 bar (the

highest tested) due to cavitation in the shear layer and this vortex effect. The pressure signal received at the chamber would therefore be more difficult to interpret with additional error components.

Development of a Quasi-Dimensional Spray Evaporation and Mixture Formation Model for Direct-Injection Spark-Ignition Engines

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This paper presents a phenomenological quasi-dimensional model of the processes that lead to charge preparation in a Direct-Injection Spark-Ignition (DI-SI) engine, focusing on the physics of atomization and drop evaporation, spray development and the mutual interaction between these phenomena. Atomization and drop evaporation are addressed by means of constant-diameter drop parcels, which provide a discrete drop-size distribution. A discrete Probability Density Function (PDF) approach to fuel/air mixing is proposed, based on constant-mixture-fraction classes that interact with each other and with the drop parcels. The model has been developed in the LMS Imagine.Lab Amesim™ system simulation platform for multi-physical modeling and integrated in a generic SI combustion chamber submodel, CFM1D [15], of the IFP-Engine library.
The validation of the approach is performed on an experimental test case consisting of a high pressure isooctane injection in a constant volume vessel for which mie-scattering and high-speed schlieren visualizations for different thermodynamic conditions were performed at IFPEN within the framework of the French government MAGIE R&D project. Liquid and vapor penetration as well as spray angle data from experiments are then used to tune the RANS CFD simulations performed with the IFP-C3D code. CFD provides further data which is not directly available from the experiments such as drop size and charge distributions as well as spray properties outside the optical measurement field, which are then used to tune and validate the 0D model.
Good accordance is found between validation data and the results obtained with the proposed model showing the advantages of a detailed - though phenomenological - description of the main phenomena involved.

Numerical Modelling of the In-Nozzle Flow of a Diesel Injector with Moving Needle during and after the End of a Full Injection Event

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The design of a Diesel injector is a key factor in achieving higher engine efficiency. The injector's fuel atomisation characteristics are also critical for minimising toxic emissions such as unburnt Hydrocarbons (HC). However, when developing injection systems, the small dimensions of the nozzle render optical experimental investigations very challenging under realistic engine conditions. Therefore, Computational Fluid Dynamics (CFD) can be used instead. For the present work, transient, Volume Of Fluid (VOF), multiphase simulations of the flow inside and immediately downstream of a real-size multi-hole nozzle were performed, during and after the injection event with a small air chamber coupled to the injector downstream of the nozzle exit. A Reynolds Averaged Navier-Stokes (RANS) approach was used to account for turbulence. Grid dependency studies were performed with 200k-1.5M cells. Both k-ε and k-ω SST models were considered in the validation process, with the k-ω SST found to predict better the injector's flow rate. The cavitation models of Schnerr-Sauer and the Zwart-Gerber-Belamri were employed for validation against optical data of cavitation in a simplified nozzle geometry obtained from the literature. The Schnerr-Sauer model was in better agreement with the experiments, hence this model was subsequently employed for the real injector simulations. The motion of the injector needle was modeled by a dynamic grid methodology. An injection pressure of 400 bar was applied at the inlet of the injector. Two outlet pressures were examined, 60 bar and 1 bar. The results showed that the flow was far from steady-state during the injection event and that hysteresis existed between the needle opening and closing phases. This indicated the importance of transient simulations, contrary to widely-used steady state simulations at fixed needle lifts. The two outlet pressures resulted in very different final states of the flow-field in the nozzle. Specifically, the nozzle ended up either full of liquid fuel at the end of injection or full of air after most of the fuel had been ejected into the chamber downstream. These

predictions highlighted phenomena that can increase HC emissions due to fuel leakage, as well as processes that may be linked to different formation mechanisms of nozzle deposits.

Schlieren and Mie Scattering Imaging System to Evaluate Liquid and Vapor Contours of a Gasoline Spray Impacting on a Heated Wall

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In internal combustion engines, the direct injection at high pressures produces a strong impact of the fuel on the combustion chamber wall, especially in small-bore sizes used for passenger cars. This effect is relevant for the combustion process resulting in an increase of the pollutant emissions and in a reduction of the engine performances. This paper aims to report the effects of the injection pressure and wall temperature on the macroscopic behavior and atomization of the impinging sprays on the wall.

The gasoline spray-wall interaction was characterized inside an optically accessible quiescent chamber using a novel make ready Z-shaped schlieren-Mie scattering set-up using a high-speed C-Mos camera as imaging system. The arrangement was capable to acquire alternatively the schlieren and Mie-scattering images in a quasi-simultaneous fashion using the same line-of-sight. This methodology allowed complementing the Mie scattering images, adapting to the liquid phase, with the schlieren ones for the determination both of the liquid and vaporing phase during the single cycle. A single-hole axially disposed injector was used, 0.200 mm in diameter L/d=1.0, while the injection pressure and the wall temperature ranged between 5.0 - 20.0 MPa and ambient to 573 K, respectively. Optical investigations were carried out at atmospheric backpressure and ambient gas temperature. The images of the impact, resolved in the cycle, were processed by a customized algorithm able to catch the contours of the liquid phase and the vapor/atomized zone. Spatial and temporal evolutions were measured for both the phases in terms of width penetration and thickness growth.

Mixture Formation in a CNG-DI Engine in Stratified Operation

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In a study using a single-cylinder engine a significant potential in fuel efficiency and emission reduction was found for stratified operation of a high pressure natural gas direct injection (DI) spark ignition (SI) engine. The control of the mixture formation process appeared to be critical to ensure stable inflammation of the mixture. Therefore, optical investigations of the mixture formation were performed on a geometric equivalent, optically accessible single-cylinder engine to investigate the correlation of mixture formation and inflammability.

The two optical measurement techniques infrared (IR) absorption and laser-induced fluorescence (LIF) were employed. Mid-wavelength IR absorption appeared to be qualified for a global visualization of natural gas injection; LIF allows to quantify the equivalence ratio inside a detection level. While LIF measurements require complex equipment, the IR setup consists merely of a black body heater and a mid-wavelength sensitive IR camera. Methane, the main part of natural gas, absorbs IR radiation at about 3.4 μm. The LIF technique was used to get detailed information about the charge distribution in the region of the spark plug, complementary to the global view acquired by the IR technique.

Optimization of the Mixture Formation for Combined Injection Strategies in High-Performance SI-Engines

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Alongside with the severe restrictions according to technical regulations of the corresponding racing series (air and/or fuel mass flow), the optimization of the mixture formation in SI-race engines is one of the most demanding challenges with respect to engine performance.

Bearing in mind its impact on the ignition behavior and the following combustion, the physical processes during mixture formation play a vital role not only in respect of the engine's efficiency, fuel consumption, and exhaust gas emissions but also on engine performance. Furthermore, abnormal combustion phenomena such as engine knock may be enhanced by insufficient mixture formation. This can presumably be explained by the strong influence of the spatial distribution of the air/fuel-ratio on the inflammability of the mixture as well as the local velocity of the turbulent flame front.

With regard to the mixture formation processes and thus engine performance, both SI-engines with direct and port fuel injection show intrinsic advantages and drawbacks. The combination of the above systems may give rise to new possibilities in combining the particular benefits of both systems. Therefore, the potential of combined injection strategies, with reference to high performance and race engine applications, is presently investigated at the *Institute of Internal Combustion Engines* of the *Technische Universität München* by means of experimental approaches. Both a single cylinder research engine and optical spray diagnostics are used. Thus, the question of whether combined injection strategies can potentially enhance power output is examined.

Furthermore, numerical 3d-CFD-simulations of gas exchange, mixture formation as well as combustion are carried out at the *Forschungsinstitut für*

Kraftfahrwesen und Fahrzeugmotoren Stuttgart with regard to the above injection strategies. The numerical data can then be validated by the experimental investigations from the single cylinder research engine.

Investigation of the Injection Process in a Research CR Diesel Engine using Different Blends of Propane-Diesel Fuel

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Blends of propane-diesel fuel can be used in direct injection diesel engines to improve the air-fuel mixing and the premixed combustion phase, and to reduce pollutant emissions. The potential benefits of usinf propane in diesel engines are both environmental and economic; furthermore, its use does not require changes to the compression ratio of conventional diesel engines. The present paper describes an experimental investigation of the injection process for different liquid preformed blends of propane-diesel fuel in an optically accessible Common Rail diesel engine. Slight modifications of the injection system were required in order to operate with a blend of propane-diesel fuel. Pure diesel fuel and two propane-diesel mixtures at different mass ratios were tested (20% and 40% in mass of propane named P20 and P40). First, injection in air at ambient temperature and atmospheric pressure were performed to verify the functionality of the modified Common Rail injection system. Second, injection process was investigated within the engine. In both configurations, images of the injection process were recorded; in particular, the in-cylinder process was visualized through a sapphire window in the piston bowl. The experimental investigation was performed at four engine operating points of the NEDC (New European Driving Cycle). Results show that the penetration of the blend fuel is as long as the diesel one in the first phase of the injection and is shorter than the diesel fuel at the end of the injection. The cone angle of the blend fuel is always higher than diesel because of the sudden evaporation of propane exiting from the nozzle hole. For these reasons, the use of propane-diesel blends in a diesel engine could allow a better homogenization of the air-fuel mixture.

Spray Analysis of $C_8H_{18}O$ Fuel Blends using High-Speed Schlieren Imaging and Mie Scattering

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Targeted fuel blending is a known method to improve the performance of an automotive engine. Two candidates for a biofuel blend are the linear $C_8H_{18}O$ isomers 1-octanol and di-*n*-butyl ether (DNBE). Both fuels feature an increased amount of oxygen that reduces soot emissions. However, physical properties of both fuels differ significantly and thus, a different type of spray mixing and combustion is expected: The low reactivity of 1-octanol causes a long ignition delay enabling a better mixture homogenization, but also causes HC and CO emissions. DNBE in contrary is highly volatile, has a short ignition time and thus can act as an ignition booster for 1-octanol without losing positive effects concerning emissions. In this work a spray study is performed for blends of 1-octanol and DNBE. Measurements are conducted under diesel-like engine conditions with an 8-hole piezo injector. High-speed Schlieren and Mie scattering techniques are used for spray visualizations. The recorded images allow an extraction of the macroscopic spray dimensions, i.e. penetration and cone angles of both, liquid and vapor phase. The results show a significant influence of the blend composition on the liquid spray phase, whereas the outer boundaries of the vapor phase remain unchanged.

Soot Investigation on Fish Oil Spray Combustion in a Constant Volume Cell

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Maritime environmental regulations stipulate lower emissions from the shipping industry. To cope with these rules, improving the combustion processes, make use of cleaner alternative fuels and implement exhaust gas cleaning systems is necessary. Alternative fuels, like fish oil, have a potential to reduce soot formation during the combustion process and will be deeply investigated in this paper. For this purpose, two different types of fish oil and their blends with marine gas oil (MGO) have been tested in a constant volume pre-combustion cell (CVPC). The CVPC laboratory was built in collaboration between MARINTEK and NTNU. To generate similar injection condition in the combustion cell as in an internal combustion engine, the CVPC is heated using a chemical heating process. The CVPC is used as a fundamental investigation tool for studying the fuel injection system for large engine applications. Parameters that were studied include the combustion, spray development, fuel evaporation process and ignition delay. The general experimental setup of the test facility is described and the optical methods applied are explained for the investigation of fish oil. The aim is to study soot intensity and spray development and to compare the results to pure low-sulphur MGO as a reference fuel. The results conclude that the combustion and ignition properties of fish oil are very similar to marine gas oil and this makes it applicable as an alternative fuel for power generation in the maritime industry. The tests also showed a significant decrease in soot formation for the two fish oils.

Momentum Flux Measurement on Single-Hole GDI Injector under Flash-Boiling Condition

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Direct Injection technology for Spark Ignition engines is currently undergoing a significant development process in order to achieve its complete potential in terms of fuel conversion efficiency, while preserving the ability to achieve future, stringent emission limits. In this process, improving the fuel spray analysis capabilities is of primary importance. Among the available experimental techniques, the momentum flux measurement is one of the most interesting approaches as it allows a direct measurement of the spray-air mixing potential and hence it is currently considered an interesting complement to spray imaging and Phase Doppler Anemometry. The aim of the present paper is to investigate the fuel spray evolution when it undergoes flash boiling, a peculiar flow condition occurring when the ambient pressure in which the spray evolves is below the saturation pressure of the injected fluid. These thermodynamic conditions can occur in part load operation for GDI (Gasoline Direct Injection) engines, causing the spray flow structure and hence the mixture formation process to be completely altered with respect to standard flow conditions.

To investigate the effects of flash-boiling on the spray evolution, a single-hole GDI research injector designed by Magneti Marelli was analyzed in terms of both global spray shape evolution and of spray momentum flux. A preliminary injection rate analysis was also carried out to investigate the hydraulic behavior of the research injector. The spray tests were executed inside a quiescent vessel at ambient pressure ranging from 40 to 300 kPa. To obtain the flash-boiling conditions, both the injector fixture and the test fuel (*n*-heptane) temperatures were set between 30 °C and 120 °C. For the spray momentum flux tests, distances from 5 to 40 mm from the nozzle were used. Aiming to compare the

internal spray structure under low and high temperature conditions, momentum spatial distribution was also investigated over planes at different distances from the nozzle. The results of this work, obtained in well-defined conditions in terms of fuel composition and spray configuration (single jet), can assist the development of CFD numerical tools as well as contribute to a better understanding of the flash-boiling phenomenon effect to the spray formation and evolution.

Combustion Characteristics of Pistacia Lentiscus Biodiesel in DI Diesel Engine

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These last years, much of researches were carried out to find the appropriate substitution fuel to the fossil fuels. The use of biofuel prepared from non-edible vegetable oils are becoming a promising source to produce a fuel for diesel engine, commonly referred to as “biodiesel”. Considering the high oil extraction yield (around 40%) and the great quantity of pistacia lentiscus (PL) trees available in arid and semi-arid areas of Mediterranean countries, it is selected in the present work to study the biodiesel prepared from PL oil. PL biodiesel is obtained by converting PL seed oil with a single-step homogenous alkali catalyzed transesterification process. PL biodiesel characterization, according to the standard methods, shows that the physicochemical properties are comparable to those of conventional diesel fuel. In a second part, a single cylinder air-cooled, DI diesel engine is used to test PL biodiesel at 1500 rpm under various engine load conditions. The combustion characteristics (cylinder pressure, ignition delay, heat release rate and combustion duration) of biodiesel are compared with those of diesel fuel. The combustion characteristic results show in all engine load conditions that biodiesel exhibits shortens ignition delays with extended combustion duration.

Optical Studies on the Influence of di-n-butyl ether (DNBE) on Combustion and Partical Number Emissions

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Finite fossil energy sources and carbon dioxide as a main cause for climate changes are still under critical discussion. Therefore, scientists work on the replacement of fossil by alternative diesel fuels from biomass. Hence, in this study the in-cylinder combustion and particle number emissions of di-n-butyl ether (DNBE), as a representative of second generation biofuels, and of reference diesel fuel (B0) for comparison were analyzed by several measurement techniques at different injection and boost pressures. The heat release rate and thus the ignition delay as well as the center of combustion were analyzed by monitoring the global in-cylinder pressure signal using a pressure sensor. The combustion process was also visualized by simultaneous imaging of the hydroxyl radical and a spectral range of soot luminescence. This allows the analysis of the in-cylinder soot formation and oxidation process. Changes in physical properties of the emitted particles were measured by a Scanning Mobility Particle Sizer. Our measurements show a much more homogeneous combustion for DNBE compared to B0. This can be explained by the dissimilar fuel properties of DNBE in comparison to B0 causing significant differences in in-cylinder mixture formation. As a consequence of the nearly homogeneous combustion of DNBE, particle number emissions are considerably lower and the size of the emitted particles is smaller than for B0.

Reducing NO in a Biodiesel Fueled Compression Ignition Engine - An Experimental Study

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The replacement of fossil diesel with neat biodiesel in a compression ignition engine has advantage in lowering unburned hydrocarbon, carbon monoxide and smoke emissions. However, the injection advance experienced with biodiesel fuel with respect to diesel injection setting increases oxides of nitrogen emission. In this study, the biodiesel-NO control is attempted using charge and fuel modification strategies with retarded injection timing. The experiments are performed at maximum torque speed and higher loads viz. from 60% up to full load conditions maintaining same power between diesel and biodiesel while retarding the timing of injection by 3 deg. crank angle. The charge and fuel modifications are done by recycling 5% by volume of exhaust gas to the fresh charge and 10% by volume of methanol to Karanja biodiesel. The comparison of experimental results using the two NO control strategies show 35 to 45 % decrease in NO concentration at the load conditions specified above and 60 and 90% lower smoke respectively relative to diesel. Unlike using exhaust gas recirculation with biodiesel which reduces nitric oxide at an expense of increasing soot, the use of methanol blended biodiesel result in simultaneous reduction of both nitric oxide and smoke.

Combustion Analysis on an IDI CI Engine Fueled by Microalgae

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The third generation of biodiesels, derived from microalgae, is one of the most interesting options for the replacement of fossil fuels. While the use of first generation biodiesels on different types of compression ignition engines is well documented in the open literature, much less information is available on algal fuels. As a matter of fact, the influence on combustion and pollutant emissions is not definitively assessed, depending on the combination of the specific features of both fuel and engine.

The aim of this paper is to analyze the combustion process in a small industrial engine fueled by an algal Biodiesel, blended with standard Diesel fuel. The blend composition is the one typically used in most applications, i.e. 20% of biodiesel and 80% of Diesel (B20). In order to give a rigorous reference, all the experiments have been repeated with pure Diesel fuel, and with a blend made up of 20% of commercial rapeseed biodiesel, one of the most representative first generation biofuel.

The experimental campaign has been carried out on an IDI 4-cylinder 1.4 liter naturally aspirated engine. It was found that the algal B20 slightly improves fuel conversion efficiency, in comparison to standard Diesel. This result is due to the different combustion rate, as well as to a more complete burning process. Differently from previous studies, no advantage has been found in terms of soot. Finally the algal B20 requires a higher fuel mass flow rate in order to compensate the lower heating value.

Optical Investigation of Biofuel Effects on NO and PAH Formation in Diesel-Like Jets

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In order to reduce engine out CO_2 emissions it is a main subject to find new alternative fuels out of renewable sources. For this reason in this paper a blend out of 1-octanol and di-n-butylether and pure di-n-butylether are investigated in comparison to n-heptane as diesel-like fuel. The alternative fuels have a different combustion behavior particularly concerning important combustion parameters like ignition delay and mixture formation. Especially the formation of pollutants like nitrogen oxides in the combustion of alternative fuels is of global interest. The knowledge of the combustion behavior is important to design new engine geometries or implement a new calibration of the engine. In previous measurements in a single cylinder engine it was found out that both alternative fuels form nearly no soot emissions. For this reason now NO_x is investigated optically to avoid the traditional soot NO_x trade-off in diesel combustion. The three fuels are investigated in a High-Pressure Chamber (HPC) to avoid any influence of ambient- air turbulence on the combustion of the fuels. For the analysis of the fuels the optical measurement technique Laser Induced Fluorescence (LIF) was installed at the test bench. The measurement technique was implemented on the centerline of the fuel jet and positioned near the lift-off length of the flames. To investigate also the mixture formation of the fuels the rail pressure and the time of injection were varied. The measurements show the different behavior of NO_x formation under mainly lean or rich conditions respectively which are caused by the different fuels.

Experimental Investigation of Combustion and Exhaust Emission Characteristics of a Variable Compression Ratio Engine Using Isopropyl Alcohol (2-Propanol)-Diethyl Ether Blend with Diesel

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The continuous growth of population and development of industries give rise to massive increase in the global energy demand in recent years. Therefore present work investigated the combustion and emission characteristics of an unmodified four stroke single cylinder variable compression ratio diesel engine utilizing isopropyl alcohol (2-propanol)-diethyl ether blends with diesel. The different fuel samples were prepared using 10% isopropyl, alcohol 5% diethyl ether by volume (IPD15), 15% isopropyl alcohol, 5% diethyl ether by volume (IPD20) and 20% isopropyl alcohol 5% diethyl ether by volume (IPD25) with neat standard diesel. All experiment tests were performed with at variable compression ratio 17 and 18 at different load conditions. The effect of blends and compression ratio on combustion parameters viz. peak cylinder pressure and rate of heat release along with exhaust emissions CO, CO_2, HC and NO_x, were investigated. The results of the experiment has been investigated and compared with standard diesel and results exhibited the higher peak cylinder pressure and heat release for IPD15 and IPD20 than that of IPD25 at both compression ratio 17 and 18. However exhaust emissions strongly depend on engine operating conditions and proportions of isopropyl alcohol-diethyl ether blends though It has been observed that increase in concentration of isopropyl alcohol in isopropyl alcohol (2-propanol)-diethyl ether blends reduces NO_x emissions, while increasing CO and HC emissions at compression ratio 18.On the basis of combustion and emission studies of present investigation IPD15 and IPD20 may be used as suitable alternative fuels for diesel engines without major modification in engine compounds.

Alternative Energy Technologies: The Unconventional Dependable

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AETs are imperative to mitigate the twin crisis of environmental degradation and simultaneous fossil fuel depletion, there are wide concerns about GHG emissions which have paved ways for the development and deployment of energy technologies that do not use fossil fuels. These technologies would provide tangible benefits in terms of fossil-fuel costs, which are likely to increase as restrictions on GHG emissions are imposed. However, a number of challenges need to be overcome prior to market positioning, and the commercialization of alternative energy technologies which require a staged approach given price and technical risk. An unconventional new alternative technology is one possibility, where one could undertake cost-reducing production enhancement measures as an intermediate step prior to deployment. This paper explores the factors affecting the use of AETs in automobiles further includes in depth analysis and results obtained from real time experiments conducted on AET based automobiles. This paper empirically examines the preferences for alternative energy sources or propulsion technologies in vehicles. In order to simulate a realistic future purchase situation, the following alternative technologies i.e. hybrid, gas, biofuel, hydrogen, and electric vehicles were considered besides common gasoline and diesel vehicles. The estimation results reveal that younger potential car buyers have a higher stated preference for biofuel and electric vehicles, males have a higher stated choice of hydrogen vehicles, and environmentally aware potential car buyers have a higher stated preference for hydrogen and electric vehicles. These results suggest that common policy instruments such as the promotion of research and development, taxation, or subsidization in the field of electro mobility could be supplemented by policies to increase the social acceptance of alternative vehicle types that are directly oriented to these population groups.

Real Driving Emissions of Two Older Ordinary Cars Operated on High-Concentration Blends of N-Butanol and ISO-Butanol with Gasoline

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Butanol, which can be produced from biomass, has been suggested as an alternative to ethanol, due to its higher energy density, lower oxygen content and more favorable hygroscopic and corrosive properties. In the Czech Republic, E85 is widely sold at fuel stations and used in ordinary vehicles, both with and without aftermarket control units. This work investigates the potential of ordinary automobiles to run on butanol, and the associated effects on exhaust emissions under real driving conditions.

A Škoda Felicia car with a throttle body injection and a Škoda Fabia car with a multi-point port injection have been run on gasoline and its mixtures with up to 85% volume of ethanol, of n-butanol, and of isobutanol (2-methyl-1-propanol). An auxiliary control unit has been used with higher alcohol content. On each fuel, each car was driven 5-6 times along a local test route. The emissions of gaseous pollutants and other parameters were measured by a portable on-board emissions monitoring system.

The results suggest that the engine control units of both cars prolonged the fuel injection pulse width allowing the engines to operate on all tested mixtures. On the throttle body injected engine, oscillations of air to fuel ratio to both rich and lean mixture compositions were observed for all alcohol containing mixtures, especially for mixtures with high butanol share. This resulted to significant increase of nitrogen oxides emissions with a lack of significant decrease of carbon monoxide. On the engine with multipoint injection system, only minor general shift of air to fuel ratio was observed, with minor changes of air to fuel ratio peak to peak value. This resulted in less apparent changes of gaseous pollutants production.

A Comparative Analysis on Engine Performance of a Conventional Diesel Fuel and 10% Biodiesel Blends Produced from Coconut Oils

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This paper presents engine performance and emissions of coconut oil-derived 10% biodiesel blends in petroleum diesel demonstrating simultaneous reduction of smoke and NO_x emissions and increased brake power. The experiments were performed in a single-cylinder version of a light-duty diesel engine for three different fuels including a conventional diesel fuel and two B10 fuels of chemical-catalyst-based methyl-ester biodiesel ($B10_{mc}$) and biological-catalyst-based ethyl-ester biodiesel ($B10_{eb}$). The engine tests were conducted at fixed speed of 2000 rpm and injection pressure of 130 MPa. In addition to the fuel variation, the injection timing and rate of exhaust gas recirculation (EGR) were also varied because they impact the combustion and thus the efficiency and emissions significantly. For each operating condition, the in-cylinder pressure traces were recorded using a piezo-electric pressure transducer, which was used to calculate the indicated mean effective pressure (IMEP), apparent heat release rate (aHRR), burn duration. The brake MEP (BMEP) was calculated from a brake torque reading in the EC dynamometer, which was then used to obtain friction MEP (FMEP) as the difference between IMEP and BMEP. The results show lower IMEP for $B10_{mc}$ and $B10_{eb}$ than that of petroleum diesel, which is expected considering the lower calorific value of B10 fuels. However, the BMEP of $B10_{mc}$ displays a comparable value to that of petroleum diesel. The reason for this unexpected observation is likely enhanced lubrication and thus reduced frictional loss because the addition of coconut-derived biodiesel compensates for the reduced IMEP. This effect is higher when $B10_{eb}$ is used, showing even higher BMEP than the petroleum diesel fuel, particularly at the earliest and latest injection timings. The advantages of $B10_{eb}$ over $B10_{mc}$ as well

as petroleum diesel are also evident in the engine-out emissions. The emission results show that the smoke emissions are significantly lower for $B10_{eb}$ than those of $B10_{mc}$ or the petroleum diesel. The NO_x emissions of $B10_{eb}$ are also lowest among the tested fuels. This finding is significant because $B10_{mc}$ show higher NO_x emissions than the diesel fuel and $B10_{eb}$. Another interesting finding from the experiments was the fact that EGR can be more effective in achieving further NO_x reduction when $B10_{eb}$ was used than the petroleum diesel. For tested conditions of this study, the EGR tests demonstrate that $B10_{eb}$ achieves 10% opacity and 4 g/kWh NO_x emission, which are lower than 20% opacity and 5.5 g/kWh NO_x emission of the petroleum diesel. Therefore, $B10_{eb}$ in this study not only demonstrate a benefit in increasing the brake power of a conventional diesel fuel but also in simultaneously reducing smoke and NO_x emissions.

Effects of Ethanol and Gasoline Blending and Dual Fueling on Engine Performance and Emissions

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Ethanol is the most promising alternative fuel for spark ignition (SI) engines, that is blended with gasoline, typically. Moreover, in the last years great attention is paid to the dual fueling, ethanol and gasoline are injected simultaneously. This paper aims to analyze the better methods, blending or dual fueling in order to best exploit the potential of ethanol in improving engine performance and reducing pollutant emissions.

The experimental activity was carried out in a small displacement single cylinder engine, representative of 2-3 wheel vehicle engines or of 3-4 cylinder small displacement automotive engines. It was equipped with a prototype gasoline direct injection (GDI) head. The tests were carried out at 3000, 4000, and 5000 rpm full load. The investigated engine operating conditions are representative of the European homologation urban driving cycle. Engine performance and gaseous and particle emissions were measured at the exhaust by means of a gas analyzer and a smoke meter. Particle size distribution function was measured in the range from 5.6 to 560 nm by means of an Engine Exhaust Particle Sizer (EEPS). The gaseous and particle measurements were performed upstream and downstream of a three way catalyst (TWC), respectively. The results show that the dual fuel configuration allows an improvement of the engine performance and a reduction of exhaust emissions.

An Experimental Study on the Use of Butanol or Octanol Blends in a Heavy Duty Diesel Engine

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Global warming driven by “greenhouse gas” emissions is an increasingly serious concern of both the public and legislators. A potentially potent way to reduce these emissions and conserve fossil fuel resources is to use n-butanol, iso-butanol or octanol (2-ethylhexanol) from renewable sources as alternative fuels in diesel engines. The effects of adding these substances to diesel fuel were therefore tested in a single-cylinder heavy duty diesel engine operated using factory settings. These alcohols have better calorific values, flash points, lubricity, cetane numbers and solubility in diesel than shorter-chain alcohols. However, they have lower cetane numbers than diesel, so either hydrotreated vegetable oil (HVO) or Di-tertiary-butyl peroxide (DTBP) was added to the diesel-alcohol mixtures to generate blends with the same Cetane Number (CN) as diesel. Blends containing 10 and 20% of n-butanol or iso-butanol, or 30 % octanol were tested at four operating points from the European Stationary Cycle. The same engine settings were used in all cases.

The average engine performance in tests with the blends was similar to that achieved with pure diesel but the blends generated less cycle-to-cycle variation. The brake thermal efficiency was similar for all the fuels but the brake specific fuel consumption was slightly higher for the blends due to their lower calorific value. Because of their oxygen content, the blends produced much lower emissions of soot and carbon monoxide than were achieved with diesel. Blends yielded slightly higher NOx emissions than pure diesel and all the fuels produced similar hydrocarbon emissions. Possibly because of its branched molecular structure, the iso-butanol blends yielded slightly higher soot emissions than the n-butanol blends. Because HVO contains no aromatics, its addition to fuel blends reduced soot emissions. Overall, these results confirm the substantial potential of renewable longer-chain alcohols as components of blended diesel fuels.

Reduced Chemical Mechanism for the Calculation of Ethanol / Air Flame Speeds

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Ethanol currently remains the leading biofuel in the transportation sector, with special focus on spark ignition engines, as a pure as well as a blend component. In order to provide reliable numerical simulations of gasoline combustion processes under the influence of ethanol for modern engine research, it is mandatory to develop well validated detailed kinetic combustion models. One key parameter for the numerical simulation is the laminar burning velocity. Under the aspect of minimizing the general simulation effort for burning velocities, well-validated models have to be reduced. As a base kinetic mechanism for the reduction and optimisation process with respect to burning velocity calculations, a detailed model presented by Zhao et al. (Int. J. Chem. Kin. 40 (1) (2007) 1-18) is chosen. The model has been extensively validated against shock tube, rapid compression machine and burning velocity data. The detailed model consists of 55 species and 290 reactions. A stochastic model calibration approach is undertaken for the optimisation of the base mechanism against data found in the literature. New experimental data at 5 bar and 373 K are used for validation. The optimised mechanism is significantly reduced within this work applying a multi-stage reduction strategy using the directed relation graph with error propagation (DRGEP) technique. The reduced mechanism is again validated with the experimental data used before. Overall, the reduced mechanism consists of 36 species and 215 reactions. It predicts experimental flame speeds very well.

Estimation of the Composition of Methane-Hydrogen Mixtures from Engine Control Variables

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Modelway srl

Low Carbon fuels will play a relevant role in the transportation sector contributing, over the powertrain technology progress, to mitigate global CO_2 emissions. Compressed Natural Gas (CNG), mainly composed by methane, is one of the best candidate thanks to its chemical composition and to its wide diffusion and use. Blending Hydrogen in Natural Gas could represent a further step for a better CO_2 footprint (considering renewable or biohydrogen) but also to optimize the combustion process, increasing the engine thermal efficiency and reducing pollutant formation. On the other hand, capability to automatically adapt the engine parameters to variable concentrations of Hydrogen in Natural Gas (in the range from 0% to 40% by volume) is a mandatory step to maintain engine performance, emissions and efficiency The activities described in this paper are part of a large collaborative project, “Biomethair”, funded by Regione Piemonte, where material specifications on gas tanks, valves, feeding lines, gas pressure regulator, engine pipes and injectors have been set and prototype components procured and implemented into the demonstrator vehicle to ensure safe operating conditions.

In this paper a software algorithm is presented, able to provide, during normal car operation, real time estimates of methane-hydrogen composition, allowing the engine control system to adapt the control parameters engine. The algorithm is based on the innovative data-driven technology Direct Virtual Sensor, which allows to design the Virtual Sensor from the experimental data collected from a testing car, subject to suitable manoeuvres in different operational conditions, without requiring deep first principle modelling of the involved systems.

The Virtual Sensor has been designed and implemented on the Electronic Control Unit of the demonstrator vehicle, giving suitably discretized estimates of Methane-Hydrogen composition, using measurements of engine revolution speed, of the lambda probe value and a variable from engine control unit. Experimental results of the Virtual Sensor performance evaluated in different operational conditions are presented.

Hydrocracked Fossil Oil and Hydrotreated Vegetable Oil (HVO) Effects on Combustion and Emissions Performance of “Torque-Controlled” Diesel Engines

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ENI SpA

The present paper describes the results of a research activity aimed at studying the potential offered by the use of Hydrocracked fossil oil (HCK) and Hydrotreated Vegetable Oil (HVO) blends as premium fuels for next generation diesel engines.

Five fuels have been tested in a light duty four cylinder diesel engine, Euro 5 version, equipped with closed loop control of the combustion. The set of fuels comprises four experimental fuels specifically formulated by blending high cetane HVO and HCK streams and oneEN590-compliant commercial diesel fuel representative of the current market fuel quality.

A well consolidated procedure has been carried out to estimate, for the tested fuels, the New European Driving Cycle (NEDC) vehicle performance by means of the specific emissions at steady-state engine operating points. The procedure included combustion, emission and fuel consumption analysis at seven steady state partial speed/loads test points which are representative of the urban and extra-urban part of the engine homologation cycle (NEDC) and at high speed/high load engine operating condition outside the NEDC area.

The results of the experimental activity proved that HCK-HVO blends give several benefits when used in modern Euro 5 automotive engines. While Nitrogen Oxides (NOx) emission are mainly controlled by the Exhaust Gas Recirculation (EGR) level, all other engine emissions and comfort parameters can be significantly improved significantly by using specific fuels tailored blended for light duty engines. The research also pointed also out the predominant role of the HVO natural high cetane number on the emissions and Noise, Vibration and Harshness (NHV) performance.

Diesel Fuel Lubricity Comparisons with HFRR and Scuffing Load Ball-on-Cylinder Lubricity Evaluator Methods, Part II

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The sulphur level of diesel fuels began to be limited in Europe at the end the 20th century. Quite soon after that it was noticed that the processes for removing sulphur also removed other polar compounds and the natural lubricity of the diesel fuel was lost. Lubricity additives were introduced to restore lubricity properties. Also, a rapid laboratory method was developed to measure lubricity i.e. High Frequency Reciprocating Rig (HFRR). The method (HFRR) ISO 12156-1 was introduced in 1997 and included in EN 590.

In recent years purely paraffinic diesel fuels, such as GTL (Gas To Liquid) and renewable HVO (Hydrotreated Vegetable Oil), have been introduced to the market. Unlike traditional biodiesel (FAME, Fatty Acid Methyl Ester), paraffinic diesel fuels require the use of lubricity additives to reach a sufficiently high level of lubricity.

In this study two methods were applied in testing lubricity: HFRR and SLBOCLE (Scuffing Load Ball-On-Cylinder Lubricity Evaluator) on diesel fuels with aromatic levels between 0 and 14.5 wt.-%. Two types of lubricity additives (with different dosing rates) were included.

The aim of this study was to investigate how the current lubricity additives perform in diesel fuels with varying aromatic content and to compare the reliability of the two test methods HFRR and SLBOCLE

The results from the HFRR values were logical; the HFRR values got better with an increasing additive dosing level rate in all aromatic levels while in contrast the SLBOCLE results were inconsistent. SLBOCLE values did not for all samples improve with an increase in lubricity additive. These observed SLBOCLE results thus supported the previously published work that repeatability and reproducibility of this method needs to be substantially improved.

In addition, according to the results from this study, there is no evidence that low or zero aromatic content diesel fuel is more critical for lubricity than higher aromatic containing diesel fuels. Adequate lubricity can be achieved with conventional lubricity additives regardless of aromatic level of diesel.

Numerical Investigation on the Effects of Water/Methanol Injection as Knock Suppressor to Increase the Fuel Efficiency of a Highly Downsized GDI Engine

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A new generation of highly downsized SI engines with specific power output around or above 150 HP/liter is emerging in the sport car market sector. Technologies such as high-boosting, direct injection and downsizing are adopted to increase power density and reduce fuel consumption. To counterbalance the increased risks of pre-ignition, knock or mega-knock, currently made turbocharged SI engines usually operate with high fuel enrichments and delayed (sometimes negative) spark advances. The former is responsible for high fuel consumption levels, while the latter induce an even lower A/F ratio (below 11), to limit the turbine inlet temperature, with huge negative effects on BSFC.

A possible solution to increase knock resistance is investigated in the paper by means of 3D-CFD analyses: water/methanol emulsion is port-fuel injected to replace mixture enrichment while preserving, if not improving, indicated mean effective pressure and knock safety margins. The peak power engine operation of a currently made turbocharged GDI engine is investigated comparing the adopted fuel-only rich mixture with stoichiometric-to-lean mixtures, for which water/methanol mixture is added in the intake port under constant charge cooling in the combustion chamber and same air consumption level. In order to find the optimum fuel/emulsion balance analytic considerations are carried out. Different strategies are evaluated in terms of percentage of methanol-water emulsion rate, to assess the effects of different charge dilutions and mixture compositions on knock tendency and combustion efficiency. Thanks to the lower chemical reactivity of the diluted end gases and the faster burn rate allowed by the methanol addition, the water/methanol-injected engine allows the spark advance (SA) to be increased; as a consequence, engine power target is met, or even crossed, with a simultaneous relevant reduction of fuel consumption.

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Experimental Analysis of the Urea-Water Solution Temperature Effect on the Spray Characteristics in SCR Systems

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One of the favored automotive exhaust aftertreatment solutions used for nitrogen oxides (NO_x) emissions reductions is referred to as Selective Catalytic Reduction (SCR), which comprises a catalyst that facilitates the reactions of ammonia (NH_3) with the exhaust nitrogen oxides (NO_x). It is customary with these systems to generate the NH_3 by injecting a liquid aqueous urea solution (AUS-32) into the exhaust. The urea solution is injected into the exhaust and transformed to NH_3 by various mechanisms for the SCR reactions.

Understanding the spray performance of the AUS-32 injector is critical to proper optimization of the SCR injection system.

Results were previously presented from imaging of an AUS-32 injector spray under hot exhaust conditions at the injector spray exit for an exhaust injection application. Those results showed substantial structural differences in the spray between room temperature fluid conditions, and conditions where the fluid temperature approached and exceeded 104° C and "flash boiling" of the fluid was initiated. The visualization techniques used in the testing permitted for the first time a quantification of the droplet size distribution changes under flash boiling conditions. However, the flash boiling could only be initiated at very high exhaust temperatures due to the construction of the injection unit.

The spray investigations results presented in this paper follow up on the previous macroscopic imaging work by forcing flash boiling conditions even at reduced exhaust temperatures. The test facility concept and operation are

described. The global spray structure changes observed in the previously published hot airflow measurements are confirmed, and conclusions drawn on the relative effects of injection air temperature and injected fluid temperature. Quantified comparisons of the spray atomization characteristics are presented.

Internal and External Measures for Catalyst Light-Off Support

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Within a project of the Research Association for Combustion Engines e.V., different measures for rising the temperature of exhaust gas aftertreatment components of both a passenger car and an industrial/ commercial vehicle engine were investigated on a test bench as well as in simulation. With the passenger car diesel engine and different catalyst configurations, the potential of internal and external heating measures was evaluated. The configuration consisting of a NO_x storage catalyst (NSC) and a diesel particulate filter (DPF) illustrates the potential of an electrically heated NSC. The exhaust aftertreatment system consisting of a diesel oxidation catalyst (DOC) and a DPF shows in simulation how variable valve timing in combination with electric heated DOC can be used to increase the exhaust gas temperature and thus fulfill the EU6 emission limits.

The measurements of the industrial/commercial vehicle engine showed that the use of heating measures allows for operating such an engine for off-road applications. Even in a transient cycle, a compliance with the limits of the EUVI emission standard could be achieved. Simulative optimizations reduced fuel consumption for all configurations and engine variants without exceeding EU6/EUVI limits, though they were still too high. However, with low temperature activity of the aftertreatment components, and a better isolation of the exhaust system or a reduction of the engine raw emission level, there is still potential to further reduce fuel consumption.

Therefore, heating measures investigated in this paper were not only evaluated regarding EU6 emission standards, but also with respect to their CO_2 emissions. For this purpose the simulation tool AbSim was developed.

Fluid Dynamic Comparison of AdBlue Injectors for SCR Applications

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The injection process of urea-water solution (AdBlue) determines initial conditions for reactions and catalysis and is fundamentally responsible for optimal operation of selective catalytic reduction (SCR) systems. The spray characteristics of four, commercially available, injectors (one air-assisted and three pressure-driven with different nozzle-hole configurations) are investigated with non-intrusive measuring techniques.

Injection occurred in the crossflow of a channel blowing preheated air in an exhaust duct similar configuration. The effect of several gas temperatures and flows on the spray propagation and entrainment has been extensively studied by shadow imaging. Shadow images, in addition, show that the spray of the pressure-driven injectors is only marginally affected by the gas crossflow. In contrast, the air assisted spray is strongly deflected by the gas, the effect increasing with increasing gas flow. Phase Doppler Anemometry (PDA) measurements delivered droplet size distributions and droplet velocities. Measurements have been performed in several locations near the opposed channel wall area. Sauter mean diameters of the droplets from the pressure-driven injectors are between 60-80μm while of the air assisted 20μm. Higher velocities have been associated with the larger droplets in the pressure-driven spray after the primary breakup while droplet velocities have been evenly distributed to all droplets sizes in the air-assisted spray.

Investigation of Vanadium Sublimation from SCR Catalysts

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Liebherr Machines Bulle SA

The aim of the study is to evaluate the possible vanadium emissions from different commercially available vanadium-based SCR monoliths. The vanadium sublimation was studied at laboratory scale using a monolith sample (16 mm diameter × 19 mm long). Vanadia vapors were disposed on an alumina bed placed downstream the catalyst sample, in the hot zone of a furnace. Experiments were carried out with a space velocity of 42 000 h^{-1}. The reactive gas flow was composed of 5%O_2, 5%H_2O, 500ppm NO and 500ppm NH_3. Catalyst samples and alumina bed were exposed to this reactive gas flow during 10 hours at 500°C, 600°C, 650°C, 675°C, 700°C and 750°C, successively. After each test, alumina samples were mineralized from HNO_3, HF and HCl mixture. The digests were then diluted with high purity water prior, to ICP-MS analysis.

The results revealed that, for full body type catalysts, sublimation of vanadium increases in a significant way from an exposure to the reactive gas flow at 675°C. From 650°C to 675°C the amount of vanadium emitted increases by a factor from 3 to 5. On a SCR monolith composed of a catalytic coated substrate a temperature higher than 700°C is necessary to obtain a significant increase of the amount of vanadium sublimated.

Comparison of Lab Versus Engine Tests In the Development of a Highly Efficient Ammonia Formation Catalyst for a Passive SCR System

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Commercial three way catalysts have limited capacity towards reducing NO_x in the presence of excessive oxygen. This prevents lean-burn combustion concepts from meeting legislative emission standards. A solution towards decreasing NO_x emissions in the presence of excess air is the use of a passive-SCR system. Under rich conditions ammonia is formed over an ammonia formation catalyst, the ammonia is stored in the SCR and in its turn reacts with the NO_x under lean engine conditions.

Here up-scaled Pt/Al_2O_3 and Pd/Al_2O_3 catalysts as well as a commercially Pd-Rh based three-way catalyst (TWC) are evaluated using both engine and further lab-scale tests.

The purpose of these tests is to compare the ammonia production for the various catalysts under various lambda values and temperatures by means of engine and lab scale tests. The Pd/Al_2O_3 showed little sensitivity to temperature both under engine and lab scale experiments. The Pt/Al_2O_3 was affected to a large extend by temperature for both test methods. The TWC showed stable production during the engine measurements while under lab tests an increased temperature resulted in a lower ammonia yield.

Differences between the engine and lab scale tests are mainly due to catalyst temperatures, space velocity, CO poisoning and uncertainties in the composition of the engine's exhaust gas. Both Pt/Al_2O_3 and Pd/ Al_2O_3 form ammonia although the former generate higher amounts at high temperature but are believed to suffer from CO poisoning at low temperatures.

Application of a Modular Simulation Approach: Optimizations from Combustion to Vehicle Management

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The world of diesel is becoming more technically complex due to the increasingly restrictive legislation regarding emissions, fuel consumption, and real driving emissions evaluations (RDE). Simulation provides a mechanism for the investigation and optimization of diesel engine performance, new engine concepts, RDE, and after-treatment design. This can contribute to solve the problems that the restrictive legislation creates.

In addition to these generally valid capabilities of simulations, our model development is focused on the mission to use correctly sized models to reduce the usage of resources and make simulation an even more rapid and cost effective method.

In this contribution, we present our approach for simulation as an advanced integrated tool capable of answering challenging questions presented by emission and fuel consumption reduction in future legislation frameworks. Furthermore, the application of this approach is shown for different simulations of NOx storage catalysts that can be used either for exhaust gas treatment (EGT), calibration strategy optimization (lean model), or for EGT system layout definition (detailed chemical model).

Engine and After-Treatment System Performance within the Cold Start Transient: New Modelling and Experiments

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Nowadays, due to catalyst improvements and electronic mixture control of last generation vehicles equipped with internal combustion engine, the most significant part of the total emissions of carbon monoxide and unburned hydrocarbons takes place during the cold phase, if compared with those exhausted in hot conditions, with a clear consequence on air quality of urban contexts. The purpose of this research, developed by the Department of Industrial Engineering of the University of Naples Federico II with reference to an European background, is a deeper analysis of the engine and after-treatment system behaviour within the cold start transient and the evaluation of cold start additional emissions: a methodology was developed and optimized to evaluate the cold transient duration, the emitted quantities during the cold phase and the relevant time-dependence function.

The whole procedure was applied on the exhaust emissions of one scooter belonging to the Euro-3 legislative category, equipped with catalytic converter, and with a displacement of 280 cm^3. Experimental tests were performed on a chassis dynamometer in cold and hot functioning conditions, during both driving cycle regulated by law and real world driving cycles. The study was focused on this specific vehicle because the pertinent information aren't very extensive in scientific literature, with particular reference to the appraisal of real world and cold-start extra emissions of this particular two-wheeler vehicular class (Euro-3 legislative category and displacement between 250 and 750 cm^3), which in the last years is taking on an increasing chief role in private mobility.

Cylinder Pressure Based Fuel Path Control for Non-Conventional Combustion Modes

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Model-based control strategies along with an adapted calibration process become more important in the overall vehicle development process. The main drivers for this development trend are increasing numbers of vehicle variants and more complex engine hardware, which is required to fulfill the more and more stringent emission legislation and fuel consumption norms. Upcoming fundamental changes in the homologation process with EU 6c, covering an extended range of different operational and ambient conditions, are suspected to intensify this trend.

One main reason for the increased calibration effort is the use of various complex aftertreatment technologies amongst different vehicle applications, requiring numerous combustion modes. The different combustion modes range from heating strategies for active Diesel Particulate Filter (DPF) regeneration or early SCR light-off and rich combustion modes to purge the NOx storage catalyst (NSC) up to partially premixed combustion modes. A combination of advanced physically oriented control strategies and new model-based calibration procedures seems therefore favorable in order to significantly reduce the overall calibration effort and increase the robustness for the different combustion modes.

Within this publication, a new model-based approach for fuel path control of Diesel engines is presented as an example of such an advanced control strategy. The control concept combines a model-based feed-forward control with a cylinder pressure based feedback control. The models for feed-forward control are derived by splitting the entire thermodynamic process into combustion and energy conversion. For feedback control new fuel path control parameters such as the “centroid-of-heat-release” are introduced and combined with a structure variable controller that changes the control parameters depending on the injection strategy. Besides a detailed description of the novel control algorithm,

the benefits in terms of calibration effort are analyzed and discussed. Finally, for experimental validation the control strategy is implemented on a Rapid Control Prototyping (RCP) system. Exemplary results including a rich event during a transient acceleration are shown to illustrate the potential of the control concept.

Real Driving Emissions of a Light-Duty Vehicle in Naples. Influence of Road Grade

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The aim of this study is to investigate the parameters influencing the real driving emission monitoring with particular attention towards the influence of road gradient. For this purpose, an experimental activity was carried out with a Euro 5 Diesel light-duty vehicle, driven along two tracks of Naples characterized by a different road gradient: the first pattern is quite flat, the second includes positive (+2.9%) and negative (−3.6%) road gradient.

Exhaust emissions of CO, THC, NOx, CO_2 were acquired on road by using a portable emission measuring system (PEMS) connected also to the Engine Control Unit for saving the main engine parameters and to the GPS for the geographical coordinates and altitude. The acquired speed profiles were repeated on the chassis-dynamometer without simulating the road gradient. In such way, comparison between on road and laboratory results over the flat pattern allowed to identify the main differences among the two testing procedures for pollutant emission measurements. Moreover, the influence of slope variability was statistically evaluated by comparing laboratory and on-board results of the pattern in altitude.

Results highlight a good correlation of emission monitoring during on-road and laboratory tests for all the analyzed pollutants with the exception of NOx which are strongly influenced by the operating engine temperatures. Slight differences of intake air temperature (almost 10 degC) can provide great difference of NOx exhaust emissions. A negative road gradient could cause a reduction higher in magnitude than the increase caused by a positive road gradient compared to a gradient-neutral test.

Investigations of NO_2 in Legal Test Procedure for Diesel Passenger Cars

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As a result of increased use of catalytic exhaust aftertreatment systems of vehicles and the low-sulfur Diesel fuels there is an increasing share of nitrogen dioxide NO_2 in the ambient air of several cities. This is in spite of lowering the summary nitric oxides NO_x emissions from vehicles.
NO_2 is much more toxic than nitrogen monoxide NO and it will be specially considered in the next legal testing procedures.
There are doubts about the accuracy of analyzing the reactive substances from diluted gas and this project has the objective to show how NO_2 is changing as it travels down through the exhaust- and the CVS systems.
For legal measurements of NO_2 a WLTP-DTP subgroup (Worldwide Light Duty Test Procedures - Diesel Test Procedures) proposed different combinations of NO_x-analyzers and analysis of NO and NO_x. Some of these set-ups were tested in this work.
The investigated WLTP - NO_2-measuring methods have been found in the present work as useful tools to estimate the NO_2- levels and there were no indications of reactivity at these low concentration levels.
Generally there are no clear tendencies of increasing, or decreasing concentrations of the investigated NO_2 along the gas way. This is the result of different factors, like: reactivity (theoretically influenced by the conditions of flow, temperature and concentrations of reactants), estimate of dilution factor and also emission fluctuations of the vehicle during the test time.
The paper also shows some difficulties which arise by estimate of low emission concentrations influenced by several systems and conditions.

Particle Emission Measurements from L-Category Vehicles

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In 2011 a particle number (PN) limit was introduced in the European Union's vehicle exhaust legislation for diesel passenger cars. The PN method requires measurement of solid particles (i.e. those that do not evaporate at 350 °C) with diameters above 23 nm. In 2013 the same approach was introduced for heavy duty engines and in 2014 for gasoline direct injection vehicles. This decision was based on a long evaluation that concluded that there is no significant sub-23 nm fraction for these technologies. In this paper we examine the suitability of the current PN method for L-category vehicles (two- or three-wheel vehicles and quadri-cycles). Emission levels of 5 mopeds, 9 motorcycles, 2 tricycles (one of them diesel) and 1 quad are presented. Special attention is given to sub-23 nm emission levels. The investigation was conducted with PN legislation compliant systems with particle counters measuring above 23 nm and 10 nm. In addition other approaches using catalytic strippers and counters from 3 nm or particle sizers were used to confirm the nature of the particles. The results showed that there is a significant portion of solid particles not counted with the current PN method. On the other hand, the high amount of volatile material can lead to artifacts below 23 nm, and thus great care has to be taken when measuring the PN of this category.

Effects of n-Butanol and Isobutanol on Particulate Matter Emissions from a Euro 6 Direct-injection Spark Ignition Engine During Laboratory and on-Road Tests

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N-butanol and isobutanol are alcohols that can be produced from biomass by fermentation and are possibly more compatible with existing engines than ethanol. This work reports on the effects of these two isomers on exhaust emissions of an unmodified direct injection spark ignition (DISI) engine. A Ford Focus car with a 1.0-liter Euro 6 Ecoboost DISI engine has been tested on a chassis dynamometer using WLTP and Artemis driving cycles, and on the road on a one-hour test loop containing urban, rural and motorway driving. Two isomers of butanol, 1-butanol and 2-methyl-propanol, were each blended with gasoline at 25% volume. Non-oxygenated gasoline and 15% ethanol in gasoline (E15) were used as reference fuels.

The vehicle performed well in terms of cold start, drivability, general performance, and off-cycle particle emissions, staying within several mg of particle mass and about 2×10^{12} particles (per PMP procedure) per km during laboratory tests. While E15 had little effect, both butanol blends have decreased PN emissions by about one half; effects on other pollutants were less consistent or not significant. Only roughly one half of particles was larger than 23 nm, and of these, only about half were non-volatile. Particle emissions during real driving were unevenly distributed, were not excessively different from the Artemis cycle, and were highest for gasoline, lower for E15, lower for 25% n-butanol, and lowest for 25% isobutanol, with most of the reductions taking place during high-power operation.

Overall, both n-butanol and isobutanol blends yielded a considerable reduction in particle number emissions relative to both gasoline and E15.

Ceria-zirconia Nanocatalysts for Diesel Soot Combustion

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A set of ceria-zirconia nanocatalysts with different Zr-contents and structural properties was prepared to study the effect of both the Zr-amount and surface-dependent activity towards soot combustion in "loose" and "tight" soot-catalyst contact. The properties of the catalysts were examined using several physico-chemical techniques. The best soot oxidation activities were achieved for the $Ce_{0.9}Zr_{0.1}O_2$-NP catalyst (NP means nano-polyhedra and 0.9 indicates the atomic ratio of Ce/ Ce+Zr), due to its easier reducibility, compared to high-surface area catalysts with the same Ce/Zr ratio. Moreover, better performances were reached for $Ce_{0.9}Zr_{0.1}O_2$-NP, than similar nano-polyhedra with higher Zr-amounts (denoted as $Ce_xZr_{1-x}O_2$-NP, where x = 0.8 or 0.7). On the other hand, worse activities were obtained for both mesoporous and microporous catalysts with the same Ce/Zr ratio.

THE Post Injection: Coalescence of 3D CFD-CMC Simulation, 2D Visualizations in a Constant Volume Chamber and Application in a Modern Passenger Car Diesel Engine

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Past research has shown that post injections have the potential to reduce Diesel engine exhaust PM concentration without any significant influence in NOx emissions. However, an accurate, widely applicable rule of how to parameterize a post injection such that it provides a maximum reduction of PM emissions does not exist. Moreover, the underlying mechanisms are not thoroughly understood. In past research, the underlying mechanisms have been investigated in engine experiments, in constant volume chambers and also using detailed 3D CFD-CMC simulations. It has been observed that soot reduction due to a post injection is mainly due to two reasons: increased turbulence from the post injection during soot oxidation and lower soot formation due to lower amount of fuel in the main combustion at similar load conditions. Those studies do not show a significant temperature rise caused by the post injection.

Previous investigations led to the conclusion that the effectiveness of a post injection increases with the amount of oxygen transported from the post injection into the soot cloud of the main injection. Hence, the potential of interaction of the two soot clouds as well as the local oxygen availability increase the soot reduction through post injection. This creates a trade-off, since the interaction potential usually increases with lower (global) oxygen availability. The current work provides new 3D simulations in an engine and 2D visualisation of soot evolutions recorded in an optically high accessible

constant volume chamber, with focus on the trade-off between oxygen availability and soot cloud interaction potential. Moreover, the conclusions of this work have been applied in a standard modern common rail passenger car engine. The engine is equipped with an optical light probe to obtain the in-cylinder soot evolution.

The 3D simulations highlight the importance of the interaction between the soot clouds and show the transport of oxygen due to the post injection into the soot cloud of the main injection. The reduction of ambient oxygen concentration increases the oxidation rate up to a certain limit due to higher degree of soot cloud interaction. The results of the constant volume chamber confirm that soot reduction is limited at a certain oxygen availability limit. The engine experiments show the trade-off between oxygen availability and the interaction potential and thus confirm the results obtained from the simulation and the generic test rig.

Investigation of the Oxidation Behavior of Soot in Diesel Particle Filter structures

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EMPA

Particulate matter in diesel exhaust is captured in diesel particulate filters (DPFs). Since increased load in the filter and thus increased pressure drop deteriorates the engine performance, the filter load of the DPF has to be removed during a process referred to as regeneration. Measures for successful regeneration aim at accelerating soot oxidation and increase fuel consumption. Regeneration lay-out and thus fuel consumption increase is strongly depending on the oxidation behavior of soot.

The aim of the present study is the investigation of soot oxidation characteristics. Therefore particle filters have been loaded with soot using the exhaust gas of small heavy duty vehicle operated under defined conditions on an engine dynamometer. The particle filters have been then dismantled and fragmented on their constituting segments. Each filter segment has been regenerated individually in a specifically designed test bench. Heated gas of constant temperature has been induced through the segments. Based on the species balances measured, soot oxidation rates have been computed. In parallel, a scale with milligram resolution recorded the time evolution of the segment weight.

Based on the soot oxidation rates characteristic kinetic parameters have been computed. Regeneration progress has been approached by a simple Arrhenius, a shrinking core and a random pore size distribution growth model. The influence of two different oxygen levels in the feed gas has been investigated. Soot regeneration characteristics in segments from the filter core have been similar exhibiting rather low activation energies of around 50kJ/mol. Soot in filter segments located in the periphery had substantially higher activation energies, 80kJ/mol. This different behavior is attributed to the lower temperatures of the filter periphery during the loading procedure and differences in the soot structure and composition.

Investigations into Particulate Emissions from Euro 5 Passenger Cars with DISI Engines Tested at Multiple Ambient Temperatures

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Particulate matter in vehicular exhaust is now under great scrutiny. In the EU, direct injection spark ignition (DISI) engines running on petrol now have limits for particulate emissions set for both mass and number. Current legislative test procedures represent a best-case scenario - more aggressive driving cycles and lower ambient temperatures can increase particulate emissions massively. Ambient temperature is generally the environmental parameter of most importance regarding particulate emissions from an engine, particularly for the reasonably brief periods of operation typical for passenger cars operating from a cold start. Two Euro 5 vehicles with DI SI engines were laboratory tested at three ambient temperatures on two different commercially available fuels, with particulate emissions results compared to results from the same fuels when the vehicles were tested at 25°C. Testing was performed on a chassis dynamometer in a climate-controlled test chamber, using the legislative European test procedure at a total of three test temperatures. The impact of the fuel type of particulate emissions was found to be vastly smaller than the impact of ambient temperature. Particulate emissions increased unambiguously to varying degrees as test temperature fell, sometimes by up to an order of magnitude, when compared to tests at 25°C, confirming the previous findings that temperatures lower than the legislative test temperature lead to increased particulate emissions, in terms of both mass and number. Continuous particle concentration data were used to examine specific periods of the cycle for the impact of ambient temperature.

Measured and Predicted Soot Particle Emissions from Natural Gas Engines

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Due to the new challenge of meeting number-based regulations for particulate matter (PM), a numerical and experimental study has been conducted to better understand particulate formation in engines fuelled with compressed natural gas. The study has been conducted on a Heavy-Duty, Euro VI, 4-cylinder, spark ignited engine, with multipoint sequential phased injection and stoichiometric combustion. For the experimental measurements two different instruments were used: a condensation particle counter (CPC) and a fast-response particle size spectrometer (DMS) the latter able also to provide a particle size distribution of the measured particles in the range from 5 to 1000 nm. Experimental measurements in both stationary and transient conditions were carried out. The data using the World Harmonized Transient Cycle (WHTC) were useful to detect which operating conditions lead to high numbers of particles. Then a further transient test was used for a more detailed and deeper analysis. Finally 3-D Computational Fluid Dynamics (CFD) simulations were performed and the numerical results obtained were compared to particle size distributions (PSDs) derived from the experimental measurements carried out in stationary conditions. In this way the influences of engine load and regime on particle size distribution (PSD) were determined. A semi-detailed soot model and a chemical kinetic model, including poly-aromatic hydrocarbon (PAH) formation, were coupled with a spark ignition model and the G equation flame propagation model for the SI engine simulations and for predictions of soot mass and particulate number density. Qualitative agreements of in-cylinder particle distributions were obtained and results are helpful to understand particulate formation processes.

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The Drive for Minimum Fuel Consumption of Passenger Car Diesels: An Analytical Study to Evaluate Key Architectural Choices

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Fuel consumption, and the physical behaviours behind it, have never been of greater interest to the automotive engineering community. The enormous design, development and infrastructure investment involved with a new engine family which will be in production for many years demands significant review of the base engine fundamental architecture.

Future CO2 challenges are pushing car manufacturers to consider alternative engine configurations. As a result, a wide range of diesel engine architectures are available in production, particularly in the 1.4 to 1.6 L passenger car market, including variations in cylinder size, number of valves per cylinder, and bore:stroke (B/S) ratio. In addition, the 3 cylinder engine has entered the market in growing numbers, despite its historic NVH concerns.

Ricardo has performed a generic architecture study for a midsize displacement engine in order to assess the pros and cons of each engine configuration. A range of concept engine designs were prepared, drawing heavily on design guidelines and benchmarking information. Friction analysis was used to predict friction levels for each design. 1-D gas dynamics simulation was used for performance and fuel consumption prediction, which incorporates pumping losses and in cylinder heat transfer. Heat release curves were derived using in-cylinder 3-D CFD. Vehicle modelling was then used to assess vehicle drive cycle fuel consumption across several cycles.

Modelling detailed, small architectural changes challenges the simulation tools and techniques due to the balance of behaviours present, including friction, pumping and thermodynamic effects. Throughout the analysis activities, sensitivity studies on the modelling approach were carried out to ensure the approach was appropriate.

The study has enabled the definition of what is considered an optimum fuel consumption architecture in terms of cylinder number, number of valves per cylinder and cylinder proportions, with a rigorous understanding of the behaviours contributing to the fuel consumption across the cycles, and the subtle interactions between them.

Experimental Evaluation of an Advanced Ignition System for GDI Engines

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A plasma ignition system was tested in a GDI engine with the target of combustion efficiency improvement without modifying engine configuration. The plasma was generated by spark discharge and successively sustained to enhance its duration up to 4 ms.

The innovative ignition system was tested in an optically accessible single-cylinder DISI engine to investigate the effects of plasma on kernel stability and flame front propagation under low loads and lean mixture ($\lambda \cong 1.3$). The engine was equipped with the head of a commercial turbocharged engine with similar geometrical specifications (bore, stroke, compression ratio). All experiments were performed at 2000 rpm and 100 bar injection pressure.

UV-visible 2D chemiluminescence was applied in order to study the flame front inception and propagation with particular interest in the early combustion stages. A bandpass filter allowed selecting luminous signal due to OH radicals. Plasma ignition improved the efficiency and stability of early combustion stages. Moreover, increase in the OH emission intensity and area was detected. Flame front and OH emissions morphology were correlated with thermodynamic data and CO, NOx, HC exhaust emissions.

On Cooler and Mixing Condensation Phenomena in the Long-Route Exhaust Gas Recirculation Line

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The abatement of nitrogen oxides emissions is a topic of major concern for automotive manufacturers. In addition to aftertreatment solutions such as LNT or SCR devices, the use of exhaust gas recirculation (EGR) is necessary in most of the applications to meet emissions regulations. Due to the high specific humidity of the exhaust gases, a high condensate flow may be generated if EGR gases are significantly cooled down. In the case of long-route EGR (LR-EGR) usage, this condensate flow would reach the compressor wheel. This paper explores the variables governing the condensation process and the potential effects of the liquid droplets and streams on the compressor wheel durability combining experimental and theoretical approach. For this purpose, visualization of both the condensate flow and the compressor wheel are performed. Tests are conducted in a flow test rig in which LR-EGR water content is reproduced by water injection on the hot air mass flow. Two different sources of condensate flow are considered: LR-EGR cooling and fresh air and LR-EGR mixing. The potential of both of these sources to generate condensates is explored by means of a lumped psychrometric model solving LR-EGR cooling and mixing with intake flow. While LR-EGR cooling is a source of condensate flow at low coolant temperature (during engine warm-up) and limits LR-EGR rate at low load, condensation in the mixing process is very dependent on the ambient temperature. This source becomes important as ambient temperature comes down combined with low LR-EGR rate and high LR-EGR outlet specific humidity, imposing additional constraints to LR-EGR usage.

Review of Turbocharger Mapping and 1D Modelling Inaccuracies with Specific Focus on Two-Stag Systems

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The adoption of two stage serial turbochargers in combination with internal combustion engines can improve the overall efficiency of powertrain systems. In conjunction with the increase of engine volumetric efficiency, two stage boosting technologies are capable of improving torque and pedal response of small displacement engines. In two stage sequential systems, high pressure (HP) and low pressure (LP) turbochargers are packaged in a way that the exhaust gases access the LP turbine after exiting the HP turbine. On the induction side, fresh air is compressed sequentially by LP and HP compressors. The former is able to deliver elevated pressure ratios, but it is not able to highly compressor low flow rates of air. The latter turbo-machine can increase charge pressure at lower mass air flow and be by-passed at high rates of air flow. In fact, by-pass valves and waste-gated turbines are often included in two stage boosting systems in order to regulate operations and divert flow away from the turbocharger when necessary. By-pass valves are often external to the turbocharger and wastegates valves are incorporated in the turbine housing.

One-dimensional modelling approaches are considered fundamental to investigate interaction between boosting systems and internal combustion engines. In this scenario, turbomachinery performances are imposed into the model through compressor and turbine maps which are previously measured in gas stands as single stages. This procedure could not capture all the effects that occur in a system layout due to combination of heat transfer and motion of internal flow. This has a significant importance for defining HP compressor and LP turbine performances which could be influenced by swirling flows induced by the previous turbo-component in the series. Additionally, bends between the two compressors/turbines can reduce uniformity of flow and cause pressure drops at the same time. As in single turbochargers, heat transfer influences the boundary conditions which would influence performance predictions of the

machine in the sequence. In this paper, a review of the available literature containing approaches and study to quantify the effects of heat transfer on turbocharger efficiency and flow non-uniformities on two stage serial turbochargers performance predictions is explored. Furthermore, an appropriate mapping strategy has been proposed which could minimize the cause of inaccuracies in predicting turbochargers performance in two-stage systems. Conclusively, a methodology for map integration into 1D models has been proposed.

Experimental Characterization and Modelling of a Turbocharger Gasoline Engine Compressor By-Pass Valve in Transient Operation

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On actual gasoline turbocharged engines it is common to use a compressor by-pass valve in order to solve the compressor surge problem when the throttle pedal position is released and closes rapidly. The paper deals with a methodology based on experiments to measure the discharge coefficient of an integrated compressor by-pass valve, to understand the possible difference between the steady flow test bench and turbocharger test bench discharge coefficient measurements. To determine if there is some compressor outlet flow field influence due to compressor blades rotation that could modify the discharge coefficient measurement, compared to the steady flow test bench measurements, a fully instrumented turbocharger was used to measure the difference between steady flow test bench and turbocharger test bench discharge coefficients results. Effects of different boundary conditions on turbocharger test bench tests and how they affect the discharge coefficient measurement are also presented.

Furthermore, the measured compressor by-pass valve discharge coefficient on the steady flow test bench is used as input for an 1D model in order to verify or modify the compressor by-pass valve geometry design. The model is used to modify the compressor by-pass diameter and analyze the influence in the compressor behavior during a typical throttle pedal release situation.

The results should lead to design improvements and better understanding of these integrated compressor by-pass valves in order to avoid compressor surge in gasoline turbocharged engines during a throttle pedal release situation.

Use of Ionization Current to Estimate CO Rate in a Small 2-Stroke SI Engine

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This paper presents an experimental study on a 2-stroke SI engine, used on small portable tools for gardening or agriculture, aimed to identify possible correlations between parameters related to ionization current and air/fuel mixture richness, considering different fuels and spark plug wear. This, to realize a simple system to control the engine parameters and adapt them to engine aging and fuel type changing.

The engine was fed with commercial gasoline, low octane number gasoline, alkylate gasoline and a blend of 80% gasoline and 20% ethanol. In all tests carried out with varying engine speed and spark advance the ionization signal was characterized by a single peak, resulting in the impossibility of distinguishing chemical and thermal ionization. All data collected were analyzed looking for correlations between all the available data of CO emissions and several characteristic parameters obtained from the ionization signal.

The correlations are targeted to estimate CO rate at exhaust so as to realize a virtual CO sensor for AFR control purposes. An effective strategy, based on the measurement of a series of ionization waveforms while the richness of the mixture is changing, normalized with respect to the maximum values and considering operating conditions where CO rate is more than 2%, is set up making feasible the control of these small 2-stroke engines using the ionization current signal.

Numerical Investigation in a Gear Drive of an Engine Balancing Unit with Respect to Noise, Friction and Durability

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This paper presents a methodology for numerical investigation of a full flexible balancer drive together with engine and crank train under realistic operating conditions where shaft dynamics, gear contact and rattle impacts, gear root stresses and friction losses in bearings and gear interaction are taken into account and can be balanced against each other to achieve the design criteria.

Gear rattle is driven by the speed fluctuation of the crank train, the resistance torque (mainly friction), shaft inertia and the backlash in the gears. The actual trend to engine downsizing and up-torqueing increases the severity to rattle as engines are running on higher combustion pressures. This increases torque and speed fluctuation, which makes the detailed investigation in this torque transfer even more demanding.

A common method to reduce gear rattle is the usage of so-called scissors gears. The layout of those gears has significant influence on the gear durability and the overall losses, which requires a detailed and precise model to find the best compromise for the spring stiffness and preload.

The investigation is shown for a modern Inline 4-cylinder Diesel engine, equipped with a 2nd order mass balancing system and scissors gear between the crankshaft and the first balancer shaft. The change of gear contact loads, gear rattle, root stresses and balancer drive losses versus the operating range is

presented and discussed. Sensitivity analysis of gear profile data and parameters of the scissors gear is performed.

This methodology allows the engineer a precise layout and detailed design of such system to reduce noise and losses and avoid gear failure, considering main and contra-dictionary effects, and within reasonable time.

Experimental and Numerical Comparison of the Acoustic Performance of the Air Filter Box of a SI-ICE

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In an Internal Combustion Engine, the design of the intake system is a very critical aspect since it affects both the engine power output and noise emissions at the intake side. In particular, downsized VVA engines typically produce higher gas-dynamic noise levels since, due to the intake line de-throttling at part-load, a less effective attenuation of the pressure waves is realized. In this work, the acoustic performance of the intake air filter of a commercial VVA engine is numerically and experimentally analyzed. In particular, a FEM model of the system is realized in order to compute the Transmission Loss (TL) parameter of the base device. The numerical analysis accounts of fluid-structure interaction, which gives the possibility to determine the effect of structure participation on the TL profile. Contemporarily, the experimental tests are performed on an acoustic test bench based on the multi-microphone technique for the evaluation of the acoustic parameters. Numerical outcomes are compared with experimental findings, showing a very good correlation.

Yaw Moment Control of the Vehicle by Means of a Magnetorheological Semi-Active Differential

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A new controllable limited slip differential is proposed and tested in software environment. It is characterized by the employment of a magnetorheological fluid, which presents the property of changing its rheology thanks to an applied magnetic field. A vehicle model has been designed and employed for the synthesis of a sliding controller. The control is based on a double level scheme: the upper controller aims to generate the target locking torque, while the lower controller generates, as control action, the supply current for the controllable limited slip differential.

The obtained results show the effectiveness of the device in terms of vehicle dynamics improvement. Indeed, the results reached by the vehicle in presence of the new differential confirm the improved performances for both steady and unsteady state manoeuvres.

Application of Order Analysis for Gear Fault Diagnosis under Variable Speed Conditions

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A vehicle gearbox serves for torque and speed conversion with help of rotating elements. Therefore the gearbox experiences periodic excitation forces with a fundamental frequency following the rotation frequency. These excitation forces give rise to corresponding periodic response signals, i.e. signals having content at the fundamental (rotational) frequency and its harmonics. Order analysis is an analysis technique which is used to extract these harmonic orders from the response signals. This article intends to use the order tracking analysis for gearbox fault diagnosis under variable speed conditions to compare between healthy and faulty cases by using order extraction. Finally, determine maximum Root Mean Square (RMS) as severity index. All the experimental data are acquired from vehicle gearbox which is tested on the laboratory stand equipped with three dynamometers; the input dynamometer serves as internal combustion engine, the output dynamometers introduce the load on the flanges of output joint shafts. The pitting defect is manufactured on one tooth of pinion gear on the output shaft. The results are obtained from practical experiments prove that order tracking analysis is a correct way for gear fault diagnosis under variable speed conditions. One can thus say that the order tracking analysis method has extracted narrow-band (order) information from the signal which is not revealed in the frequency spectrum.

An Investigation of Sub-Synchronous Oscillations in Exhaust Gas Turbochargers

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Due to the demands for today's passenger cars regarding fuel consumption and emissions, exhaust turbo charging has become a fundamental step in achieving these goals. Especially in upper and middle class vehicles it is also necessary to consider the noise comfort. Today, floating bushings are mainly used as radial bearings in turbochargers. In the conventional operating range of the turbocharger dynamic instability occurs in the lubrication films of the bearings. This instability is transferred by structure-borne noise into audible airborne sound and known as constant tone phenomenon. This phenomenon is not the major contributor of the engine noise but its tonal character is very unpleasant.

In order to gain a more detailed understanding about the origin of this phenomenon, displacement sensors have been applied to the compressor- and the turbine-side of the rotor, to be able to determine the displacement path. Also, part of this investigation is the measurement of the rotational speed of the floating bearing bushings on turbine-and compressor-side of the turbocharger. The investigations are carried out on turbochargers from 1.6l and 2.0l four-cylinder gasoline engines. The turbocharger has been decoupled from the internal combustion engine to separate the turbocharger related effects from engine related sources.

The constant tone can be identified in both the structure-borne and the airborne noise of the turbocharger. At the beginning of the constant tone, during a ramp-up of the rotor, the amplitude of the shaft-movement increases on turbine-and

compressor-side. At the same time, a high, jump-like increase in the bearing bushing speed is ascertained. For a detailed analysis, the signals from the displacement sensors are separated into their components, consisting of 1st order of the rotor and the sub-synchronous oscillations. It is shown that the proportion of 1st order in amplitude remains unchanged and the proportion of sub-synchronous oscillation increases significantly. This oscillation is transmitted by the bearing system to the turbocharger housing and emitted from there to structure-borne and airborne noise.

Considering now only the sub-synchronous portion of the movement on the turbine-and compressor-side, not only an increase in the amplitude can be seen, but also a change in motion of the rotor at the start of the constant tone, from a conical into a cylindrical motion.

Evaluation of Valve Train Variability in Diesel Engines

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The continuously decreasing emission limits lead to a growing importance of exhaust aftertreatment in Diesel engines. Hence, methods for achieving a rapid catalyst light-off after engine cold start and for maintaining the catalyst temperature during low load operation will become more and more necessary. The present work evaluates several valve timing strategies concerning their ability for doing so. For this purpose, simulations as well as experimental investigations were conducted. A special focus of simulation was on pointing out the relevance of exhaust temperature, mass flow and enthalpy for these thermomanagement tasks. An increase of exhaust temperature is beneficial for both catalyst heat-up and maintaining catalyst temperature. In case of the exhaust mass flow, high values are advantageous only in case of a catalyst heat-up process, while maintaining catalyst temperature is supported by a low mass flow. Another focus of simulation was on analyzing the exhaust temperature gaining effects relevant for the considered alternative valve timings. Simulation results have shown that an early exhaust valve opening, a late intake valve closing and the deactivation of cylinders is of particular interest for exhaust thermomanagement. Besides the validation of simulation results, the main focus of measurements was on analyzing effects which are not covered by simulation (transient operation, cold engine conditions 298 K, emissions, test cycles), which is exemplarily shown here for early exhaust valve opening (EEVO). In addition to the methods based on alternative valve timings, conventional exhaust thermomanagement methods like a retarded combustion were also considered in simulations. Moreover, an electrical heating device was considered experimentally and compared to EEVO in the FTP75 with regard to SULEV30 for passenger cars.

A High Resolution 3D Complete Engine Heat Balance Model

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The focus on engine thermal management is rapidly increasing due to the significant effect of heat losses on fuel consumption, engine performance and emissions. This work presents a time resolved, high resolution 3D engine heat balance model, including all relevant components. Notably, the model calculates the conjugated heat transfer between the solid engine components, the coolant and the oil. Both coolant and oil circuits are simultaneously resolved with a CFD solver in the same finite volume model as the entire engine solid parts.

The model includes external convection and radiation. The necessary boundary conditions of the thermodynamic cycle (gas side) are mapped from a calibrated 1D gas exchange model of the same engine. The boundary conditions for the coolant and at the oil circuits are estimated with 1D models of the systems. The model is calibrated and verified with measurement data from the same engine as modeled. The simulation results are also compared with other measurements of similar engines.

Experiments give information on the absolute energy flows in the engine system (fuel input, mechanical power and heat flows). This is used to calibrate and verify the overall accuracy of the numerical model. The model gives high-resolution space-time temperature distribution of all modeled components. Therefore, it can be used to study in detail the difference between alternative thermal management strategies. Furthermore, the model can give information about critical local temperatures for durability. These types of information are important for the optimal design of the complete vehicle cooling system, the engine-bay thermal management and the structural reliability of the engine.

Fuel Transport across the Piston Ring Pack: Development of a Computationally Efficient Simulation Model

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Increased quantities of fuel in the lubricating oil of CI engines pose a major challenge to the automotive industry in terms of controlling the oil aging and the wear caused by dilution. Due to a lack of methods to calculate the oil-fuel-composite transport across the ring pack, predicting the fuel ratio in the oil sump has been an extremely challenging task for engine manufacturers. An accurate and computationally efficient simulation model is critical to predict the quantity of fuel diluted in the oil in the preliminary development stage of automotive engines.

In this work, the complex composite transport across the piston ring pack was reduced to a simple transport model, which was successfully implemented into a multi-body simulation of the ring pack. The calculation domain was partitioned into two parts, the ring grooves and the piston lands. Inside the grooves the oil flow caused by the pumping and squeezing action of the piston rings was calculated using the Reynolds equation. On the piston lands simplified Navier-Stokes equations were used to calculate the oil flow caused by the inertia force and dragging action of the blow-by gases.

This reduced model enables a calculation of the composite transport in a minimum of time and is therefore well suited for DoE. The main oil flow was observed to be driven by the dragging action of the blow-by gases. The computed integral volume of fuel leaking into the oil sump was successfully validated against the measured value of accompanying experiments.

Fuel Transport across the Piston Ring Pack: Measurement System Development and Experiments for Online Fuel Transport and Oil Dilution Measurements

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The limitation of fuel entry into the oil sump of an internal combustion engine during operation is important to preserve the tribological properties of the lubricant and limit component wear. For observation and quantification of the effects leading to fuel entry, a highly sensitive and versatile measurement system is essential. While oil sampling from the sump followed by laboratory analysis is a common procedure, there is no system for automatic sampling of all the positions and fast online analysis of the samples.

For the research project ‘Fuel in Oil’, a measurement system was developed especially for the described tasks. The system is placed next to the engine in the test cell. Sampling points are the target point of the fuel injector jet and the liner below, the oil sump and the crankcase ventilation system. The system consists of a microliter volume and an aerosol sampling setup, a probe evaporator, an isothermal gas chromatograph and a triple quadrupole mass spectrometer with a modified ion source.

To quantify the fuel emission from the cylinder wall into the exhaust, an online exhaust gas measurement was carried out using a direct inlet system with the same mass spectrometer.

With the use of the described setup, it was possible to observe and quantify the effects leading to fuel entry into the oil sump as well as fuel leaving the sump.

Evaluation of Fuel Economy Potential of an Active Grille Shutter by the Means of Model Based Development Including Vehicle Heat Management

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In the automotive field, reducing harmful pollutant, CO2 emissions and fuel consumption of vehicles while increasing customer comfort is a continuous challenge that requires more and more sophisticated technology implementations. However, it is often difficult to anticipate the advantages and drawbacks of a technology without having its prototype parts and/or knowing the optimal control strategy. In order to meet these challenges, the authors have developed a vehicle thermal model in AMESim platform to evaluate the benefits of an Active Grille Shutter (AGS) on fuel economy when applied. The vehicle model was based on a C-Segment vehicle powered by a 1.4L Diesel engine. The complete oil and coolant circuits were modeled as well as a friction model based on engine coolant and oil temperature. The entire model was validated on the European homologation cycle (NEDC) at −7°C and +25°C ambient temperature and achieved an accurate estimation of the fuel consumption, coolant and oil temperatures. Then, an AGS model was developed and integrated into the vehicle thermal model in order to assess the control of the coolant temperature (radiator cooling efficiency) and the vehicle road load (drag coefficient). Several control strategies were investigated on an in-house country-highway driving cycle to clarify the best compromise among fuel consumption reduction, engine coolant temperature control stability and AGS durability. The model demonstrated a potential fuel economy of 1.7% and 2.0% at +25°C ambient temperature on NEDC and in-house country-highway driving cycles respectively. In addition, the model showed further fuel economy up to 2.4% on NEDC at −7°C ambient temperature thanks to the combined effects of reduced frictions and road load. Finally, simulation and experimental results were compared and the fuel economy predicted by the model achieved a deviation lower than 0.3%.

Engine Modeling and Diagnostics
Engine Combustion
Fuels and Lubricants
Exhaust Aftertreatment and Emissions
New Engines, Components, Actuators, & Sensors

Hybrid and Electric Powertrains

Drive Cycle Particulate and Gaseous Emissions from a Parallel Hybrid Combustion Engine and Electric Powertrain

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The emissions from a parallel hybrid combustion engine and electric powertrain operated on a modified New European Drive Cycle (NEDC) was investigated in order to determine the relation between emissions and the road and engine load profile. The effect of simulated electric motor assistance during accelerations on emissions was investigated as a means to reduce particulate and gaseous emissions. The time resolved particulate number and size distribution was measured in addition to gaseous emissions. The combustion engine was a downsized, three cylinder spark ignited direct injection (SIDI) turbocharged engine fuelled with gasoline. Electric motor assistance during accelerations was simulated by reduction of the vehicle mass. This reduced engine load during accelerations. Fuel rich engine transients occurred during accelerations. NOx emissions were reduced with electric assistance due to a reduction in engine load. CO emissions were the result of air to fuel ratio transients and increased slightly with electric assist. HC emissions occurred during deceleration with downshifts. Particulate emissions were attributed to soot formation from fuel rich engine transients during accelerations and fuel rich engine operation at large load and both particulate number and mass emissions peaked during accelerations. Particulate number emissions increased with electric assistance. The reduction of in cylinder temperatures with electric assist due to reduction in engine load is hypothesized to have resulted in reduced in-cylinder soot oxidation and the observed increase in particulate number emissions with electric assist. Both with and without electric assist the particle size distributions were centered at 100 nm. Simulated electric motor assistance during load accelerations reduced fuel consumption as expected.

Design and Development of a Test Rig for E-bike Performance Evaluation

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The paper describes the development of an innovative test rig for the evaluation of e-bikes in terms of energetic performances and control system.

The test rig has been realized starting from a commercial cyclist training system and suitably modified. The test rig is able to reproduce an aforethought route or paths acquired during road tests. It is possible to measure the performance of the e-bike in terms of instantaneous power and speed, by the installed sensors and data acquisition system. The experimental test rig can simulate the resistant torque of a predetermined track and it aims to test and to optimize the control strategy available on the electronic control unit (ECU). An important feature of the system is represented by the possibility to adopt a hardware in the loop approach for the testing of the e-bike and of its control. Indeed, the whole control algorithm can be implemented on a suitable controller board able to execute real time processes.

The preliminary tests have been carried out for the development of a new model of pedelec designed at the Department of Industrial Engineering of the University of Naples Federico II. The research activity has been financially supported by MIUR (Ministero Istruzione Università e Ricerca) under the grant named PON04a3_00408 “Bicicli e Tricicli elettrici a pedalata assistita di nuova generazione”.

The experimental results have allowed to evaluate the performance of the electric bike for several simulated tracks in the urban area of Naples, Italy.

Development of a Fuel Economy and CO_2 Simulation Platform for Hybrid Electric Vehicles - Application to Renault EOLAB Prototype

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The worldwide trends for future CO_2 regulation standards will push car manufacturers for more and more development of Electric and Hybrid Electric Vehicles. Many different configurations of Hybrid Electric Vehicles exist, including parallel hybrid, series hybrid, plug-in hybrids, Battery Electric Vehicles with Range Extender, etc. The choice of the optimal architecture depends on many different parameters, and is a key issue to be solved at the beginning of vehicle development.

In order to help decision making in the early phase of projects, simulation tools are essential. A specific simulation platform for simulation of fuel economy and CO_2 emissions for hybrid electric vehicles has been developed by Renault. This platform called GREEN is dedicated to the selection of vehicle and powertrain architecture, to the pre-design of powertrain components, and to the determination of Fuel Economy and CO_2 targets in the early phase of projects, and to monitoring of Fuel Economy and CO_2 during vehicle development.

Design of the Storage System of a High Performance Hybrid Vehicle

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Within the “Industria 2015” Italian framework program, the HI-ZEV project has the aim to develop two high performance vehicles: one full electric and one hybrid. This paper deals with the electric energy storage (EES) design and testing of the hybrid vehicle.

A model of the storage system has been developed, simulating each cell like an electric generator with more RC circuits in series. To take account of the heat transfer, a forced convection model has been used with the air speed proportional to the vehicle speed.

The model had two calibration steps: the first has determined the electrical parameters of the model (open voltage circuit, internal resistances and capacitors); the second to calibrate the heat transfer model. The first calibration has been made on a climatic chamber at 23 °C discharging one single module with different constant currents from 5C (5 times the nominal capacity) to 25C and charging with currents in the range from 1C to 5C. (where C means the current rate the flow in the battery in 1 hour)

The results show that for all the tested cycles the battery pack designed is able to run safely, not exceeding the limit temperature (50 °C). The model developed and validated can be a useful tool in the design phase of a battery pack system.

Dynamic Simulation of Hybrid Powertrains using Different Combustion Engine Models

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This study presents a comparison of different approaches for the simulation of HEV fuel consumption. For this purpose a detailed 1D-CFD model within an HEV drivetrain is compared to a ‘traditional’ map-based combustion engine model as well as different types of simplified engine models which are able to reduce computing time significantly while keeping the model accuracy at a high level.

First, a simplified air path model (fast running model) is coupled with a quasi dimensional, predictive combustion model. In a further step of reducing the computation time, an alternative way of modeling the in cylinder processes was evaluated, by replacing the combustion model with a mean value model. For this approach, the most important influencing factors of the 1D-CFD air path model (temperature, pressure, A/F-ratio) are used as input values into neural nets, while the corresponding outputs are in turn used as feedback for the air path model. However, while the computing speed of the simulation can be further increased, this model type loses its predictiveness, compared to detailed combustion models.

The performance of said engine models is evaluated within a HEV drivetrain model. Results for the New European Driving Cycle as well as the Artemis Urban Driving Cycle are shown.

Optimal Components Design of a Fuel Cell Electric Vehicle

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Alternative vehicle powertrains (hybrid, hydrogen, electric) are among the most interesting solutions for environmental problems afflicting urban areas. Electric and hybrid vehicles are now slowly taking place in the automotive sector, but on a Tank To Wheels (TTW) basis, the most effective alternative powertrain is surely represented by Fuel Cell Electric Vehicles (FCEV): those fuelled by hydrogen seem to be the ones closest to market. The design of a FCEV however, is not straightforward and involves several issues (fuel cell sizing, hydrogen storage, components efficiency, sizes and weights).
Basing on these considerations, the Authors present a software procedure for the optimal design of the components of a passenger FCHEV (Fuel Cell Hybrid Electric Vehicle).
A comprehensive energy balance of the whole vehicle during a driving cycle has been implemented in order to find the overall optimal sizing and control strategy of the fuel cell, the energy storage system (ESS) and the hydrogen storage system. The propulsive power needed to run a car on a given reference driving cycle, in fact, may be given by the two on-board power sources: hydrogen and electricity, stored in proper ESS. At the same time, power requirements depends also on the whole vehicle weight, which comprehends fuel cell, batteries and fuel tank weight and hydrogen amount (each of which having to be opportunely evaluated in relation to designing parameters). In particular, fuel cell and battery power have to fulfill the traction power request, while fuel tank and hydrogen amount (which may be stored on-board through various different technologies and at different thermodynamic conditions: gaseous or liquefied at different temperatures and pressures) have to fulfill vehicle mileage requirements.
Different designing options of electricity and hydrogen on-board storage technologies are here compared by the Authors, in order to evaluate the effect of various design parameters (including mileage, FC maximum power output, hydrogen storage pressure and others) on the overall performances of the vehicle (including its weight and overall energy consumption).

A New Control Scheme for Automated Manual Transmission with Electromagnetic Powder Clutch

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This study aims to provide modeling and control approaches for automated manual passenger and commercial vehicle transmissions in order to improve the overall disengagement-gear shifting-engagement performance using electromagnetic powder clutch (EMPC). The rationale behind selecting this clutch is its rapid behavior.

During the modeling procedure of the EMPC, the analogy between this type of clutches and dry plate friction clutches has been exploited and a simple control method is proposed.

The study also includes modeling method for gear shifting and selecting mechanisms of the automated manual transmission gearbox as well as development and implementation of controllers which is designed for these mechanisms. Automated manual transmission gearbox is utilized due to its combination of ease of construction and ability for electronic automation.

Optimal Energy and Emission Management of a Diesel Hybrid Electric Vehicle Equipped with a Selective Catalytic Reduction System

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This paper deals with the problem of obtaining the optimal energy and emission management strategy for a diesel hybrid electric vehicle. The vehicle is assumed to be equipped with a selective catalytic reduction device for the removal of harmful NOx emissions.

The authors present a model-based procedure: The energy flows of the hybrid vehicle are modelled in a standard way, while the engine-out emissions are calculated based on a temperature-corrected engine map. For the simulation of the SCR system a combination of two existing first-principle physical models is used. The optimal energy and emission strategy for a given driving cycle is then obtained using dynamic programming.

In terms of results, three case studies are presented. One case study illustrates the trade-off between fuel consumption and tailpipe NOx emissions for various relative weights of these objectives. The second case study investigates the influence of the size of the SCR system on fuel consumption and tailpipe NOx emissions. The third case study shows the influence of neglecting the thermal effects and the emission considerations in the derivation of the optimal control strategy.

ORAL PRESENTATIONS

Long-term Source Apportionment of Ambient PM2.5 in the Los Angeles Basin: A Focus on Emissions Reduction from Vehicular Sources

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Positive Matrix Factorization (PMF) was utilized to identify and quantify sources of PM2.5 in central Los Angeles (LA) and Rubidoux, using the Speciation Trends Network (STN) data, collected between 2002 and 2013. Vehicular emissions (including both gasoline and diesel vehicles) were found to be the second major contributor to PM2.5, following secondary aerosols, with a near 20% contribution to total mass in both sites. During 2002 to 2004, the median and annual average values of vehicular emissions were relatively constant at both sites. Their contributions peaked in 2007 and 2005, respectively in LA and Rubidoux, while trended downward afterward until 2013. In 2013, the median values of daily-resolved vehicular emissions source contributions in LA and Rubidoux were respectively 70 and 52% lower than their corresponding values in 2007 and 2005. Starting in 2007, all manufactured diesel trucks must meet the EPA 2007 emission standard, requiring a 90% reduction in their PM emissions. Moreover, after 2007, several major steps were taken by the California Air Resources Board and the ports of LA and Long Beach to reduce emissions from vehicular sources, particularly from diesel trucks. To assess the effect of these regulations, daily-resolved vehicular emissions source contributions from 2002 to 2006 were pooled together and compared to the combination of 2008 to 2012 datasets. Compared to 2002-2006 dataset, the median values of vehicular emissions in 2008-2012 statistically significantly (p 0.001) decreased by 24 and 21% in LA and Rubidoux, respectively. These reductions were noted despite an overall increase (about 5%) in the median value of the daily flow of vehicles in downtown LA after 2007, while the traffic counts were comparable before and after 2007 in Rubidoux. Overall, our

findings demonstrate the effectiveness of stringent regulations in reducing PM emissions from vehicular sources in the LA basin over the past decade.

Effects of Lubricant Composition on Low-Speed Pre-Ignition in Direct-Injection Spark-Ignition Engines

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The requirement to lower CO_2 emissions and improve fuel consumption is driving the increased penetration of downsized boosted gasoline engines in all markets. These engines have increased susceptibility toward low speed pre-ignition (LSPI), which has been shown to have some sensitivity to lubricant composition. Mega- (or super-) knock events with high peak pressures (250-350 bar) and high knock intensity (up to 130 bar peak-to-peak) may follow LPSI. A single "mega-knock" event has the potential to cause severe engine damage. LSPI constrains the advancement of aggressively downsized engines with progressively increasing boost pressures and reducing swept-volume, and so is a barrier to all engine manufacturers pursuing this technology route.

It is known that lubricant can enter the combustion chamber *via* the top land crevice either as a lubricant droplet or a particle and various studies have visualised experimentally the phenomena of pre-ignition thought to be due to this mechanism. This paper re-visits the potential mechanism of lubricant-derived droplets effecting LSPI using a single-cylinder optical spark-ignition engine. Evidence for lubricant droplets traversing the combustion chamber and auto-igniting the fuel-air mixture is discussed before the occurrence of the spark event. A range of lubricants conforming to the SAE 16 grade and comprising different types and quantities of metal-based additives is assessed with respect to their propensity to exacerbate or suppress pre-ignition. Two turbocharged direct-injection spark-ignition (DISI) engines, using different injector configurations, were employed. The influence of lubricant composition was generally similar across engine configurations that calcium-based detergents were found to worsen PI whereas magnesium-based detergents were found to be benign. Evidence was found for zinc dialklydithiophosphate (ZDDP) acting to supress LSPI.

Direct Numerical Simulation of Flow Physics and Chemistry inside SCR Reactors

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The selective catalytic reduction (SCR) is perhaps the most efficient process to reduce nitrogen oxides (NOx) emissions in engine exhaust gas. Research efforts are currently devoted to realizing and tuning SCR-reactors for automotive applications to meet the severe future emission standards, such as the European "Euro VI", in terms of NOx and particulate matter produced by vehicles. In this paper, for the first time, we develop a detailed 2D computational model to study the performance of a SCR reactor.

Our model is based on the Lattice Boltzmann Method (LBM), which has been recently adopted for the study of complex phenomena of technical interest, and it is characterized by a detailed reproduction of both the porous structure of SCR reactor and the fluid-dynamic and chemical phenomena that take place in it. The aim of our model is to predict the behavior and performances of SCR reactor by accounting for the physical and chemical interactions between exhaust gas flow and the reactor. Our results prove the reliability of our model as an accurate numerical tool for SCR performance prediction across physical space-scales.

Can RANS Models show Cycle-to-Cycle Variations in Internal Combustion Engine Simulations?

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Reynolds-averaged Navier-Stokes (RANS) modeling is expected to deliver an ensemble-averaged result for the majority of turbulent flows. This could lead to the conclusion that multi-cycle engine simulations performed using RANS must exhibit a converging numerical solution after a certain number of consecutive cycles. However, for some engine configurations, unsteady RANS simulations are not guaranteed to deliver an ensemble-averaged result. In this presentation it is shown that, when using RANS modeling to simulate multiple engine cycles, the cycle-to-cycle variations (CCV) coming from different initial conditions at each cycle are not damped out even after a large number of cycles. A single-cylinder GDI research engine is simulated using RANS modeling and the numerical results for 20 consecutive engine cycles are evaluated for selected operating conditions, characterized by different COV_{IMEP} values. Numerical results show good agreement with experimental data in terms of cyclic variability. An in-depth analysis of the most significant physical and chemical quantities highlights that CCV are caused primarily by the variability of the in-cylinder flow. For stoichiometric combustion this does not greatly affect flame propagation. However, in the event of dilute combustion, the variability of the flow gains more importance, therefore delivering large cyclic fluctuations of the in-cylinder pressure traces. This presentation demonstrates that the occurrence of CCV when using multi-cycle RANS modeling is not a numerical artifact but an intrinsic feature of engine simulations that can only be damped out by increasing numerical viscosity. As such, RANS simulations have the potential to capture typical combustion stability features in an internal combustion engine.

The Achates Power Opposed-Piston Engine: Dawn of a New Age of Brake Thermal Efficiency

Dave Johnson, John Koszewnik, Roland Martin

Achates Power, Inc.

Globally, governments are passing more stringent CO_2 regulations. To meet these standards, car and truck manufacturers are evaluating new technologies. However, most of these technologies deliver only a modest improvement over the current status and cause a significant increase in manufacturing cost. In order to meet upcoming emissions regulations without incurring excessive cost, OEMs are now considering alternative engine architectures, including the opposed-piston engine.

The opposed-piston engine has several inherent advantages over conventional engine architectures, including reduced heat losses, leaner combustion and faster and earlier combustion at the same pressure rise rate. With the benefit of computer-aided engineering tools and the latest engineering practices, Achates Power has optimized the basic opposed-piston architecture, introducing a patented combustion system and thermally optimized design. At the same time, historic challenges (emissions, oil consumption, thermal management, durability) have been addressed and successfully resolved.

In addition to an overview of these efficiency and emissions enablers, the technical paper will include detailed dynamometer results of an Achates Power multi-cylinder prototype engine configured to meet international vehicle emissions requirements. These results demonstrate the engine's ability to achieve Euro 6 and EPA 2010 emissions standards while significantly improving fuel efficiency over the best diesel engines in the same class.

The paper also includes a discussion of planned road map items for further optimizations to combustion, pumping and friction in order to further increase the brake thermal efficiency (BTE) and achieve targets far beyond 46% (on cycle average) using the example of a future medium-duty production engine. An outlook on the scalability of the technology from small engines for compact passenger cars to heavy-duty truck will also be presented.

Particle Number and Size Distribution Measurement from Engine Exhaust in the field and in the lab

Séverine Dubroecq, Thomas Krinke, Torsten Tritscher

TSI GmbH, Particle Instruments

Emissions from engines and almost any combustion process are a worldwide known issue with negative impacts on human health and the environment. In the recent years the combination of modern engine technologies, efficient aftertreatment and emission standards has led to drastically lower particle emission levels in Europe. Particularly the introduction of diesel particulate filters (DPF) has significantly reduced the total mass and number of particulate matter emissions from diesel engines. When operating properly, DPFs can remove greater than 99% of particulate matter from the exhaust. Nonetheless the conventional methods defined to test particle emissions fail at such low levels as they are aimed at determining the mass of the particles. This led to particle number (PN) measurement as the method of choice for low particle emissions. With emission standards like Euro 5b/6 or Tier 4, solid PN concentration has become a proven and widely accepted metric for researchers and regulators to determine compliance of various combustion sources with emissions limits. A portable instrument capable of measuring the total number concentration of solid particles resulting from combustion sources has been developed. The Nanoparticle Emission Tester (NPET, TSI Model 3795). This field instrument consists of a built-in sample dilution and conditioning system that prevents condensation and removes humidity and supermicron particles from the sample. Volatile particles are removed by a built-in catalytic stripper (CS) before the number concentration of solid particles is measured using an isopropanol based condensation particle counter (CPC). The NPET is capable of measuring number concentration from less than 1 000 to 5 000 000 particles per ccm. The emission tester provides reliable measurements below the detection threshold for opacimeters and has been certified by METAS as compliant testing instrument for Switzerland's new emissions regulation 941.242.

The TSI Engine Exhaust Particle Sizer™ (EEPS™) spectrometer is widely used to measure the submicrometer size distribution of fast changing aerosols. It records particle size distributions at a rate of 10 Hz; allowing for the measurement and analysis of rapidly changing aerosols. For slow transient (down to time resolution of 0.2Hz) or steady-state aerosols, higher resolution measurements can be made using the TSI Scanning Mobility Particle Sizer™ (SMPS™) spectrometer.

Automotive industry: many solutions for higher performance

Fabio Sgarzi

SIAD Spa

In an increasingly competitive global marketplace, many vehicle manufacturers seek process improvements and solutions, which will enhance their productivity and performance and give them an edge. SIAD, a leader in the development of innovative technologies, continuously invests in research and development in order to come up with advanced, cost-effective solutions that benefit its customers.

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- The EasyCleaner® kit consists of an innovative device and a special mixture for the MIG/MAG welding torches cleaning.

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- gas mixtures calibrated analytically by comparison with other traceable samples of the Centre in accordance with standard ISO 6143; these are the traceable mixtures.

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- Cryo cleaning: Used along all the automotive supply chain, the cryo cleaning is the most effective and environmentally sustainable system to increase productivity and reduce production costs.

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