SAE NAPLES SECTION

ICE2013

11th International Conference on Engines & Vehicles

September 15-19 @ Capri, Napoli

abstracts

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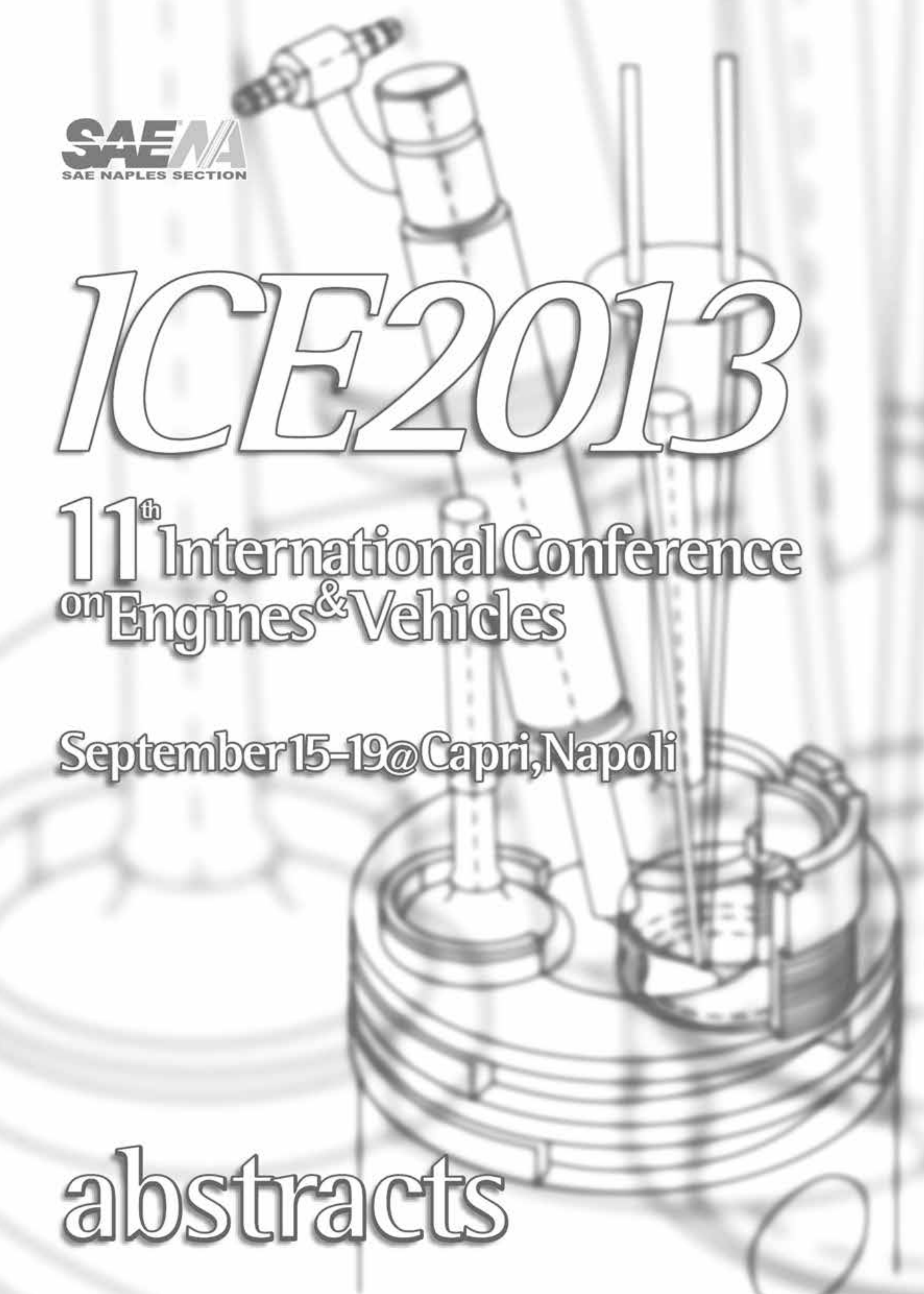

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SAE NAPLES SECTION

ICE2013

11th International Conference on Engines & Vehicles

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The Use of Ethanol Fuels in Engines	**Sebastian Verhelst** *Ghent University (Belgium)*

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Preface

Dwindling fuel reserves and greenhouse gas concerns have resulted in aggressive new fuel economy and CO2 emissions standards in Europe, the Americas, and Asia. Meanwhile, continued public health concerns have brought about stricter criteria emissions standards and new particulate number limits. As a result, vehicle manufacturers are under enormous pressure to simultaneously improve vehicle efficiency while lowering harmful emissions. To reach the required targets, advanced engine and hybrid-electric vehicle technologies as well as the use of alternative fuels will be required.

ICE2013, the 11th International Conference on Engines & Vehicles, is intended to facilitate the rapid development of the required technologies and their adaptation to alternative fuels. The organizers, Sandia National Laboratories, Istituto Motori – National Research Council of Italy (CNR), and SAENA – the Italian Section of SAE International, have again selected the isle of Capri to provide an ideal setting for a fruitful interaction among research centers, academic institutions, and industries that are involved in the engine and vehicle technologies fields.

To encourage international participation and intensive discussion, 180 papers from approximately 30 countries have been selected for presentation after a rigorous review process following SAE International standards. These contributions cover a wide variety of aspects, from advanced internal combustion engines to hybrid systems, from liquid and gaseous fuels to alternative fuels, and from innovative experimental diagnostics to the newest numerical methodologies for modeling, simulation and control. In addition, experts in several topical areas have been invited to deliver plenary lectures on the state-of-the-art and future development trends for the disciplines associated with the conference.

We want to express our gratitude to the staff of SAE International, and in particular to Melissa Jena and Abby Hartman, for their kindness and their precious help. We also thank the session and sub-session organizers for volunteering and for their hard work; and all the authors and reviewers for their contributions. A right and proper thank you is also due to our sponsors for their financial support.

Finally, special thanks are due to all those who contributed to the organization of ICE2013 with their enthusiasm, effort and time.

Paul Miles and Bianca M. Vaglieco

Plenary Lectures

Directions and Future Challenges in Vehicular Emissions

Timothy V. Johnson
Corning Incorporated (USA)

The vehicular industry is facing unprecedented challenges moving forward. In developed markets, citizens and regulators are requiring near-zero criteria pollutant emissions and aggressive tightening of greenhouse-gas emissions. In developing countries, citizens and governments are facing growth challenges, very high pollution levels, and energy security issues. Templated across all this is the prognosis for stable fossil-fuel energy sources and pricing, and the impact on attractiveness of advanced vehicle technology and on the environment. This presentation attempts to take a high-level perspective on the challenges, and offers some perspectives.

Vehicle efficiency is economically advancing while tailpipe emissions are dropping. Technologies such as direct injection gasoline, improved diesel combustion, hybridization, weight reduction, exhaust filters, and advanced lean-NOx technology like SCR (selective catalytic reduction) are providing clean, economical, and efficient transportation; and more advances are in the works, such as the multitude of low-temperature combustion strategies. Future challenges include low-temperature criteria pollutant reduction.

In the developing markets, stable economic growth is synergistic with advanced vehicle technology, wherein clean trucks and buses can return to owners and society attractive payback periods in fuel savings and reduced health costs.

Future challenges will be on developing ever-more efficient vehicles that are still attractive to consumers with regard to first cost and operating cost.

Can Surrogate Fuels Improve CI Engine Performance?

Charles J. Mueller
Sandia National Laboratories, Livermore, California, (USA)

The high-efficiency, low-emissions, compression-ignition (CI) engine will remain a key powertrain component for mobility and industrial applications for the foreseeable future. While a great deal of effort has been devoted to combustion-system optimization in such engines, a relatively small fraction of this effort has been focused on understanding the effects of fuel-property changes on engine performance. This is in part because CI engines typically burn diesel fuel, the composition of which is complex and variable both geographically and over time. As a result, the fuel is often an incompletely controlled parameter in engine studies.

Although engine designers have largely succeeded at making conventional CI combustion systems less sensitive to fuel-property changes, the emergence of fuel-sensitive advanced combustion technologies, as well as the growing use of renewable and other non-petroleum fuel blendstocks, has intensified the interest in science-based optimization of future fuel/engine systems. Detailed quantitative compositional characterization of real-world diesel fuels also has recently become possible. As a result, the development of accurate surrogate fuels, which are chemically simplified representations of real-world fuels, is now feasible.

Accurate surrogate fuels can support engine research and development efforts by enabling experiments in which all fuel variables are correct, quantified, and controlled. The relative chemical simplicities of surrogate fuels also facilitate computational engine optimization including detailed chemical-kinetic mechanisms for evolving real-world fuels.

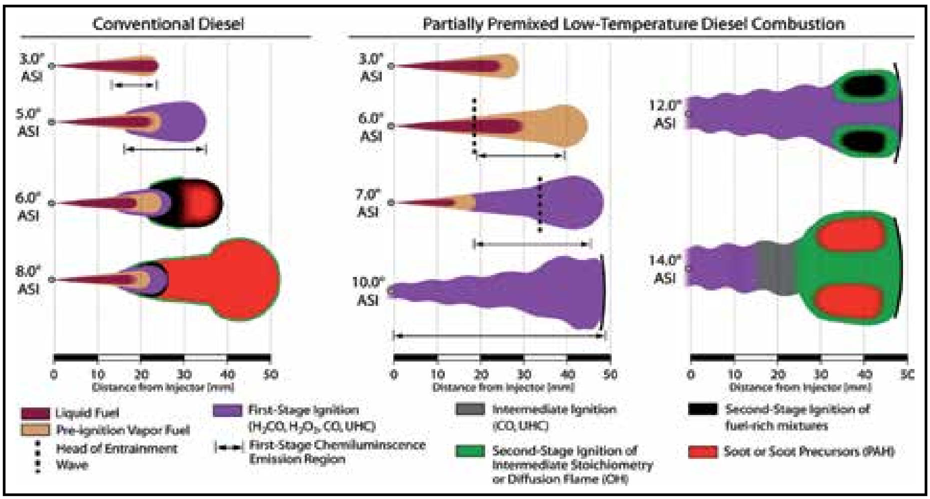
This presentation gives an overview of some of the key aspects involved in creating accurate diesel surrogate fuels. These aspects include compositional characterization of the real-world "target" fuel upon which the surrogate is based, definition of the properties that are to be matched between the surrogate and target fuels, selection of the set of pure compounds from which the surrogate will be blended, and formulation of the surrogate for optimal property matching.

Some recent results from an interdisciplinary, international team operating under the auspices of the Coordinating Research Council are summarized. The results show that the answer to the question in the title of this presentation is emphatically both "No!" and "Yes!"

Conceptual Models for Low-Temperature Partially Premixed Compression Ignition in Small- and Large-Bore Diesel Engines

Mark P.B. Musculus, Paul C. Miles, Lyle M. Pickett
Sandia National Laboratories, Livermore, California, (USA)

Conceptual models for low-temperature combustion (LTC) in compression-ignition engines are described. The models are supported by multiple optical diagnostic observations within optically accessible engines and constant-volume combustion chambers, as well as homogeneous reactor simulations using detailed chemical kinetic mechanisms. An established conceptual model framework for conventional diesel combustion is first reviewed and updated. Then, extensions to the existing conceptual model for LTC conditions are proposed.



The LTC conceptual models are not intended to describe all LTC strategies, but rather a common subset of low-load, single-injection, premixed-charge compression ignition conditions that are diluted by exhaust-gas recirculation to oxygen concentrations in the range of 10-15%. The models describe the spray formation, vaporization, mixing, ignition, and pollutant formation and destruction mechanisms that are consistent with experimental observations and modeling predictions for LTC diesel engines.

Two separate subcategories are offered for either heavy-duty, large-bore or for light-duty, small-bore engines. Defining features of the LTC conceptual models include longer liquid-fuel penetration, an extended ignition delay with more premixing of fuel, a temporally extended two-stage ignition, a more spatially uniform second-stage ignition, reduced and altered soot formation regions, and increased overmixing leading to incomplete combustion.

Complexities of Fuel Sprays at Engine Like Conditions

Scott E. Parrish
General Motors Global Research and Development (USA)

It is well known that the fuel economy and emissions of engines are significantly influenced by the fuel injection process and in particular the characteristics of the fuel spray. As a result an extensive amount of work has been performed in the area of fuel spray characterization. While extensive, the large majority of the work has been confined to characterization of the liquid phase under non-vaporizing conditions. Far less has been reported regarding spray characterization at conditions typical of operating engines. This lecture will summarize research findings from multiple investigations that utilized realistic, engine like, conditions. The dramatic differences observed in gasoline fuel spray characteristics between early and late injection timings will be illustrated. The merits of employing multiple injection to reduce spray penetration will also be discussed. High-speed images of liquid and vapor from a Diesel injector will be presented as a means to assess event evolution and variability. Details of the employed optical diagnostics will be provided where appropriate.

Control systems fulfilling future OBD and service diagnosis requirements

Ipek Sarac
BOSCH (Germany)

More stringent fuel consumption and emission regulations as well as ever growing customer expectations concerning driving behavior requires more complex powertrain systems. This affects not only traditional Gasoline and Diesel but also advanced concepts such as Hybrid powertrain.

On-Board Diagnosis (OBD) requirements of monitoring emission-related components and systems have been increased particularly in Europe and US. In addition to monitoring of components and systems, OBD legislation requires identification of faulty components.

From the perspective of an end customer, acceptance of a complex powertrain system is influenced by the repair costs in case of a failure. For a cost effective repair, service diagnosis should ensure a fast and accurate identification of the smallest exchangeable unit. To accomplish this, service diagnosis should combine guided trouble shooting with available OBD information, specific diagnosis and service routines.

A joined OBD and service diagnosis development process is a major success factor. The main features of this process are combined management, joint analysis of OBD diagnosis and service requirements, coordinated and parallel development of OBD and service diagnosis as well as robust validation of diagnosis solutions.

In this keynote, the approach of Robert Bosch GmbH to increase synergies for the development of diagnosis solutions among its worldwide organizations for Gasoline, Diesel and Hybrid systems is presented based on technical examples.

Corporate Average Fuel Economy (CAFE) regulation

David L. Schutt
SAE International Vice-President (USA)

In August 2012, the U.S. government finalized the most stringent vehicle fuel efficiency regulations yet in North America. The new Corporate Average Fuel Economy (CAFE) regulation raises the average fuel efficiency required of each automaker's car and light truck models from the current 27.3 mpg, to 54.5 mpg (107 g CO2/km) in 2025. It will drive the U.S. toward parity with the other major global regions in terms of light-vehicle CO2 emissions within the next decade.

54.5 mpg represents a 99% overall increase in vehicle fuel economy from today's level—an enormous leap for an industry in which a 5% gain in product efficiency is considered a major triumph. And it must be achieved within 12 years—a compressed time frame that is barely three product cycles from today.

While the aggressive new CAFE law provides certainty about fuel economy requirements, it also creates new challenges for automakers, suppliers, and consumers. Which technologies should automakers use to meet the new standards? How much will the new standards drive up vehicle prices to consumers?

Although daunting, the new CAFE regulation presents a major opportunity for product planners, vehicle engineers, R&D teams, and suppliers. New technologies—lightweight materials, advanced powertrains, better aerodynamics, tires, bearings, controls, and new global standards—will be needed to deliver the enormous leap in vehicle efficiency, while maintaining the performance, style, comfort, utility, and affordability that customers demand. And to attract, educate, and retain a new generation of engineers, chemists, and technicians to meet the 54.5-mpg challenge, academia and industry must partner on an even greater scale than today.

As the premier global organization for mobility engineers, scientists, and technical professionals, SAE International is a key industry partner on all fronts related to increasing sustainability.

Application of CFD to engine design

Atsushi Teraji
Nissan Motor Co. Ltd. (Japan)

There are strong demands today for further improvement of the efficiency of internal combustion (IC) engines amid growing concerns about the environment. On the contrary, low cost for engine development is more strongly needed to meet the global demand of motorization. CFD techniques for application to IC engine design have progressed rapidly in recent years, due in part to further advances in computer performance. In this regard, the importance of CFD analysis has been increasing every year, as computational tools play a key role in many different areas of engine development, including engine performance predictions and in-cylinder phenomena analysis. Research and development of techniques for predicting combustion phenomena in spark-ignition engines has also been increasing, and the possibility of developing an engine without conducting any experiments and using only a computer-based 3-D virtual engine is becoming increasingly more feasible. Therefore, the role of CFD has been shifting from the understanding of in-cylinder phenomena to the decision of key parameters and factors of engine design to expand new technology into other engines in a low development cost. The current CFD role and application examples in engine design process from concept development phase to product development phase will be introduced here.

Combustion modeling using DNS with relevance to engines

Ananias Tompoulidis
University of Western Macedonia (Greece)

Flows in internal combustion engines involve very complex processes which are turbulent, unsteady, multiphase and exhibit high cycle to cycle variations. The numerical simulation and modeling of such processes is very demanding and has been limited mostly to RANS and only recently to LES. In principle, LES can adequately describe unsteady flow phenomena in internal combustion engines which cannot be captured by RANS; however, even the most advanced LES approaches are subject to limitations in modeling combustion processes occurring at sub-grid scale levels as well as uncertainties in sub-grid scale models, particularly for processes in the proximity of walls, which are prominent in engines.

In contrast to LES and RANS, Direct Numerical Simulation (DNS) solves the equations of motion directly without any modeling. The resulting very accurate description of the turbulent flow field with DNS can be considered as high-quality numerical experiment. Due to the high computational effort needed to resolve all turbulent scales, very few DNS simulations in complex geometries with moving boundaries can be found in the literature. However, although the DNS of real engine flows is still not attainable even on the largest HPC systems, valuable information can be extracted about detailed processes occurring in engines using DNS.

Two such examples will be presented in this lecture. The first is related to early flame kernel development in a turbulent environment with relevance to spark ignition engines. The overall burning rate is influenced by both flame area increase due to flame wrinkling as well as by modification of the flame speed due to aerodynamic stretch induced by flow turbulence. During the early stages of its development the flame kernel size is too small to be resolved by an LES grid. DNS can be used towards the development and validation of improved spark ignition and early flame kernel development models for LES codes used in engine simulation. Moreover, detailed comparisons of DNS results with asymptotic theory estimates on the modification of flame speed by aerodynamic stretch and curvature at the limit of low stretch can provide valuable information. These findings can lead to improved understanding of the phenomena involved and to the development of more accurate models.

The second example is related to flow in an engine-like geometry which has also been investigated experimentally in the past. Turbulence generating mechanisms are multiple and their effects overlap in time and space, creating strong challenges for the currently used turbulence models. Better understanding of these underlying mechanisms is very important, since it affects wall heat losses, cycle-to-cycle variations and combustion and therefore the efficiency of internal combustion engines. The highly scalable spectral element solver nek5000 was used in conjunction with the Arbitrary Lagrangian-Eulerian (ALE) formulation to simulate flow in this engine-like geometry. Mesh resolution studies were performed and mean and fluctuation quantities were compared with available experimental data for multiple cycles, with emphasis on cycle-to-cycle variations. The generated database can be used for validation of RANS and LES simulations.

The work reported here has been performed in collaboration with the Swiss Federal Institute of Technology in Zurich, Switzerland and the Argonne National Laboratories, IL, USA.

Fuel Injection and Combustion Processes: Modeling

Fuel Injection and Combustion Processes: Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Transient Rate of Injection Effects on Spray Development

Lyle M. Pickett, Julien Manin
Sandia National Laboratories
Raul Payri, Michele Bardi, Jaime Gimeno
Universidad Politecnica de Valencia

Transients in the rate of injection (ROI) with respect to time are ever-present in direct-injection engines, even with common-rail fueling. The shape of the injection ramp-up and ramp-down affects spray penetration and mixing, particularly with multiple-injection schedules currently in practice. Ultimately, the accuracy of CFD model predictions used to optimize the combustion process depends upon the accuracy of the ROI utilized as fuel input boundary conditions. But experimental difficulties in the measurement of ROI, as well as real-world affects that change the ROI from the bench to the engine, add uncertainty that may be mistaken for weaknesses in spray modeling instead of errors in boundary conditions. In this work we use detailed, time-resolved measurements of penetration at the Spray A conditions of the Engine Combustion Network to rigorously guide the necessary ROI shape required to match penetration in jet models that allow variable rate of injection. The discrete control-volume jet model of Musculus and Kattke is utilized, and improved to account for variable spreading angle with axial distance, also based upon experimental measurements. Considerations are also made for effects such as gas initially in the sac of the injector, as well as variable fuel temperature at the start of injection. The penetration-derived ROI shape is in agreement with an "educated" ROI, developed considering hydraulic models of the injector as well as known experimental problems with ROI instrumentation. In the end, improved ROI shapes are made available for detailed CFD modeling of engine spray and combustion. The methodology provides advances beyond traditional analytical model analysis, which lacks the capability to treat variable ROI or spreading angle.

Experimental and Numerical Characterization of Gasoline-Ethanol Blends from a GDI Multi-Hole Injector by Means of Multi-Component Approach

Simone Malaguti, Giuseppe Bagli
Univ. of Modena & Reggio Emilia
Alessandro Montanaro, Stefano Piccinini, Luigi Allocca
Istituto Motori CNR

This paper reports an experimental and numerical investigation of the spray structure development for pure gasoline fuel and two different ethanol-gasoline blends (10% and 85% ethanol).

A numerical methodology has been developed to improve the prediction of the pure and blends fuel spray. The fuel sprays have been simulated by means of a 3D-CFD code, adopting a multi-component approach for the fuel simulations. The vaporization behavior of the real fuel has been improved testing blends of 7 hydrocarbons and a reduced multi-component model has been defined in order to reduce the computational cost of the CFD simulations. Particular care has been also dedicated to the modeling of the atomization and secondary breakup processes occurring to the GDI sprays. The multi-hole jets have been simulated by means of a new atomization approach combined with the Kelvin-Helmholtz/Rayleigh-Taylor hybrid model. At the nozzle hole exit an initial distribution of atomized droplets has been predicted by the numerical approach taking into account cavitation phenomena and turbulent effects.

Sprays have been investigated using a 6-hole gasoline direct-injection (GDI) injector and injecting fuel into an optically-accessible constant volume vessel at 5.0, 10.0, and 15.0 MPa of injection pressure, at ambient back pressure. Mie-scattering images have been performed using a high-speed camera and a pulsed-wave flash system which is able to track liquid phase in order to estimate the spray development, morphology and cone angle. Moreover fuel injection rates measurements have been carried out using a meter working on the Bosch tube principle to characterize the injected mass. The liquid fuel penetration registered highest values for gasoline fuel with respect to its blends with ethanol at different percentages.

Single Pulse Jet Impingement on Inclined Surface, Heat Transfer and Flow Field

Mirko Bovo
Chalmers University / Volvo Cars
Borja Rojo
Chalmers University

This paper focuses on the heat transfer and flow field resulting from a single pulse impinging jet. The size, time scale and jet characteristics are relevant to automotive diesel injection process. The purpose is to study jet impingement by correlating and cross comparing different measurements and simulations of the same event. The pulse jet impinges on a flat surface at different angles (0°, 30°, 45°, 60°) and a 90° rounded edge.

Experiments are performed deploying various techniques to record the event; PIV for the flow field, high acquisition rate thermocouples and infrared camera for surface temperature. The cases are reproduced with CFD simulations including conjugated heat transfer. The flow is simulated using LES.

The results highlight that the jet penetration rate is a function of the target angle. Also, the heat transfer magnitude and space distribution depends on the surface inclination. Alongside, the consistency of the results validates CFD as a powerful tool to study this type of flow.

Determination of Supersonic Inlet Boundaries for Gaseous Engines Based on Detailed RANS and LES Simulations

Fabian Müller, Martin Schmitt, Yuri M. Wright, Konstantinos Boulouchos
Swiss Federal Institute of Technology

The combustion of gaseous fuels like methane in internal combustion engines is an interesting alternative to the conventional gasoline and diesel fuels. Reasons are the availability of the resource and the significant advantage in terms of CO2 emissions due to the beneficial C/H ratio. One difficulty of gaseous fuels is the preparation of the gas/air mixtures for all operation points, since the volumetric energy density of the fuel is lower compared to conventional liquid fuels. Low-pressure port-injected systems suffer from substantially reduced volumetric efficiencies. Direct injection systems avoid such losses; in order to deliver enough fuel into the cylinder, high pressures are however needed for the gas injection which forces the fuel to enter the cylinder at supersonic speed followed by a Mach disk. The detailed modeling of these physical effects is very challenging, since the fluid velocities and pressure and velocity gradients at the Mach disc are very high. A detailed simulation of these effects in CFD calculations of real engine geometries is numerically challenging and computationally expensive. The main goal of this study is hence to develop inlet boundary conditions which can accurately reproduce the most important physical mechanisms without increasing the complexity of a real engine simulation significantly.

To this end, two and three-dimensional underexpanded flows for a single-orifice injector were numerically investigated in STAR-CD. The two dimensional setup was used to investigate the spatial and temporal resolution requirements. Based on these findings a three-dimensional setup, with the same nozzle diameter as in the real engine was created and the flow field simulated using RANS and LES approaches. The results showed very good agreement with an empirical correlation concerning the position of the Mach disc for pressure ratios of 16.5 and 32. The numerical data was statistically post-processed and then used as a basis for derivation of inlet conditions which reproduce velocity, turbulence and CH4 mixture fraction fields downstream of the Mach disc.

Direct Numerical Simulation of Flow Induced Cavitation in Orifices

Giacomo Falcucci, Elio Jannelli
Univ. of Naples Parthenope
Stefano Ubertini
Univ. of Tuscia
Gino Bella
Univ. of Rome Tor Vergata

In this paper, a multiphase Lattice Boltzmann approach is adopted to directly simulate flow conditions that lead to the inception of cavitation in an orifice.

Different values of fluid surface tension are considered, which play a dramatic role in the evolution of vapour cavity, as well as different inlet velocities at the computational domain boundary.

The results of the flow simulations in terms of density and velocity magnitude fields are examined, with special focus on the components of the stress tensor inside the cavitating region: a comparison with cavitation inception criteria known form literature is proposed, highlighting the good agreement between our direct numerical simulations and theoretical predictions.

Integrated 1D/2D/3D Simulation of Fuel Injection and Nozzle Cavitation

Valdas Caika, Peter Sampl
AVL LIST GmbH
David Greif
AVL Slovenia d.o.o.

To promote advanced combustion strategies complying with stringent emission regulations of CI engines, computational models have to accurately predict the injector inner flow and cavitation development in the nozzle. This paper describes a coupled 1D/2D/3D modeling technique for the simulation of fuel flow and nozzle cavitation in diesel injection systems.

The new technique comprises 1D fuel flow, 2D multi-body dynamics and 3D modeling of nozzle inner flow using a multi-fluid method. The 1D/2D model of the common rail injector is created with AVL software Boost-Hydsim. The computational mesh including the nozzle sac with spray holes is generated with AVL meshing tool Fame. 3D multi-phase calculations are performed with AVL software FIRE. The co-simulation procedure is controlled by Boost-Hydsim. Initially Hydsim performs a standalone 1D simulation until the needle lift reaches a prescribed tolerance (typically 2 to 5 µm). From this time instant the 1D/2D/3D co-simulation with the FIRE multiphase solver is started. During the co-simulation process Boost-Hydsim transmits to FIRE the displacement vector of the needle tip and fuel pressure and temperature at the nozzle interface. Based on this data, FIRE moves the computational mesh, adjusts boundary conditions, computes the time step and sends back to Boost-Hydsim the hydraulic force vector acting on the needle tip, sac pressure and mass flow rate through the needle seat and nozzle holes.

Multi-Component Modeling of Diesel Fuel for Injection and Combustion Simulation

S. Möller, G.K. Dutzler
Virtual Vehicle Research Center
P. Priesching
AVL List GmbH
J.V. Pastor, C. Micó
Universitat Politècnica de València

Accurate simulation tools are needed for rapid and cost effective engine development in order to meet ever tighter pollutant regulations for future internal combustion engines. The formation of pollutants such as soot and NOx in Diesel engines is strongly influenced by local concentration of the reactants and local temperature in the combustion chamber. Therefore it is of great importance to model accurately the physics of the injection process, combustion and emission formation.

It is common practice to approximate Diesel fuel as a single compound fuel for the simulation of the injection and combustion process. This is in many cases sufficient to predict the evolution of the in-cylinder pressure and heat release in the combustion chamber. The prediction of soot and NOx formation depends however on locally component resolved quantities related to the fuel liquid and gas phase as well as local temperature.

The AVL FIRE CFD code has physical sub models for multi-component spray evaporation and multi-component combustion implemented. This work presents the validation of these models under realistic IC engine conditions. For this purpose five binary mixtures of Decane and Hexadecane were considered. The simulation results for the binary mixtures are compared against experimental data recorded in a special optical test engine. It is shown that an optimization of the parameters of the multi-component spray model could improve the predictions for liquid-length and spray penetration over a wide range of injection pressures as well as combustion chamber pressures and temperatures. The basic ignition and combustion behavior of these mixtures was simulated and compared to the experimental results from the optical test engine. Comparisons for ignition delay and flame lift-off-length are presented.

Experimental Characterization of the Geometrical Shape of ks-hole and Comparison of its Fluid Dynamic Performance Respect to Cylindrical and k-hole Layouts

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Diesel engine performances are strictly correlated to the fluid dynamic characteristics of the injection system. Actual Diesel engines employ injector characterized by micro-orifices operating at injection pressure till 20MPa. These main injection characteristics resulted in the critical relation between engine performance and injector hole shape.

In the present study, the authors' attention was focused on the hole geometry influence on the main injector fluid dynamic characteristics. At this purpose, three different nozzle hole shapes were considered: cylindrical, k, and ks nozzle shapes.

Because of the lack of information available about ks-hole real geometry, firstly it was completely characterized by the combined use of two non-destructive techniques. Secondly, all the three nozzle layouts were characterized from the fluid dynamic point of view by a fully transient CFD multiphase simulation methodology previously validated by the authors against experimental results. The experimental characterization of the ks-hole geometry was a mandatory task to assure a good numerical simulation accuracy.

From the fluid dynamic point of view, the three nozzle layouts were compared by the average fluid dynamic conditions recorded on the nozzle hole outlet sections and by the cavitating flow evolution inside the injector hole themselves.

Detailed Kinetic Analysis of HCCI Combustion Using a New Multi-Zone Model and CFD Simulations

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A new multi-zone model for the simulation of HCCI engine is here presented. The model includes laminar and turbulent diffusion and conduction exchange between the zones and the last improvements on the numerical aspects. Furthermore, a new strategy for the zone discretization is presented, which allows a better description of the near-wall zones. The aim of the work is to provide a fast and reliable model for carrying out chemical analysis with detailed kinetic schemes. A preliminary sensitivity analysis allows to verify that 10 zones are a convenient number for a good compromise between the computational effort and the description accuracy. The multi-zone predictions are then compared with the CFD ones to find the effective turbulence parameters, with the aim to describe the near-wall phenomena, both in a reactive and non-reactive cases. Finally, the model is validated against experimental data of HCCI combustion of fossil and bio-fuels (n-heptane, methyl-hexanoate, and methyl-decanote).

Reduced Kinetic Mechanisms for Diesel Spray Combustion Simulations

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Detailed chemistry represents a fundamental pre-requisite for a realistic simulation of combustion process in Diesel engines to properly reproduce ignition delay and flame structure (lift-off and soot precursors) in a wide range of operating conditions. In this work, the authors developed reduced mechanisms for n-dodecane starting from the comprehensive kinetic mechanism developed at Politecnico di Milano, well validated and tested in a wide range of operating conditions [1]. An algorithm combining Sensitivity and Flux Analysis was employed for the present skeletal reduction. The size of the mechanisms can be limited to less than 100 species and incorporates the most important details of low-temperature kinetics for a proper prediction of the ignition delay. Furthermore, the high-temperature chemistry is also properly described both in terms of reactivity and species formation, including unsaturated compounds such as acetylene, whose concentration controls soot formation.

The consistency between reduced and detailed mechanism was verified in several reference experiments. Then, the mechanism was applied to diesel spray combustion modeling. Simulations were performed by using the Lib-ICE code, entirely developed by the authors and based on OpenFOAM technology. To evaluate the predictive capability of the reduced mechanisms, combustion simulations were performed using the MRIF (Multiple Representative Interactive Flamelets) model. Such model approximates the flame structure as a set of multiple unsteady flamelets and their evolution is computed in the mixture fraction space, where species and energy equations are solved. Experimental data from the Engine Combustion Network Database were used for validation, by comparing computed and experimental data of flame-lift off and ignition delay at different operating conditions.

Predicting In-Cylinder Soot in a Heavy-Duty Diesel Engine for Variations in SOI and TDC Temperature Using the Conditional Moment Closure Model

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Numerical simulations of in-cylinder soot evolution in the optically accessible heavy-duty diesel engine of Sandia National Laboratories have been performed with the multidimensional conditional moment closure (CMC) model using a reduced n-heptane chemical mechanism coupled with a two-equation soot model. Simulation results are compared to the high-fidelity experimental data by means of pressure traces, apparent heat release rate (AHRR) and time-resolved in-cylinder soot mass derived from optical soot luminosity and multiple wavelength pyrometry in conjunction with high speed soot cloud imaging. In addition, spatial distributions of soot relevant quantities are given for several operating conditions.

A broad range of operating conditions has been considered: a sweep in start of injection (SOI) at unchanged top dead center (TDC) ambient conditions and a sweep in TDC temperature at an ambient oxygen volume fraction of 12.7 percent, corresponding to a high level of exhaust gas recirculation (EGR). Ignition delays were captured very well, using unaltered model constants and kinetic parameters. The model was found to reproduce pressure and AHRR traces fairly well, although the premixed portion of combustion was in general slightly underpredicted. Concerning emissions, a quantitative comparison of soot mass evolution is presented. Considering the broad range of conditions the model was capable to reproduce the soot trends well; the predicted peak soot mass agreed within a factor of approximately two for almost all operating conditions considered.

Overall, the findings suggest that the presented semi-empirical soot model integrated into the CMC framework is a highly promising approach for the prediction of in-cylinder soot evolution for various diesel engine operating conditions.

Combustion Optimization of a Marine DI Diesel Engine

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Enhanced calibration strategies and innovative engine combustion technologies are required to meet the new limits on exhaust gas emissions enforced in the field of marine propulsion and on-board energy production.

The goal of the paper is to optimize the control parameters of a 4.2 dm3 unit displacement marine DI Diesel engine, in order to enhance the efficiency of the combustion system and reduce engine out emissions. The investigation is carried out by means of experimental tests and CFD simulations.

For a better control of the testing conditions, the experimental activity is performed on a single cylinder prototype, while the engine test bench is specifically designed to simulate different levels of boosting.

The numerical investigations are carried out using a set of different CFD tools: GT-Power for the engine cycle analysis, STAR-CD for the study of the in-cylinder flow, and a customized version of the KIVA-3V code for combustion. All the models are calibrated through the above mentioned experimental campaign.

Then, CFD simulations are applied to optimize the injection parameters and to explore the potential of the Miller combustion concept. It is found that the reduction of the charge temperature, ensuing the adoption of an early intake valve closing strategy, strongly affects combustion. With a proper valve actuation strategy, an increase of boost pressure and an optimized injection advance, a 40% reduction of NOx emissions can be obtained, along with a significant reduction of in-cylinder peak pressure, without penalizing fuel efficiency.

CFD Investigation on Injection Strategy and Gasoline Quality Impact on In-Cylinder Temperature Distribution and Heat Transfer in PPC

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Recently, internal combustion engine design has been moving towards downsized, more efficient engines. One key in designing a more efficient engine is the control of heat losses, i.e., improvements of the thermodynamic cycle. Therefore, there is increasing interest in examining and documenting the heat transfer process of an internal combustion engine. A heavy-duty diesel engine was modeled with a commercial CFD code in order to examine the effects of two different gasoline fuels, and the injection strategy used, on heat transfer within the engine cylinder in a partially premixed combustion (PPC) mode.

The investigation on the fuel quality and injection strategy indicates that the introduction of a pilot injection is more beneficial in order to lower heat transfer, than adjusting the fuel quality. This is due to reduced wall exposure to higher temperature gases and more equally distributed heat losses in the combustion chamber. A comparison was also made between two loads with the same fuel quality and injection strategy, which revealed that even though the relative heat load to the walls was higher in the lower load case, the gross indicated efficiency was higher, due to a lower value of the exhaust energy.

Numerical and Experimental Investigation of Combustion Regimes in a Dual Fuel Engine

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Among the new combustion concepts envisaged to meet future regulations, the Dual Fuel (DF) concept is considered to be an attractive strategy due to its potential to reduce CO2 emissions and engine-out pollutant emissions levels. A small quantity of high-cetane fuel (Diesel) is injected in the combustion chamber in order to ignite a homogeneous mixture of air and a highly volatile fuel (gasoline in our study). The DF concept has been shown to achieve improved engine thermal efficiency and low engine-out NOx and soot emissions. However, the physical mechanisms controlling DF combustion and in particular, determination of the predominant combustion regime(s) are not yet well understood. In this study, numerical simulations (CFD) and optical engine measurements are used to investigate Dual Fuel combustion. The ECFM3Z combustion model (implemented in the IFP-C3D code) is presented in this paper in addition to preliminary results which have been performed for DF internal combustion (IC) engine simulations. The approach employed in this study allowed determination of the relative contributions of auto-ignition (AI), flame propagation (ECFM) and Burned Gas (BG) to the total heat release and combustion development in terms of the spatio-temporal evolution throughout the engine cycle. The objective is first of all to evaluate the capacity/potential of existing models to cope with the various combustion regimes that might exist in DF combustion strategies and in particular transitions between different combustion modes. Results of preliminary experiments on a single cylinder optical engine are also reported in this paper. The objective was to apply advanced optical diagnostic techniques to characterize in detail the DF combustion process and provide an improved understanding of this novel combustion strategy and ultimately aid CFD model further developments.

A Numerical Methodology for the Multi-Objective Optimization of an Automotive DI Diesel Engine

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Nowadays, an automotive DI Diesel engine is demanded to provide an adequate power output together with limit-complying NOx and soot emissions so that the development of a specific combustion concept is the result of a trade-off between conflicting objectives. In other words, the development of a low-emission DI diesel combustion concept could be mathematically represented as a multi-objective optimization problem. In recent years, genetic algorithm and CFD simulations were successfully applied to this kind of problem. However, combining GA optimization with actual CFD-3D combustion simulations can be too onerous since a large number of simulations is usually required, resulting in a high computational cost and, thus, limiting the suitability of this method for industrial processes. In order to make the optimization process less time-consuming, CFD simulations can be more conveniently used to build a training set for the learning process of an artificial neural network which, once correctly trained, can be used to forecast the engine outputs as a function of the design parameters during a GA optimization performing a so-called virtual optimization. In this paper, a numerical methodology for the multi-objective virtual optimization of the combustion inside an automotive DI Diesel engine, based on artificial neural networks combined with genetic algorithms, is presented.

Diesel Engine Combustion Optimization for Bio-Diesel Blends Using Taguchi and ANOVA Statistical Methods

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Diesel engine emissions are directly influenced by the air fuel mixture within the cylinder chamber. Increasing concern over the environment impacts of the exhaust pollutants has enforced the setting of emissions legislation since the 1960s. In the last decades emissions legislations have become stricter which resulted to the introduction of multiple injection strategies and exhaust gas recirculation (EGR) in the cylinder in order to abate emissions produced. In this study, the effect of injection rate for double in-cylinder injection in combination with various EGR and bio-diesel fuel rates has been studied using CFD simulations. Taguchi orthogonal arrays have been used for reducing the number of simulations for possible combinations of different rates of injection quantities, EGR composition and bio-diesel quantities. Oneway analysis of variance technique (ANOVA) has been used to estimate the importance of the above factors to the emissions output and performance of the engine. Results showed that using statistical methods, the optimum parameters can be found for reducing the emissions output of the engine without reducing the IMEP. NOx and soot emissions for the optimized engine have been reduced by 51% and 22% respectively compared to conventional Diesel engine.

Use of an Innovative Predictive Heat Release Model Combined to a 1D Fluid-Dynamic Model for the Simulation of a Heavy Duty Diesel Engine

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An innovative 0D predictive combustion model for the simulation of the HRR (heat release rate) in DI diesel engines was assessed and implemented in a 1D fluid-dynamic commercial code for the simulation of a Fiat heavy duty diesel engine equipped with a Variable Geometry Turbocharger system, in the frame of the CORE (CO_2 reduction for long distance transport) Collaborative Project of the European Community, VII FP.

The 0D combustion approach starts from the calculation of the injection rate profile on the basis of the injected fuel quantities and on the injection parameters, such as the start of injection and the energizing time, taking the injector opening and closure delays into account. The injection rate profile in turn allows the released chemical energy to be estimated. The approach assumes that HRR is proportional to the energy associated with the accumulated fuel mass in the combustion chamber. This procedure allows an accurate calculation of different combustion parameters important for engine calibration, such as MFB50 (50% of fuel burned mass fraction crank angle).

The 0D HRR model was included in a complete 1D fluid-dynamic model of the heavy duty diesel engine, which was designed with GT-POWER commercial code.

The 0D combustion model and the 1D fluid-dynamic model were calibrated in 12 steady-state engine operating conditions acquired over the whole engine map, and the complete model was finally validated on two load transient conditions at 1100 rpm and 1400 rpm, demonstrating a very good predictive capability.

Impact of Bore-to-Stroke Ratio Over Light-Duty DI Diesel Engine Performance, Emissions and Fuel Consumption: An Analytical Study Using 1D-CFD Coupled with DOE Methodology

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It is traditionally accepted within the Diesel engine engineering community that Bore-to-stroke (B/S) ratios in the range 0.85 to 0.95 provide the best thermodynamic optimization for light-duty engines, mostly due to the favorable surface-to-volume ratio in the central phase of combustion, which reduces heat rejection, and to the torque-oriented volumetric efficiency profile. As a consequence, most engines into production exhibit B/S in that range, with few B/S 1.00 exceptions mainly for packaging issues on some V engines, and, very interestingly, on the last-generation of small and mid-sized engines.

The analysis of the technical reasons behind this recent trend is performed in the present paper, by employing a 1D-CFD approach based on Design Of Experiment (DOE) methodology. A one-dimensional analysis was carried out using a detailed GT-Power model for a 1.6 liter light-duty Mid-sized Diesel Engine (MDE), characterized by best-in-class torque and power rating in its class. In addition to B/S ratio, the effects of compression ratio, boost pressure, exhaust restriction, peak cylinder pressure and exhaust temperature was studied, in order to grasp the mutual interrelations between these factors.

The results show that, contrarily to common engineering thinking, the “square design” actually enables excellent compromise between specific power rating and low-end torque, thanks to synergy between turbocharger matching and volumetric efficiency profile. Part load heat losses are also reduced on average, thanks to lower convection which more than compensates the slightly unfavorable surface-to-volume ratio. Finally, by lowering the piston mean speed, it also benefits reciprocating and rotating components stress and friction at high speed, resulting in further fuel consumption benefits.

A second paper dealing with 3D-CFD and experimental results will follow, highlighting the impact of B/S selection also on combustion performance (heat release profile, charge utilization, EGR tolerance, pollutant emissions,...), thus deepening the present analysis to the combustion system details.

Investigation of the Effect of Boost Pressure and Exhaust Gas Recirculation Rate on Nitrogen Oxide and Particulate Matter Emissions in Diesel Engines

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In recent years, due to the growing problem of environmental pollution and climate change internal combustion engine stroke volume size has been reduced. The use of down-sized engines provides benefit for reducing emissions and fuel consumption especially at the inner city driving conditions. However, when the engine demands additional power, utilizing a turbocharging system is required. This study is a joint work of Istituto Motori CNR with Automotive Laboratory of Mechanical Engineering Faculty of Istanbul Technical University (ITU) and the objective of this study was devoted to increase the understanding of various engine operating conditions on emissions, especially at low load. The trade-off between Nitrogen Oxide (NOx) and Particulate Matter (PM) emissions in a Diesel engine has been examined depending on turbocharging rates and the rate of Exhaust Gas Recirculation (EGR) applied. Experimental and numerical investigations were carried out to study the optimum conditions for providing lowest emission rates in a Diesel engine. Within the context of this study, it is aimed to develop a multi-dimensional cycle analysis model which is capable of simulating the cases in engine combustion and expansion stroke. The change of two pollutant components with different intake boost pressures was analyzed by parametric analysis. Moreover, the effect of EGR systems used in Diesel engines on emissions regarding the EGR rate and the temperature were also analyzed. EGR application reduces NOx emissions as expected while increasing PM. But further increase in EGR rate reduces the increase of PM emissions. Increasing the intake boost pressure provides positive effect on PM emissions.

Simulation and Experimental Measurement of CO_2^*, OH^* and CH_2O^* Chemiluminescence from an Optical Diesel Engine Fueled with n-Heptane

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A means of validating numerical simulations has been developed which utilizes chemiluminescence measurements from an internal combustion engine. By incorporating OH*, CH2O* and CO2* chemiluminescence sub-mechanisms into a detailed n-heptane reaction mechanism, excited species concentration and chemiluminescence light emission were calculated. The modeled line-of-sight chemiluminescence emission allows a direct comparison of simulation results to experimentally measured chemiluminescence images obtained during combustion in an optically accessible compression ignition engine using neat n-heptane fuel. The spray model was calibrated using in-cylinder liquid penetration length Mie scattering measurements taken from the jets of the high-pressure piezo injector. The experimental, two dimensional images of CH2O* and OH* chemiluminescence during the low and high temperature heat release period were recorded with an intensified CCD camera in a wavelength range covering emission from these species. By interpreting the color content of the images taken from a CMOS high speed camera, crank-angle resolved two dimensional CO2* chemiluminescence distributions were obtained. All the chemiluminescence images taken at the same crank angle degrees were used to generate probability density function (PDF) distributions which can then be directly compared with RANS averaged CFD simulation results. The emission spectra were recorded to confirm the existence and evolution of excited-state species throughout the various stages of combustion. Chemiluminescence from excited state OH* was found to be good proxy for ground state OH, while greater temporal variations were found to exist between excited and ground state CH2O and CO2. Ground and excited state species are predicted to have different spatial distributions during the combustion process.

Numerical Analysis of Flow Structure inside a Single Cylinder of a 4 Valve Head under Steady-State Condition

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This paper deals with the numerical investigation of the in-cylinder flow structures under steady-state conditions utilizing the finite-volume CFD package, STAR CCM+. Two turbulence models were used to simulate the turbulent flow structure namely, Realizable k-ε and Reynolds Stress Turbulence Model, RSTM. Three mesh densities of polyhedral type are examined. The three-dimensional numerical investigation has been conducted on an engine head of a pent-roof type (Lotus) for a number of fixed valve lifts (2mm, 5mm, 8mm) at two pressure drops 2451.662 Pa and 6227.222 Pa that is equivalent to engine speeds of 2500 and 4000 RPM respectively. This correlation between pressure drop and engine speed is provided by Lotus engineering according to real engine studies. Based on the comparison between two turbulence models, the turbulent flow structure was simulated using RSTM model for a number of tumble and swirl planes. The nature of the flow structure together with discussions on the influence of the pressure drop and valve lift parameters on the flow structures were presented and discussed. Computed results for the mean and fluctuations velocities were validated against previously published experimental data of Picton [1] from Laser Doppler Anemometry (LDA) measurements on the same head cylinder. The CFD velocity fields, obtained under steady-state conditions, were used to calculate swirl and tumble ratios. Calculated swirl and tumble ratios that were obtained by both turbulence models and Particle Image Velocimetry (PIV) measured data were compared.

Zero-Dimensional Spark Ignition Combustion Modeling - A Comparison of Different Approaches

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Internal combustion engines development with increased complexity due to CO2 reduction and emissions regulation, while reducing costs and duration of development projects, makes numerical simulation essential. 1D engine simulation software response for the gas exchange process is sufficiently accurate and quick. However, combustion simulation by Wiebe function is poorly predictive.

The objective of this paper is to compare different approaches for 0D Spark Ignition (SI) modeling. Versions of Eddy Burn Up, Fractal and Flame Surface Density (FSD) models have been coded into GT-POWER platform, which connects thermodynamics, gas exchange and combustion sub-models. An initial flame kernel is imposed and then, the flame front propagates spherically in the combustion chamber. Flame surface is tabulated as a function of piston position and flame radius. The modeling of key features of SI combustion such as laminar flame speed and thickness and turbulence was common. This comparison focuses on the impact of turbulence on the flame front and shows the predictive capabilities of each approach.

Those three approaches have been evaluated against experimental data for several steady state operating points of a single-cylinder engine. Cylinder pressure is predicted satisfactorily. Burn rates are well predicted for the period of a freely propagating flame front, that is before flame-wall interaction occurs. The FSD model physically considers the impact of turbulence on the flame for various turbulence scales, unlike the other two models which demand more calibration parameters. It is shown that additional modeling must be incorporated so that the flame-wall interaction is taken into account.

Two-Zone Thermodynamic Model to Predict Temporal Variations in Pressure of the End Gas in an Engine Cylinder Cycle

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In this paper, we present a two-zone thermodynamic model that allows us to predict the time dependent in-cylinder conditions (P, T) in a high-speed medium BMEP engine fueled with different gas compositions. The details of this model rely on the observation that the measured combustion phasing correlates strongly with the (computed) laminar burning velocity under the conditions existing in the cylinder. To account for turbulence effects, a model parameter is introduced in the burning rate model. Calculations show that for Dutch Natural Gas (DNG)/ethane/propane mixtures a single model parameter, independent of the gas composition, is sufficient to predict the pressure profiles accurately. In contrast, the model parameter for DNG/H2 mixtures shows a dependence on the hydrogen content in the fuel. Adjustment of the model parameter resulted in successful prediction of the effect of hydrogen on the combustion phasing.

The accuracy of the pressure profiles based on the phasing model is assessed by comparing the computed autoignition delay times in the end gas based on the predicted pressure profiles with those derived from experimental profiles. Excellent agreement is found, giving us confidence in the predictive power of the two zone model. Using the derived delay times as a measure of knock propensity, the comparison of the predicted propensity with measured Knock Limited Spark Timing (KLST) data showed an excellent correlation. From this we conclude that the methodology developed accurately predicts the knock propensity of fuel gases in the lean-burn, high-speed gas engine used in this study, for all gases tested.

Multi-Zone Quasi-Dimensional Combustion Models for Spark-Ignition Engines

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The present work aims at improving the predictive capabilities of quasi-dimensional combustion models for fast and accurate automated design of spark engines. The models are based on mass and energy conservation principles supplemented by sub models based on experimental correlations. Here, we improve the accuracy of the classical two-zone model by means of two successive modifications. First, we generate a three-zone model by introducing a reacting zone near the walls. In the third zone, the gases burn at a lower temperature than in the main reacting zone, due to heat losses to the walls. Secondly, a multi-zone model is built by dynamically adding new reacting zones at given crank-angle intervals. The use of multiple zones allows to take into account temperature and concentrations gradients in the flame. To validate our models, the energy release rates and pressures time histories predicted by the three-zone and by the multi-zone models are compared to experimental data and to the standard two-zone approach for several operating conditions.

A Computational Study on the Impact of Cycle-to-Cycle Combustion Fluctuations on Fuel Consumption and Knock in Steady-State and Drivecycle Operation

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In spark-ignition engines, fluctuations of the in-cylinder pressure trace and the apparent rate of heat release are usually observed from one cycle to another. These Cycle-to-Cycle Variations (CCV) are affected by the early flame development and the subsequent flame front propagation. The CCV are responsible for engine performance (e.g. fuel consumption) and the knock behavior. The occurrence of the phenomena is unpredictable and the stochastic nature offers challenges in the optimization of engine control strategies.

In the present work, CCV are analyzed in terms of their impact on the engine knock behavior and the related efficiency. Target is to estimate the possible fuel consumption savings in steady-state operation and in the drivecycle, when CCV are reduced. Since CCV are immanent on real engines, such a study can only be done by means of simulation. For the analysis different tools are applied, from 1-D gas dynamic models with detailed combustion modeling to real-time capable engine and vehicle system simulation.

A Preliminary Research on Turbulent Flame Propagation Combustion Modeling Using a Direct Chemical Kinetics Model

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The present work focused on modeling turbulent flame propagation combustion process using a direct chemical kinetics model. Firstly, the theory of turbulent flame propagation combustion modeling directly using chemical kinetics is given in detail. Secondly, two important techniques in this approach are described. One technique is the selection of chemical kinetics mechanism, and the other one is the selection of AMR (adaptive mesh refinement) level. A reduced chemical kinetics mechanism with minor modification by the authors of this paper which is suitable for simulating gasoline engine under warm up operating conditions was selected in this work. This mechanism was validated over some operating conditions close to some engine cases. The effect of AMR level on combustion simulation is given, and an optimum AMR level of both velocity and temperature is recommended. Thirdly, the primary models used in MESIM-Converge code, which combines Ford in house code MESIM and a commercial code Converge, are described, and a unified version of simulation setup is presented. With this unified version of models and simulation setup, validation of engine combustion modeling has been completed. The validated engine conditions range from high load, medium load to low load, from high speed, medium speed to low speed. Also different engine types were validated.

All the validated cases are engine warm up operating conditions. The simulated in-cylinder pressures, burn rates and emissions including CO, NOx and UHC (unburned hydrocarbon) are compared with experimental data and good agreements are found. Engine cold start operating conditions and high EGR (exhaust gas recirculation) cases will be the next step of research.

Numerical Investigation of Combustion in a Lean Burn Gasoline Engine

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This research effort focuses on lean-burn combustion in gasoline internal combustion engines. Gasoline is largely known to be characterized by narrow flammability range, which makes the use of ultra-lean mixtures very challenging. In order to fully explore the gasoline lean burn potential, a promising strategy should combine advanced intake geometries, injection strategies, and ignition technologies.

In this paper, a CFD methodology is developed in order to provide proper insight into lean-burn gasoline combustion. A baseline homogenous/lean case is analyzed and numerical results are validated against engine data.

Two critical issues are addressed. First, a relatively large detailed mechanism is validated against the experimental data for extreme operating conditions (low pressure values, lean mixtures). The large cycle-to-cycle variation characterizing lean combustion is shown experimentally. An advanced numerical approach is proposed that delivers oscillation in the CFD results as an effect of the reduced numerical diffusion. The results indicate that the CFD methodology presented in this paper has a potential in describing the average behavior of the engine while future work will address cycle-to-cycle variation and combustion stability.

Secondly, the effect of the intake geometry on the in-cylinder flow and flame propagation is shown. Numerical simulations are able to highlight combustion features that are of primary importance for future engine optimization.

Full-Cycle CFD Modeling of Air/Fuel Mixing Process in an Optically Accessible GDI Engine

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This paper is focused on the development and application of a CFD methodology that can be applied to predict the fuel-air mixing process in stratified charge, sparkignition engines. The Eulerian-Lagrangian approach was used to model the spray evolution together with a liquid film model that properly takes into account its effects on the fuel-air mixing process into account. However, numerical simulation of stratified combustion in SI engines is a very challenging task for CFD modeling, due to the complex interaction of different physical phenomena involving turbulent, reacting and multiphase flows evolving inside a moving geometry. Hence, for a proper assessment of the different sub-models involved a detailed set of experimental optical data is required.

To this end, a large experimental database was built by the authors. In particular, the spray morphology was characterized in detail inside a constant volume vessel, where images were acquired by a CCD camera and then post-processed to evaluate the spray penetration and cone-angles. Furthermore, experiments were carried out in an optically accessible combustion chamber reproducing a real 4-stroke, 4-cylinder, high performance GDI engine. The cylinder head was instrumented by using an endoscopic system coupled to high spatial and temporal resolution cameras in order to allow the visualization of the fuel injection and the combustion process. The complete set of spray models was tuned with experiments carried out at constant-volume conditions, then full-cycle simulations were performed for the optical engine. Four different operating points were simulated accounting for different injection pressures and charge stratification levels. Validation was carried out by comparing computed and experimental data of spray and liquid film evolutions. To further verify the computed results, computed equivalence ratio distributions at spark-timing were correlated with optical images of flame propagation.

Development of Fully-Automatic Parallel Algorithms for Mesh Handling in the OpenFOAM®-2.2.x Technology

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The current development to set up an automatic procedure for automatic mesh generation and automatic mesh motion for internal combustion engine simulation in OpenFOAM®-2.2.x is here described. In order to automatically generate high-quality meshes of cylinder geometries, some technical issues need to be addressed: 1) automatic mesh generation should be able to control anisotropy and directionality of the grid; 2) during piston and valve motion, cells and faces must be introduced and removed without varying the overall area and volume of the cells, to avoid conservation errors. In particular, interpolation between discrete fields is frequent in computational physics: the use of adaptive and non-conformal meshes necessitates the interpolation of fields between different mesh regions. Interpolation problems also arise in areas such as model coupling, model initialization and visualisation. This paper discusses the efficient implementation of the sliding interface, an algorithm to handle motion and topological changes in a moving-mesh Finite Volume Method (FVM) framework, that has been implemented to work with the newest mesh handling strategy of OpenFOAM®-2.2.x in a massively parallel environment. The algorithm performs a consistent second order interpolation between flow regions connected through non-conformal interfaces, opening the use of the code to a wide range of applications: the simulation of the piston motion trough scavenging ports in a two-stroke engine, the generation of cylinder grids characterized by a high quality mesh near the valve region, the reduction of the mesh size in external flow calculations. Consistent interpolation across non conformal interfaces represents a very important factor in LES, where discretization error and interpolation errors during mesh motion can have a significant impact on the quality of the results. Finally, in order to automate the mesh generation process of complex engine geometries, the algrithm for mesh motion has been applied to work with STL geometries, that are used for run-time generation of hexahedra and split-hexahedra grids on IC geometries, by a fully parallelised algorithm with automatic domain decomposition, without the loss of any geometric feature.

Assessment of the Potential of Proper Orthogonal Decomposition for the Analysis of Combustion CCV and Knock Tendency in a High Performance Engine

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The paper reports the application of Proper Orthogonal Decomposition (POD) to LES calculations for the analysis of combustion and knock tendency in a highly downsized turbocharged GDI engine that is currently under production. In order to qualitatively match the cyclic variability of the combustion process, Large-Eddy Simulation (LES) of the closed-valve portion of the cycle is used with cycle-dependent initial conditions from a previous multi-cycle analysis [1, 2, 3]. Detailed chemical modeling of fuel's auto-ignition quality is considered through an ad-hoc implemented look-up table approach, as a trade-off between the need for a reasonable representation of the chemistry and that of limiting the computational cost of the LES simulations.

Experimental tests were conducted operating the engine at knock-limited spark advance (KLSA) and the proposed knock model was previously validated for such engine setup [3]. All the presented calculations are carried out for an increased spark advance (SA) to both promote knock onset over a large set of cases and to assess the modeling framework sensitivity to small variations in engine operations.

The analysis of combustion development and knock onset is carried out analysing 20 subsequent engine cycles through POD of both flame front evolution and local autoignition locations. Particularly, phase-dependent three-dimensional POD is implemented over the scalar distributions of progress variable of the chemical reactions and auto-ignition location, estimated based on the work by Lafossas et al. [4]. The method of snapshots introduced by Sirovich is used for POD [5]. The proposed POD analysis is critically discussed in terms of physical soundness, capability to investigate the engine knock-characteristics and applicability to the optimization of the combustion chamber.

Fuel Injection and Combustion Processes: Modeling

Fuel Injection and Combustion Processes: Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Influence of Biodiesel and Diesel Fuel Blends on the Injection Rate and Spray Injection in Non-Vaporizing Conditions

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Fossil fuel reserves are being depleted due to increasing energy requirements. One of the solutions is to partly replace fossil fuel by renewable biodiesel fuel. However, the physical properties of biodiesel fuels need to be thoroughly investigated before applying biodiesel or diesel-biodiesel blends in diesel engines, in order to improve the combustion efficiency.

This paper presents the experimental study of diesel fuel and biodiesel blends on injection flow characteristics and fuel spray behavior. Seven fuels were tested: diesel fuel, five diesel-biodiesel blends: 10%(B10), 20%(B20), 30%(B30), 40%(B40), 50%(B50), and pure biodiesel(B100) in a diesel engine equipped with a piezo injector. Injection pressures were set at 30-180 MPa for the study of the injection flow characteristics and at 30-150 MPa for the study of spray behavior in non-vaporizing conditions. The experimental results show that the injection flow characteristics and fuel spray behavior are the same with biodiesel blends as with diesel fuel. With pure biodiesel (B100), which has a density that is 5.2% higher and a viscosity 50% higher than diesel fuel, the discharge coefficient decreases by 3.63% but at injection pressure values of over 55 MPa, the effect on the discharge coefficient is insignificant. At the beginning of the injection period (up to 2000μs), the spray penetration and spray angle of B100 are different but after 2000 μs the spray behavior is similar to that of the other fuels. Correlations based on the work of Payri et al., Soteriou et al. and Naber & Siebers were used for comparison with the experimental data.

Physical-Chemical Characteristics of Diesel-Biodiesel Blends with Additives and Their Effects on the Spray Behavior

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A set of additives was selected to improve the durability of the physical-chemical and biological characteristics of mineral diesel and its blend with biodiesel. Two biodiesels were used: soybean (SME) and rapeseed (RME). Both physical-chemical properties and fuel dispersion of fuel blends and their mixtures with additives were measured that could have effects on the combustion process in diesel engines.

The dispersion of the fuel is affected by the injection nozzle integrity, influencing the capacity of the fuel to vaporize, while the modification of the fuel molecular structure can cause changes in combustion reaction. A 7 hole Common Rail (CR) 2nd generation injector, 136 μm in diameter, was used at 80 MPa and 1.0 ms injection pressure and duration, respectively. The injection rate was determined using the Bosch's Method, while the fuel dispersion was measured by analyzing the images of spray evolving in an optical accessible quiescent vessel.

The results showed that the additives have a great influence on the stability of the blends. Adding the biocide "P", antioxidant "AN" and pour point depressant "D", an increase of the oxidation stability of 390 % of the B20SME samples compared to B20 without additives. For B20SME containing "P", "AS" and "D", the oxidation stability increased of 810%.

The injection rate data showed that a slight reduction in the rate of injections (9.91% for Diesel B5RME, 8.13% relative to B20RME and 12.84% relative to B20SME) was registered when additives were used. Finally, the inclusion of the additives did not produce particular variations on the fuel spray tip penetration.

Tomography of a GDI Spray by PolyCO Based X-Ray Technique

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In this paper the investigation with X-ray Tomography on the structure of a gasoline spray from a GDI injector for automotive applications based on polycapillary optics is reported. Table-top experiment using a microfocus Cu Kα X-ray source for radiography and tomography has been used in combination with a polycapillary halflens and a CCD detector. The GDI injector is inserted in a high-pressure rotating device actuated with angular steps $\Delta\theta = 1°$ at the injection pressure of 8.0 MPa. The sinogram reconstruction of the jets by slices permits a 360° spray access to the fuel downstream the nozzle tip. A spatial distribution of the fuel is reported along the direction of six jets giving a measure of the droplet concentration in a circle of 16 mm2 below the nozzle tip at atmospheric backpressure and ambient temperature.

Spray Analysis of the PFAMEN Injector

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In an earlier study, a novel type of diesel fuel injector was proposed. This prototype injects fuel via porous (sintered) micro pores instead of via the conventional 6-8 holes. The micro pores are typically 10-50 micrometer in diameter, versus 120-200 micrometer in the conventional case. The expected advantages of the so-called Porous Fuel Air Mixing Enhancing Nozzle (PFAMEN) injector are lower soot- and CO2 emissions.

However, from previous in-house measurements, it has been concluded that the emissions of the porous injector are still not satisfactory. Roughly, this may have multiple reasons. The first one is that the spray distribution is not good enough, the second one is that the droplet sizing is too big due to the lack of droplet breakup. Furthermore air entrainment into the fuel jets might be insufficient. All reasons lead to fuel rich zones and associated soot formation.

To acquire more insight into the spray of the porous injector, several PFAMEN nozzles have been produced and investigated. The momentum of the spray was found to be an order of magnitude lower compared to conventional injectors. Afterwards, the porous injector was placed in an optically accessible engine, allowing the analysis of the spray development and combustion process. The main conclusion is that the spray penetration depth is relatively low. Finally, droplet size and velocities are presented using Phase Doppler Anemometry (PDA) and from these measurements it became clear that the droplets of the PFAMEN nozzle are larger compared to conventional injectors. This is believed to be caused by the low exit velocities.

Correlations of Non-Vaporizing Spray Penetration for 3000 Bar Diesel Spray Injection

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Increasing fuel injection pressure has enabled reduction of diesel emissions while retaining the advantage of the high thermal efficiency of diesel engines. With production diesel injectors operating in the range from 300 to 2400 bar, there is interest in injection pressures of 3000 bar and higher for further emissions reduction and fuel efficiency improvements. Fundamental understanding of diesel spray characteristics including very early injection and non-vaporizing spray penetration is essential to improve model development and facilitate the integration of advanced injection systems with elevated injection pressure into future diesel engines. Studies were conducted in an optically accessible constant volume combustion vessel under non-vaporizing conditions. Two advanced high pressure multi-hole injectors were used with different hole diameters, number of holes, and flow rates, with only one plume of each injector being imaged to enable high frame rate imaging. These injectors were studied between 2000 and 3000 bar injection pressures with ultra-low sulfur diesel fuel. The study included two part-load charge density conditions of 7.4 kg/m3 and 14.7 kg/m3 along with an elevated density boosted condition of 34.8 kg/m3. Diagnostics used included Mie backscatter imaging for liquid phase penetration. Experimental results of spray penetration were fit to an enhanced penetration correlation to represent the distinct phases of the injector opening and spray development. The spray penetration results were also compared to rate of injection data for the injectors to further understand and characterize the spray development process very early in the injection. The analysis and results provide a method of fitting and quantifying spray penetration with a revised correlation and for improved understanding of dynamics occurring in the injector the influence of elevated injection pressure on fundamental spray characteristics.

Influence of the Nozzle Geometry of a Diesel Single-Hole Injector on Liquid and Vapor Phase Distributions at Engine-Like Conditions

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The paper describes an experimental activity on the spatial and temporal liquid- and vapor-phase distributions of diesel fuel at engine-like conditions. The influence of the k-factor (0 and 1.5) of a single-hole axial-disposed injector (0.100 mm diameter and 10 L/d ratio) has been studied by spraying fuel in an optically-accessible constant-volume combustion vessel.

A high-speed imaging system, capable of acquiring Mie-scattering and Schlieren images in a near simultaneous fashion mode along the same line of sight, has been developed at the Michigan Technological University using a high-speed camera and a pulsed-wave LED system. The time resolved pair of schlieren and Mie-scattering images identifies the instantaneous position of both the vapor and liquid phases of the fuel spray, respectively. The studies have been performed at three injection pressures (70, 120 and 180 MPa), 23.9 kg/m3 ambient gas density and 900 K gas temperature in the vessel. A pre-combustion of reactants filling the vessel generated the required high-temperature and high-pressure conditions typical of diesel engine at the injection time. This pre-combustion mixture consists of C2H2, H2, O2 and N2 gases in order to obtain inert conditions (0% O2). The results obtained in the non-vaporizing conditions have been compared with those obtained on a different facility at Istituto Motori. In this paper the influence of the k-factor on the measurements of liquid and vapor penetration will be presented with the comparison of liquid penetration obtained by both the acquisition techniques and the two facilities. Then the liquid and vapor mass fraction has been estimated for several experimental conditions. Finally, fuel injection rates determinations using a meter working on the Bosch tube principle have been carried out to measure the injected mass.

Optical Investigation of Combusting Split-Injection Diesel Sprays Under Quiescent Conditions

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Multiple-injection strategies are widely used in DI diesel engines. However, the interaction of the injection pulses is not yet fully understood. In this work, a split injection into a combustion vessel is studied by multiple optical imaging diagnostics. The vessel provides quiescent high-temperature, high-pressure ambient conditions. A common-rail injector which is equipped with a three-hole nozzle is used. The spray is visualized by Mie scattering. First and second stage of ignition are probed by formaldehyde laser-induced fluorescence (LIF) and OH* chemiluminescence imaging, respectively. In addition formation of soot is characterized by both laser-induced incandescence (LII) and natural luminosity imaging, showing that low-sooting conditions are established. These qualitative diagnostics yield ensemble-averaged, two-dimensional, time-resolved distributions of the corresponding quantities. Not all of the quantities are measured simultaneously, but the distributions of all quantities can be compared precisely, due to the quiescent, well-controlled conditions in the vessel. Thereby, interfering signals are also analyzed.

In particular, the ignition mechanism of the second injection is investigated. The images indicate that the mixture fields of the first and second pulse get into contact at a certain time during the injection event. After that, a relatively fast ignition of the second pulse is observed. These findings demonstrate that the second pulse is ignited by the combusting first pulse, rather than by an auto-ignition. Thus, the ignition mechanisms of the first and the second injection pulse are fundamentally different. This behavior is found for all investigated dwell times between the pulses.

Characterization of a Set of ECN Spray A Injectors: Nozzle to Nozzle Variations and Effect on Spray Characteristics

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The Engine Combustion Network (ECN) is becoming a leading group concerning the experimental and computational analysis of Engine combustion. In order to establish a coherent database for model validation, all the institutions participating to the experimental effort carry out experiments at well-defined standard conditions (in particular at Spray A conditions: 22.8kg/m3, 900K, 0% and 15% O2) and with Diesel injectors having the same specifications. Due to the rising number of ECN participants and also to unavoidable damages, additional injectors are required. This raises the question of injector's characteristics reproducibility and of the appropriate method to introduce such new injectors in the ECN network.

In order to investigate this issue, a set of 8 new injectors with identical nominal Spray A specification were purchased and 4 of them were characterized using ECN standard diagnostics. In particular, the measurements include the nozzle hole diameter, the rate of injection, the liquid and vapor penetrations, the auto-ignition delay and the lift-off length. Variations of ambient temperature, oxygen concentration and density have also been performed.

In general the results show similar behavior to ECN standard injectors, confirming that this set of new injectors can be integrated into the pool of ECN injectors. However, discrepancies between spray characteristics were observed, although the injector specifications and the boundary conditions were sensibly the same. The sources of variations from injector to injector are analyzed in order to provide new information on the reproducibility of injectors characteristics, and improve the comparison methodology between experimental data and simulation.

Coking Effect of Different FN Nozzles on Injection and Combustion in an Optically Accessible Diesel Engine

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Interest on the issue of diesel injector nozzle deposits is rising in the last years due to its effects on engine performance. The alteration of nozzles geometry can cause a difference in fuel mass flow and influence smoke emission.

Investigation on the effects of nozzle coking in a diesel injector has been the topic of this paper. The experiments have been carried out in a single cylinder optical engine operating in premixed mode. The head of a Euro 5 production engine has been mounted on an elongated cylinder and the production CR injection system has been used. A sapphire window has been set in the piston head in order to have visible access to phenomena occurring in the combustion chamber. Three injectors with decreasing flow number (FN) have been tested. Engine has been fed with commercial diesel fuel. High spatial and temporal resolution camera has been used for the acquisition of in-cylinder injection and combustion images. It allowed obtaining interesting information about the process evolution in the bowl volume. Injectors have shown reduced performance after the coking procedure. Moreover, dependence from the FN has been observed. The alteration of injection parameters and the worsening of air/fuel mixture are the main detectable effects.

Schlieren Methodology for the Analysis of Transient Diesel Flame Evolution

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Schlieren/shadowgraphy has been adopted in the combustion research as a standard technique for tip penetration analysis of sprays under diesel-like engine conditions. When dealing with schlieren images of reacting sprays, the combustion process and the subsequent light emission from the soot within the flame have revealed both limitations as well as considerations that deserve further investigation. Seeking for answers to such concerns, the current work reports an experimental study with this imaging technique where, besides spatial filtering at the Fourier plane, both short exposure time and chromatic filtering were performed to improve the resulting schlieren image, as well as the reliability of the subsequent tip penetration measurement. The proposed methodology has reduced uncertainties caused by artificial pixel saturation (blooming). Additionally, an algorithm to calculate Lift-off length from schlieren images has been developed and compared to the more conventional OH* imaging technique.

By means of the improved setup, the analysis of transient diesel flame has been performed throughout the ignition and early combustion phases. When compared to a non-reacting vaporizing spray, the temporal evolution of the reacting case departs from the inert one at the start of combustion, when expansion in both axial (i.e. spray tip increase) and radial direction are observed. After that, the tip penetration progressively decreases on a clear transient period where the flow tries to re-organize itself in response to the induced reaction zone. Eventually, the spray undergoes an acceleration period where the reacting spray tip progresses above the non-reacting one. A parametric study has been conducted for three injection pressure levels to investigate the influence of this parameter upon transient flame evolution.

Dynamic Analysis of Emission Spectra in HCCI Combustion

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This work reports on the application of spectroscopic measurements coupled with data processing techniques in order to study, in terms of spectral emissions, the dynamic of the HCCI (Homogeneous charge compression ignition) combustion that occurs inside the combustion chamber of an optically accessible direct injection Diesel engine. A pre-processing of the recorded spectra is required for a correct analysis. The procedure of pre-processing consists of two main steps, that is: noise filtering with a technique based on the POD (Proper Orthogonal Decomposition); estimate and subtraction of the baseline. The analysis of the dynamics of the recorded spectra was carried out by the estimates of the synchronous and asynchronous 2D correlation spectra. These correlation spectra provide information on the correlation of the temporal changes of the spectral intensity among the different bands (or wavelength) of the recorded spectrum; therefore, they provide information on the temporal correlation between the various chemical species that present characteristic bands within the acquisition band. This paper reports on the analysis of the synchronous and asynchronous 2D spectra related to the emission spectra; in particular, attention is focused on the characteristic bands of radicals OH, CH and HCO. The analysis of the emission spectra reported in this work provides information that can be useful for understanding chemical mechanisms related with HCCI combustion.

Experimental Investigations for Turbulent Premixed Flame Analysis

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Increasingly stringent pollutant emission regulations have constrained car manufacturers to reduce the fuel consumption and pollutant emissions of internal combustion engines. Downsized engines appear to be the most promising way to achieve this in terms of emission reduction as well as investment minimization. The design of downsized internal combustion engines requires the understanding and quantification of thermo-fluid-dynamic processes at high pressure, high temperature and with high dilution rate. This study aims to carry out preparatory work in a fan-stirred spherical combustion vessel at conditions representative of those occurring in downsized engines. First, experimental correlations giving the laminar burning velocity from the initial pressure, the initial temperature, the dilution rate and the equivalence ratio are proposed. Then the turbulent flow inside the vessel is characterized in terms of turbulent rms velocities and integral length scales, without combustion, using Laser Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV) measurements. The integral length scale remains constant at all fan speeds and all investigated pressures and temperatures. It appears to be an inherent parameter of the experimental setup. The intensity level increases linearly up to 2.8 m/s with the fan speed. Close approximations of homogeneous and isotropic turbulence (HIT) are achieved using this setup. The flame progress is then tracked using high speed tomography. Results of the characterization of the turbulent flow are shown to be still relevant during the turbulent flame propagation. This validation stage is essential for the characterization of turbulent flames as a function of the turbulent flow characteristics. Lastly, using the turbulent combustion diagram, a comparison with turbulent flame propagation in a research engine is carried out and the relevance of the present experimental setup is highlighted.

Assessment of a New Quasi-Dimensional Multizone Combustion Model for the Spray and Soot Formation Analysis in an Optical Single Cylinder Diesel Engine

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An innovative quasi-dimensional multizone combustion model for the spray formation, combustion and emission formation analysis in DI diesel engines was assessed and applied to an optical single cylinder engine.

The model, which has been recently presented by the authors, integrates a predictive non stationary 1D spray model developed by the Sandia National Laboratory, with a diagnostic multizone thermodynamic model.

The 1D spray model is capable of predicting the equivalence ratio of the fuel during the mixing process, as well as the spray penetration.

The multizone approach is based on the application of the mass and energy conservation laws to several homogeneous zones identified in the combustion chamber. A specific submodel is also implemented to simulate the dilution of the burned gases.

Soot formation is modeled by an expression which derives from Kitamura et al.'s results, in which an explicit dependence on the local equivalence ratio is considered.

The model was used to analyze low load (BMEP = 2 bar at 1500 rpm) and medium load (BMEP = 5 bar at 2000 rpm) operating conditions in an optical single cylinder engine sharing the combustion system configuration of the 2.0L Euro5 GM diesel engine for passenger car application. The images obtained by a CCD camera were used to derive statistically averaged values of the spray tip penetration and of the dispersion angle. The soot concentration was also calculated by means of the two-colour pyrometry method. These experimental data were used for the multizone model assessment.

Independent Component Analysis of Combustion Images in Optically Accessible Gasoline and Diesel Engines

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Flame luminosity fields can nowadays be collected from optically accessible engines, with high spatial and temporal resolution, and constitute a very powerful investigation means for the transient combustion phenomena taking place in the engine chamber. Interpretation of the impressive amount of collected data can be quite challenging, mainly due to the variety of coupled phenomena involved. Application of Independent Component Analysis (ICA) aims here at separating spatial structures related to different combustion events, and is coupled with the analysis of the statistics of the coefficients of the independent components, and of the measured in-cylinder parameters. This paper reports on the comparison of the application of ICA to 2D images of combustion-related luminosity collected from two different optically accessible engines: Diesel and spark ignition. Independent components and their coefficients are first extracted from sets of luminosity images, and then used to identify leading structures and to study the transient behavior of the combustion process. The two components identified from the single Diesel cycle appear to be clearly related to early combustion along the fuel jets and later combustion near the bowl walls, respectively; quantitative analysis of coefficient statistics confirms the lower variability of the jet flames with respect to combustion near the chamber walls. The same can be said of the results of the analysis for SI combustion images, which are separated in early, median and final luminous combustion. The analysis is fast and reliable and can be prospectively applied to many different optical engine configurations.

Experimental Investigation of a Methane-Gasoline Dual-Fuel Combustion in a Small Displacement Optical Engine

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In this paper the methane-gasoline dual fuel combustion was investigated. Gasoline was injected in the intake manifold (PFI fuel), while methane was injected in the combustion chamber (DI fuel), in order to reproduce a stratified combustion. The combustion process and the related engine performance and pollutant emissions were analyzed.

The measurements were carried out in an optically accessible small single-cylinder four-stroke engine. It was equipped with the cylinder head of a commercial 250 cc engine representative of the most popular two-wheel vehicles in Europe. Optical measurements were performed to analyze the combustion process with high spatial and temporal resolution. In particular, optical techniques based on 2D-digital imaging were used to follow the flame front propagation and the soot and temperature concentration in the combustion chamber. The regulated and unregulated emissions were characterized by means of gaseous analyzers, a gas chromatography and an opacimeter at the exhaust. The measurements were performed under steady state conditions at fixed engine speed at different dual fuel ratios. The measurement showed that dual fuel operation permit to improve the quality of the gaseous fuel combustion adding the liquid fuel and the gas and particulate matter emissions are significantly lower compared to the respective ones under gasoline operation.

Development Approach for the Investigation of Homogeneous Charge Compression Ignition in a Free-Piston Engine

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In this paper the development approach and the results of numerical and experimental investigations on homogeneous charge compression ignition in a free piston engine are presented. The Free Piston Linear Generator (FPLG) is a new type of internal combustion engine designed for the application in a hybrid electric vehicle. The highly integrated system consists of a two-stroke combustion unit, a linear generator, and a mass-variable gas spring. These three subsystems are arranged longitudinally in a double piston configuration. The system oscillates linearly between the combustion chamber and the gas spring, while electrical energy is extracted by the centrally arranged linear generator. The mass-variable gas spring is used as intermediate energy storage between the downstroke and upstroke.

Due to this arrangement piston stroke and compression ratio are no longer determined by a mechanical system. The gas exchange is carried out via an electromagnetic valve train, which is mounted on the cylinder head. This combination of variable compression ratio, piston trajectory and fully variable valve train provides the ability for a fundamental optimization of the combustion process.

Homogeneous charge compression ignition (HCCI) is a promising combustion process leading to high combustion efficiencies and low raw emissions. Thereby a challenge is the active control of the ignition and combustion process. The present paper summarizes the approach for a first demonstration of HCCI combustion using the high variability of the FPLG engine concept. 3D-CFD and chemical kinetics simulations of the in-cylinder processes are the basic steps towards the implementation of HCCI combustion in the FPLG engine.

By means of these simulations new engine components and a HCCI specific operating strategy were developed. A key aspect in this context is the internal exhaust gas recirculation (EGR), which is realized by an early intake valve opening and intermediate storage of combustion gases in the intake ports. The numerical results were confirmed by experimental measurements and show a promising potential for HCCI combustion in the FPLG engine.

Towards HCCI Control by Ozone Seeding

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Nowadays, the main objectives in the automobile engine field are to reduce fuel consumption and pollutant emissions. HCCI engines can be a good solution to meet pollutant emission requirements and to achieve high combustion efficiency. However, before an HCCI engine is used as a conventional engine, several problems must be overcome, in particular control of the progression of combustion.

Many studies have been conducted into possible control methods. A new strategy consists in using oxidizing chemical species such as ozone to seed the intake of a HCCI engine. As increasingly smaller ozonizers are now being designed, this kind of device could be integrated on a vehicle and on a HCCI engine, in order to control combustion phasing and promote the future use of this engine as a conventional engine.

In the present study, experiments on a HCCI engine fuelled with iso-octane were carried out with ozone seeding in the intake. Results showed that when assisted by the addition of ozone, combustion can be enhanced and moved forward. Consequently, the use of oxidizing chemical species can be a means to control HCCI combustion. Depending on the inlet temperature, the control of combustion phasing may be more or less easy due to sensitivity to the ozone concentration. The present results also show the existence of a cool flame in the case of iso-octane combustion, indicating that ozone seeding can also be used in order to study iso-octane cool flame in a HCCI engine.

Transient RCCI Operation in a Light-Duty Multi-Cylinder Engine

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Reactivity Controlled Compression Ignition (RCCI) is an engine combustion strategy that utilizes in-cylinder fuel blending to produce low NOx and PM emissions, while maintaining high thermal efficiency. Previous RCCI steady-state performance studies provided a fundamental understanding of the RCCI combustion process in steady-state, single-cylinder and multi-cylinder engine tests. The current study investigates RCCI and conventional diesel combustion (CDC) operation in a light-duty multi-cylinder engine over transient operating conditions. In this study, a high-bandwidth, transient-capable engine test cell was used and multi-cylinder engine RCCI combustion is compared to CDC over a step load change from 1 to 4 bar BMEP at 1,500 rev/min. The engine experiments consisted of in-cylinder fuel blending using port fuel-injection (PFI) of gasoline and early-cycle, direct-injection (DI) of ultra-low sulfur diesel (ULSD) for the RCCI tests and used the same ULSD for the CDC tests. Over the step load change, both combustion modes were compared for combustion performance and emissions using fast response HC, NO and PM instrumentation. Similar intake pressures were used for both combustion modes to explore the robustness of the RCCI combustion strategy using real-world operating conditions with production viable hardware. It was found that the engine was able to operate with RCCI combustion with lower engine-out PM and NO but increased HC and CO emissions than CDC over the specified transient engine operating conditions using either open- or closed-loop feedback control of the combustion phasing.

Experimental Investigation of Soot in a Spray-Guided Single Cylinder GDI Engine Operating in a Stratified Mode

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Forthcoming reductions in legal limits for emissions of particle matter (PM) from direct injection engines have increased the need for understanding particle distributions in the engines and the factors affecting them. Therefore, in the presented study the influence on PM-emissions of potentially important factors (fuel injection pressure, load, speed and 50% mass fraction burned phasing) on particle mass, number and size distributions were experimentally investigated. The experimental system was a spray-guided, direct injection, single-cylinder research engine operated in stratified charge mode (using gasoline with 10% ethanol as fuel), under five load and speed settings that are appropriate for stratified combustion. The particle distributions obtained from operating the engine in homogeneous combustion and stratified combustion modes were also compared.

The particle distributions were measured using a Cambustion DMS500 fast particle analyzer in combination with a Dekati FPS4000 fine particle sampler and a thermodenuder in all tests except the comparison of distributions under stratified and homogeneous combustion conditions. The sampling system was designed to remove as much of the volatile unburned hydrocarbons as possible in order to sample mostly solid particles.

Under all of the stratified operating conditions studied, the results indicate that the particle distribution has a characteristic shape with a tail and one large peak. The operating speed significantly affected the size of the largest particles and the quantity of the particles represented by the tail.

An almost linear, positive relationship was found between the load and particle number. Increasing the fuel injection pressure reduced particle numbers whereas combustion phasing had no significant observed effects. More particles were generated in stratified combustion mode than in homogeneous mode.

The Effects of a Radio Frequency Ignition System on the Efficiency and the Exhaust Emissions of a Spark-Ignition Engine

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Plasma sustained ignition systems are promising alternatives to conventional spark plugs for those applications where the conditions inside the combustion chamber are more severe for spark plug operation, like internal combustion engines with high compression ratio values and with intake charge dilution.

This paper shows the results of an experimental activity performed on a spark ignition engine equipped alternatively with a conventional spark plug and a radio frequency sustained plasma ignition system (RFSI). Results showed that RFSI improved engine efficiency, extended the lean limit of combustion and reduced cycle-by-cycle variability, compared with the conventional spark plug at all test conditions. The adoption of the RFSI also had a positive impact on carbon monoxide and unburned hydrocarbon emissions, whereas nitrogen oxide emissions increased due to higher temperatures attained in the combustion chamber.

Impact of Fuel Properties and Flame Stretch on the Turbulent Flame Speed in Spark-Ignition Engines

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The current decrease in fossil energy resources requires a diversification of the liquid and gaseous fuels potentially consumable in internal combustion engines. The use of these fuels modifies the combustion process and the heat released as well. In a Spark Ignition (SI) engine, the heat released is mainly piloted not only by the mixture reactivity but also by its sensitivity to stretch effects. Only a few results can be found in the literature about stretch effects for SI engine configurations. The purpose of the present paper is to evaluate stretch effects on the flame front propagation in an optical SI engine and to investigate the relative importance of these effects depending on the fuel considered.

Different air-fuel mixtures presenting different flame stretch sensitivities were selected. Four different engine regimes (1400, 1600, 1800 and 2000 rpm) were studied for all the mixtures in order to evaluate the impact of different turbulence intensities. In-cylinder pressure analyses were performed to determine the heat release rate and the crank angle corresponding to 5% of mass burned. At the same time, direct visualizations of the flame through the piston were performed using an intensified high-speed video camera. From the recorded images, a global flame stretch and an equivalent propagation speed were defined and their evolution studied. An increase in the stretch rate is observed for higher engine speeds but the combustion process for the mixtures presenting a strong sensitivity to stretch is slowed down when the regime is increased.

Engine In-Cylinder Flow Control via Variable Intake Valve Timing

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Stereoscopic particle-image velocimetry (PIV) is used to investigate the non-reacting flow field in the combustion chamber of a motored direct-injection spark ignition (DISI) engine with tumble intake port. The in-cylinder flow is controlled by variable valve timing (VVT), i.e., shifting of the intake cam shaft to earlier or later crank angles (cam phasing). VVT systems are already implemented in production combustion engines, e.g., BMW's Vanos system, to improve the volumetric efficiency and to reduce pumping losses. In the present study, the underlying flow phenomena, i.e., the effect of VVT on the tumble development and turbulent kinetic energy, are analyzed. The flow field is investigated at a set of early, intermediate, and late intake valve opening (IVO) positions during the intake and compression strokes, thus enabling the analysis of the temporal development of the main flow structures. Two parallel, vertical measurement planes, the symmetry plane and the valve plane, are investigated. It is shown that VVT has a strong influence on the mean vorticity and the local and temporal distribution of the kinetic energy and turbulent kinetic energy. The tumble stability is improved by a late opening of the intake valves, i.e., the kinetic energy and vorticity are increased. This is due to the formation of an additional positive vortex which adds to the vorticity and kinetic energy of the main tumble. An early intake valve closure, however, leads to a stronger rear part of the ring vortex, which contains negative vorticity and decelerates the main tumble. Furthermore, the amount of turbulent kinetic energy in the intake phase strongly depends on IVO, which is important for the fuel injection and mixing.

Effects of Controlling Oxygen Concentration on the Performance, Emission and Combustion Characteristics in a Downsized SI Engine

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In the present study, experiments were carried out in a single-cylinder downsized SI engine with different rates of oxygen (15% to 27% by volume in the total mixture of intake gases except fuel) and equivalence ratios (from 0.45 to 1). Therefore, the oxygen volume fraction is due to oxygen enrichment or nitrogen dilution. The study of the impact of controlling oxygen concentration on the combustion characteristics and emissions was performed at 1400 rpm, at several loads (Indicated Mean Effective Pressure (IMEP) from 400 to 1000 kPa). For each operation point, the spark advance and the intake pressure were adjusted simultaneously in order to maintain the load and obtain a minimum value of indicated Specific Fuel Consumption (SFC).

The effect of oxygen concentration on the engine combustion characteristics was simulated by using the commercial software AMESim, with the combustion model developed by IFP-EN, and an adapted algorithm was used to avoid residual gas calibration. The in-cylinder pressures are calibrated with experimental data by adapted the integral length scale and tumble number values. By implementing a correlation for the laminar burning velocity, the in-cylinder pressures were perfectly calibrated with a maximum pressure relative error less than 2% for almost all the operation points.

Effects of Different Geometries of the Cylinder Head on the Combustion Characteristics of a VVA Gasoline Engine

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Two different modifications of the baseline cylinder head configuration have been designed and experimentally tested on a MultiAir turbocharged gasoline engine, in order to address the issue of the poor in-cylinder turbulence levels which are typical of the Early-Intake-Valve-Closing (EIVC) strategies which are adopted in Variable Valve Actuation systems at part load to reduce pumping losses.

The first layout promotes turbulence by increasing the tumble motion at low valve lifts, while the second one allows the addition of a swirl vortex to the main tumble structure. The aim for both designs was to achieve a proper flame propagation speed at both part and full load.

The experimental activity was initially focused on the part load analysis under high dilution of the mixture with internal EGR, which can allow significant further reductions in terms of pumping losses but, on the other hand, tends to adversely affect combustion stability and to increase cycle-to-cycle variations. All the three different configurations (baseline, enhanced tumble, enhanced swirl) were compared in terms of combustion duration and combustion stability for increasing levels of EGR.

The second phase of the experimental investigation was then focused on the full load performance in order to assess the effects of the cylinder head modifications on knocking occurrence: the operating points chosen were the full rated power and the full rated torque.

Finally the cylinder head featuring the best trade-off between full and part load performance was identified.

Strategy for Mode Transition between Low Temperature Combustion and Conventional Combustion in a Diesel Engine

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Mode transition between low temperature combustion (LTC) and conventional combustion was performed by changing the exhaust gas recirculation (EGR) rate from 60% to 0% or vice versa in a light duty diesel engine. The indicated mean effective pressure (IMEP) before mode transition was set at 0.45 MPa, representing the maximum load of LTC in this research engine. Various engine operating parameters (rate of EGR change, EGR path length, and residual gas) were considered in order to investigate their influence on the combustion mode transition. The characteristics of combustion mode transition were analyzed based on the in-cylinder pressure and hydrocarbon (HC) emission of each cycle.

The general results showed that drastic changes of power output, combustion noise, and HC emission occurred during the combustion mode transition due to the improper injection conditions for each combustion mode. Therefore, a strategy for smooth combustion mode transition was developed by controlling the injection parameters such as injection timing, injection duration, and the number of injections on a cycle-by-cycle basis. As a consequence of gradually retarding the injection timing, gradually decreasing the injection duration, and adding a pilot injection, the differences in power output and combustion noise between the periods before and after mode transition were reduced by up to 100% and 225%, respectively, compared to those values for the case without controlling the injection parameters.

Optimization of Diesel Combustion and Emissions with Tailor-Made Fuels from Biomass

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In order to thoroughly investigate and improve the path from biofuel production to combustion, the Cluster of Excellence "Tailor-Made Fuels from Biomass" was installed at RWTH Aachen University in 2007. Since then, a variety of fuel candidates have been investigated. In particular, 2-methyl tetrahydrofurane (2-MTHF) has shown excellent performance w.r.t. the particulate (PM) / NOx trade-off [1]. Unfortunately, the long ignition delay results in increased HC-, CO- and noise emissions.

To overcome this problem, the addition of di-n-butylether (DNBE, CN 100) to 2-MTHF was analyzed. By blending these two in different volumetric shares, the effects of the different mixture formation and combustion characteristics, especially on the HC-, CO- and noise emissions, have been carefully analyzed. In addition, the overall emission performance has been compared to EN590 diesel.

The results show that an addition of DNBE to 2-MTHF can lead to a reduction of HC- and CO-emissions by 75 % and noise emissions up to 4 dB. Simultaneously, none of the benefits gained with 2-MTHF with regard to the PM-emissions are not sacrificed. It could be proven, that by blending two molecules that are derived from biomass, a tailor-made fuel can be designed that allows optimizing the diesel combustion according to the desired criteria.

In addition, both fuels were investigated in a High Pressure Chamber (HPC). Based on the results, new characteristic fuel numbers shall be developed in order to describe the combustion behaviour of the new fuels in a proper way, since the established ones are not sufficient to describe the combustion and emission performance of these fuels.

The Effect of Compression Ratio on Low Soot Emission from a Small Non-Road Diesel Engines

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Particulate matter (PM) emission of non-road diesel engines is more and more stringently restricted by US, EU, Japan, etc. In order to achieve these emission regulations, diesel particulate filter (DPF) system is applied. However DPF system requires extra fuel consumption in order to burn accumulated particles. Furthermore, since it is difficult to install large DPF systems in limited packaging space of non-road applications, compact DPF system is desirable.

Reducing soot emission with engine technology is effective for reducing PM emission, which results in reducing extra fuel consumption and downsizing or removing of DPF system. Soot emission level mainly depends on excess air ratio (EAR), and can be reduced by keeping EAR high (lean combustion). However, lean combustion under the limited amount of air and maximum in-cylinder pressure requires decrease in fuel injection quantity, and yields decrease in engine power. Therefore, in order to achieve low soot emission without decreasing engine output, low soot combustion with minimum EAR without a significant increase in soot emissions is required. Furthermore, low compression ratio is thought to be one method for increasing power density under the limited maximum in-cylinder pressure.

In this study, the effect of compression ratio on soot emission is investigated under the constant EAR assuming higher load engine operating condition.

The results show that soot emission gets lower as compression ratio is lower because of the increase in volume of combustion chamber. In addition, the effects of fraction of premixed combustion or injection duration on soot emission are also discussed.

The Impact of Fuel Mass, Injection Pressure, Ambient Temperature, and Swirl Ratio on the Mixture Preparation of a Pilot Injection

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Fuel tracer-based planar laser-induced fluorescence is used to investigate the vaporization and mixing behavior of pilot injections for variations in pilot mass of 1-4 mg, and for two injection pressures, two near-TDC ambient temperatures, and two swirl ratios. The fluorescent tracer employed, 1-methylnaphthalene, permits a mixture of the diesel primary reference fuels, n-hexadecane and heptamethylnonane, to be used as the base fuel.

With a near-TDC injection timing of −15°CA, pilot injection fuel is found to penetrate to the bowl rim wall for even the smallest injection quantity, where it rapidly forms fuel-lean mixture. With increased pilot mass, there is greater penetration and fuel-rich mixtures persist well beyond the expected pilot ignition delay period. Significant jet-to-jet variations in fuel distribution due to differences in the individual jet trajectories (included angle) are also observed. Increased injection pressure significantly increased the mixing rate, leading to leaner mixture distributions, and with lower ambient temperature modestly richer mixtures are found near the heads of the jets. Discrete droplets near the injector were unexpectedly found to be more common at the higher ambient temperature. Lastly, increased swirl displaces the fuel to locations lower in the bowl, while generating a greater amount of over-lean mixture in the upper-central region of the combustion chamber.

Study on Spray Injection and Combustion of Fouled and Cleaned Injectors by Means of 2-D Digital Imaging in a Transparent CR Diesel Engine

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The aim of this study is to investigate how the fouling that injectors undergo after several operating hours on a vehicle can affect the injection and combustion phases. The impact of the injector fouling on the pollutant formation has been also investigated. Moreover, the effects of the injector cleaning by deposits through the top quality diesel fuel commercialized by eni that is FAME free and contains multi performance additives have been investigated. The experimentation has been carried out on transparent compression ignition engine. It is a single cylinder equipped with a Euro 5 multi-cylinder head and a second-generation common rail injection system. Three indirect-acting piezoelectric injectors have been tested. The first one has been fouled with European commercial diesel fuel through the CEC DW10 injector-coking test. The second one has been fouled in the same way and, then, it has been cleaned with eni top quality diesel fuel. This fuel has fed the third injector too. Two operating conditions have been investigated; they represent the condition at 1500 rpm and 2 bar of Brake Mean Effective Pressure (BMEP) and at 2000 rpm and 5 bar of BMEP, respectively. Tests have been performed with European commercial diesel fuel. Injection rate profiles of the three injectors have been detected. Steady-state measurements of exhaust emissions have been realized by commercial instruments. Non intrusive 2-D digital imaging has been performed to investigate both the injection and the combustion evolution. It has been found that the injector behavior in terms of spray penetration, combustion efficiency and pollutant formation is influenced in a negative way by the deposits presence. Moreover, it has been observed that the injector cleaning results in a performance improvement and a pollutant emissions reduction.

Time and Spatially Resolved Measurements of the Interaction between Liquid and Combusting Diesel Spray and Walls in Modern Diesel Engine Conditions

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Spray- and flame-wall interactions were investigated in a combustion chamber with diesel engine conditions. Several techniques were used to perform time and spatially resolved measurements of the liquid fuel phase, the premixed and diffusion-controlled combustion close to a wall.

Different wall and gas temperature variations were investigated. It was found that low temperature variations of 25K have a significant impact on the combustion process:

The lower the gas temperatures, the more liquid fuel and larger vortex structures arise. Also, the ignition delay is elongated. Consequently, the premixing period is longer, which can lead to the complete disappearance of sooty combustion.

The colder the wall, larger cooling of the spray and larger vortex structures of liquid fuel on the wall develop. The ignition delays again are noticeable longer at the colder wall. Therefore, the premixing period is longer and there is also much less sooty combustion when the wall temperature is lower.

Further, a reference fuel following the European normative EN 590 (CEC) and a rapeseed fuel (RME) were compared. The ignition delay of CEC is shorter than that of RME. This is remarkable, since measurements without wall interaction showed the opposite. It is important for the spray-wall- interaction whether the fuel is liquid or vaporized when the interaction takes place, because of an intensified heat exchange in the case of liquid wall interaction.

In-Cylinder Flow Pattern Evaluated with Combustion Image Velocimetry, CIV, and CFD Calculations during Combustion and Post-Oxidation in a HD Diesel Engine

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In-cylinder flow pattern was evaluated during diesel combustion and post-oxidation in a heavy duty optical engine and compared with CFD calculations. In this work the recently developed optical method combustion image velocimetry (CIV) is evaluated. It was used for extracting the flow pattern during combustion and post-oxidation by tracing the glowing soot clouds in the cylinder. The results were compared with CFD sector simulation on the same heavy duty engine geometry. Load was 10 bar IMEP and injection pressure was varied in two steps together with two different swirl levels. The same variations were done in both the optical engine and in the CFD simulations.

The main results in this work show that the CIV method and the CFD results catch the same flow pattern trends during combustion and post-oxidation. Evaluation of the CIV technique has been done on large scale swirl vortices and compared with the CFD results at different distances from the piston bowl surface. The flow field according to CIV is shown to resemble the flow quite near the optical piston bowl surface during the diffusion combustion period in the CFD results. During the after-oxidation period, the observed CIV data coincide with mean velocity data from CFD, calculated on the total depth from cylinder head to piston surface. Both methods indicate that the in-cylinder flow is strongly deviating from solid body rotation during the diffusion flame and after-oxidation period. This deviation is not so significant before injection. During the after-oxidation period, the deviation from solid body rotation increases with injection pressure.

An Experimental Investigation of the Effect of Bore-to-Stroke Ratio on a Diesel Engine

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The more and more severe regulations on exhaust emissions from vehicles and the worldwide demand for fuel consumption reduction impose continuous improvements of the engine thermal efficiency. Base engine geometrical setups are important aspects which have to be taken into account to improve the engine efficiency.

This paper discusses the influence of the bore-to-stroke ratio on emissions, fuel consumption and full load performances of a Diesel engine.

The expected advantage of a reduced bore-to-stroke ratio is mainly a decrease of the thermal losses, due to a higher volume-to-surface ratio, reducing the wall surfaces, responsible for the heat losses, per volume of gas. The advantages concerning the wall heat losses are opposed to the disadvantages of lower volumetric efficiency, as a smaller bore requires smaller valve diameter. Additionally does a reduction of the bore-to-stroke ratio lead to an increase of the friction losses, as the mean piston speed increases.

Within this study, three different bore-to-stroke ratios are analyzed on a single-cylinder CR Diesel engine. The methodology used for this investigation is to set constant as much engine parameters as possible between the three configurations. Therefore, the displacement, the injection system, the in-cylinder TDC swirl and the compression ratio are fixed, in order to isolate the phenomena depending on the bore-to-stroke ratio.

Five engine operating points are investigated: three partial load points, representative of the NEDC conditions on a C-class vehicle, and two full load points.

In addition to standard analysis and combustion analysis including heat exchanges, an energy strip study using an in-house tool is performed in order to evaluate which parameters have the highest influence on the efficiency differences between the three configurations.

The combustions process is significantly impacted by the bore-to-stroke ratio due to differences in wall heat losses and piston speed. Higher gas temperatures around TDC decrease the premixed combustion phase and affect exhaust gas emissions.

The main conclusion of this study is that the smallest bore-to-stroke ratio configuration shows the best trade-off between thermal and mechanical losses, with respect to the overall engine efficiency.

Spectroscopic Investigation of Post-Injection Strategy Impact on Fuel Vapor within the Exhaust Line of a Light Duty Diesel Engine Supplied with Diesel/ Butanol and Gasoline Blends

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In this paper, a high temporal resolution optical technique, based on the multi-wavelength UV-visible-near IR extinction spectroscopy, was applied at the exhaust of an automotive diesel engine to investigate the post-injection strategy impact on the fuel vapor.

Experimental investigations were carried out using three fuels: commercial diesel (B5), a blend of 80% diesel with 20% by vol. of gasoline (G20) and a blend of 80% diesel with 20% by vol. of n-butanol (BU20). Experiments were performed at the engine speed of 2500rpm and 0.8MPa of brake mean effective pressure exploring two post-injection timings and two EGR rates.

The optical diagnostic allowed evaluating, during the post-injection activation, the evolution of the fuel vapor in the engine exhaust line. The investigation was focused on the impact of post-injection strategy and fuel properties on the aptitude to produce hydrocarbon rich gaseous exhaust for the regeneration of diesel particulate trap (DPF).

The main results showed that advanced start of post-injection produced UV optical signal with a slightly lower intensity due to a tiny energy thermal activity that reduced the fuel vapor amount in the exhaust. BU20 and G20 blends induced a higher concentration of fuel vapor within the exhaust manifold and consequently a lower tendency to lubrication oil dilution.

An Improved Multi-Pipe Junction Model for Engine Thermodynamic and Gas Dynamic Simulations

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Computer software, which simulates the thermodynamic and gas dynamic of internal combustion engines, are used extensively during design and development process. This paper analyzes the 1D boundary multi-pipe junctions calculations using the Method of Characteristics (MOC).

Sonic flows can be encountered in the exhaust manifolds of internal combustion engines (especially racing engines) and in the model a check if the flow is sonic or not have been made. Flows with more than one manifold have flow toward the junction, need an equivalent "Datum" manifold, with an airflow as the sum of all flows, an averaged area and stagnation enthalpy has been defined in order to calculate the pressure loss when crossing the junction.

The pressure loss terms have been calculated as function of the flow-ratio of the gas flowing to the manifold to the total incoming flow and the pipe angle. Such terms take into account of the flow ratio referred to the "Datum" flow and the pipe angle term is the average of all the pressure losses of every duct with incoming flow.

The main model used to calculate the wave actions in the manifolds is the Two Step Lax-Wenfroff scheme, second order in space and time with the TVD flux limiter, needed to smooth the instabilities typical of second order hyperbolic schemes.

Two set of tests have been designed in order to show the advantages of the present formulation. The first is "Y" junction with an inlet duct. Increasing the inlet pressure, the flow increase up to reach the sonic flow. The second test is a Y junction with 2 inlet ducts with the third duct that goes to sonic flow.

A racing engine has also been simulated comparing the results with those from a dynamometer, showing good accordance between model and measured data.

Fluid Dynamic and Acoustic Optimization Methodology of a Motorbike Intake Airbox Using Multilevel Numerical CFD Models and Experimental Validation Tests

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In this work a multilevel CFD analysis have been applied for the design of an intake air-box with improved characteristics of noise reduction and fluid dynamic response. The approaches developed and applied for the optimization process range from the 1D to fully 3D CFD simulation, exploring hybrid approaches based on the integration of a 1D model with quasi-3D and 3D tools. In particular, the quasi-3D strategy is exploited to investigate several configurations, tailoring the best trade-off between noise abatement at frequencies below 1000 Hz and optimization of engine performances.

Once the best configuration has been defined, the 1D-3D approach has been adopted to confirm the prediction carried out by means of the simplified approach, studying also the impact of the new configuration on the engine performances. The calculations have been further validated by an extensive experimental campaign carried out not only on the test bench for engine performance analysis but also on an acoustic test bench developed by the University of Florence. The experimental acoustic characterization is based on the Multi-Microphone Technique, which guarantees a wider reliable frequency range of analysis and lower errors in the evaluation of the acoustic properties of the examined devices (such as mufflers or intake lines, etc.).

Results of the calculations on both the baseline and optimized configurations have been compared to the measured acoustic performance carried with null flow conditions showing an encouraging agreement.

Dissipative Silencers Based on Micro-Perforated Plates

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Micro-perforated plates (MPP:s) can be defined as a perforated plate where the hole impedance is dominated by viscous losses. This will always be true for sufficiently low frequencies or small holes. In addition for a standard MPP the perforation ratio is chosen so that the normalized acoustic resistance is between 1-2, which yields optimum damping for incident plane waves. Historically MPP:s have been used as panel absorbers to reduce reflections in rooms and enclosures. More recently the potential for machinery and vehicle applications has come into focus, e.g., dissipative exhaust silencers. Some advantages offered by a MPP solution, when compared to traditional dissipative silencers, are that it can reduce the weight and the problem with fibre breakout. In this paper the work on cylindrical MPP dissipative silencers at KTH is summarized. One important question being how an optimum damping is achieved, for a certain frequency band and for a given volume (length & area ratio) of the silencer.

Extended Investigations on Micro-Grooved Elements - A Novel Solution for Noise Control

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The goal of this paper is to provide a complete characterization of acoustic performance for a novel type of advanced acoustic material - micro grooved element (MGE). In a previous study, the MGEs have been proved to offer a respectable alternative for the existing and increasingly popular micro perforated elements (MPEs).

The MGEs are multi-layer elements where the acoustic attenuation effect originates from viscous losses taking place in a number of sub-millimeter grooves forming acoustic micro-paths inside the material. This new configuration allows to replace the laser perforation process, used to manufacture the MPEs, with less time consuming and more cost effective technologies. Moreover, such elements preserve low weight and surface roughness. Experiments have demonstrated that the MGEs can be regarded as suitable solution for noise control in a wide range of applications.

In this work, the transfer impedance and the absorption coefficient of a number of MGEs, composed of geometrically different apertures, have been investigated by using the classical two-port method. The effect of the main geometrical parameters controlling the acoustic performance has been analyzed and modeled. Also, the interaction between the micro-paths has been studied. The non-linear behavior, observed in the presence of high excitation levels has been included in the model.

The acoustic impedance of the micro-grooved elements has been derived from the experimentally obtained TL curve in the presence of grazing flow. Consequently, the model developed for MGEs has been further extended to the grazing flow conditions and compared to the well-known models proposed by Rice for micro-perforated elements.

Numerical Simulation for Exhaust Manifold Based on the Serial Coupling of STAR-CCM+ and ABAQUS

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Exhaust manifolds are the main heated parts of internal combustion engine which connect with the cylinder head directly, transfer the high temperature gas to the following exhaust system. The phenomenon of exhaust manifold fatigue rupture often occurs when the internal engine durability tests are conducted owing to the severe work environment such as the heavy thermal load, high thermal stress, high frequency of heat cycle shock. To predict the thermal fatigue life of exhaust manifolds effectively, it's necessary to make the transient heat coupling analysis of fluid and structure, calculate the transient fluctuation situation of temperature and thermal stress, find the weak place of the structure so as to provide references for the improvement of manifolds' design and supply thermal boundary conditions for the analysis of thermal fatigue.

There's a widespread phenomenon in nature and engineering practices occurred for two or more fields' interactions in one system, which we called Multi Physics Problems (MPPS). MPPS of manifolds mainly involve the coupling of structure fields, fluid fields and temperature fields. It can be classified into the following 5 aspects' coupling: fluid-thermal coupling, structure-thermal coupling, fluid-structure coupling (fluid-solid interaction, FSI problems), fluid-structure thermal coupling (the coupled heat transfer or conjugate heat transfer problems) and fluid-structure-thermal coupling. The first four are two-fields coupling and the third one is three-fields coupling. The researches of fluid-thermal and structure-thermal coupling are more than the coupled heat transfer and FSI. Now, the author has realized the research of the transient strong coupling heat transfer of automotive engine piston and cylinder-liner motion contact, but the heat transfer process between combustion gas and combustion chamber components is a weak coupling. Other researchers mainly adopt reverse algorithm to study the coupling heat transfer of cylinder head, piston, etc.: measured several key points' temperatures, adjusted the thermal boundary conditions to make the calculated value correspond with the measured value. After more than one hundred times of trials in literature, the calculated value of a few key points is closed to the measured value, but the calculation cycle is long and the cost is relatively high. Reverse algorithm is based on the temperature measurements, can only improve the existing engines, can't provide guidance for the new design.

Thus, the author uses the serial FSI method of STAR-CCM+ and ABAQUS to acquire the transient temperature fields, provide boundary conditions for thermal fatigue analysis and conduct thermal stress analysis of exhaust manifolds.

Fuel Injection and Combustion Processes: Modeling

Fuel Injection and Combustion Processes: Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Benchmarking Hybrid Concepts: On-Line vs. Off-Line Fuel Economy Optimization for Different Hybrid Architectures

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The recent advance in the development of various hybrid vehicle technologies comes along with the need of establishing optimal energy management strategies, in order to minimize both fuel economy and pollutant emissions, while taking into account an increasing number of state and control variables, depending on the adopted hybrid architecture.

One of the objectives of this research was to establish benchmarking performance, in terms of fuel economy, for real time on-board management strategies, such as ECMS (Equivalent Consumption Minimization Strategy), whose structure has been implemented in a SIMULINK model for different hybrid vehicle concepts. The results obtained from these simulations have then been compared with those derived from a general purpose, off-line optimization technique, based on deterministic DP (Dynamic Programming), and capable of finding the numerical global optimum and of generating the optimal cycle-based control trajectory over a discretized multidimensional grid of the selected state and control variables. The paper investigates the structure of the DP problem and its interactions with the specific hybrid architecture, especially in terms of the most appropriate selection of state and control variables. The implications of the chosen modeling approach are also critically evaluated, searching for the best compromise between accurate simulation results and reliable comparisons between off-line and on-line optimization results.

One of the outcomes is that the system model should be designed in order to be compatible with efficient DP techniques implementation, with the objective of obtaining robust optimal control policies while achieving acceptable computational costs.

The concepts that have been analyzed in this work are the following two parallel

hybrid architectures: HEV (Hybrid Electric Vehicle), normally applied in current hybrid vehicles production, and HSF-HV (High Speed Flywheel Hybrid Vehicle), an interesting and promising hybrid mechanical solution. An example of the influence of the selected gear has also been investigated by implementing a multi-dimensional DP optimization routine. In order to perform this analysis, a general purpose DP MATLAB function, including specifically designed algorithms to avoid numerical interpolation issues that typically occur in constrained problems, has been modified to run any SIMULINK-based engine-vehicle model.

Pollution Constrained Optimal Energy Management of a Gasoline-HEV

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In Hybrid Electric Vehicles (HEV), the electrical hybridization offers different ways to reduce the fuel consumption: kinetic energy recuperation during vehicle deceleration, possibility of stopping the engine, and intelligent Energy Management System (EMS). Besides, with the future more stringent standards, there is a need to integrate the pollutant emissions in the EMS, since strictly reducing the fuel consumption can increase the emissions.

The paper presents an optimal energy management strategy with constraints on pollutant emissions for gasoline-HEV, taking into account the 3-Way Catalyst Converter (3WCC). Based on a complete model of the powertrain, a mixed fuel consumption / pollutant emissions performance index is minimized with the Pontryaguin Minimum Principle (PMP) and two states, the battery State Of Charge and the 3WCC temperature. Simulation results are presented showing that simply including the 3WCC dynamics in the pollutant emissions leads to a 1-state problem, easier to solve and giving better results for reducing fuel consumption and pollutants emissions, with a lesser use of the battery.

Instantaneous Optimization Energy Management for Extended-Range Electric Vehicle Based on Minimum Loss Power Algorithm

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Most of the existing energy management strategies for Extended-Range Electric Vehicles (E-REVs) are heuristic, which restricts coordination between the battery and the Range Extender. This paper presents an instantaneous optimization energy management strategy based on the Minimum Loss Power Algorithm (MLPA) for a fuel cell E-REV. An instantaneous loss power function of power train system is constructed by considering the charge and discharge efficiency of the battery, together with the working efficiency of the fuel cell Range Extender. The battery working mode and operating points of the fuel cell Range Extender are decided by an instantaneous optimization module (an artificial neural network) that aims to minimize the loss power function at each time step. In order to solve the local optimum problem, a Range Extender output power gain coefficient is introduced, which can automatically adjust the output power of the Range Extender according to the residual amount of on-board hydrogen. Thus battery energy and hydrogen may be extinguished at approximately the same time, allowing global optimal results. To validate the proposed strategy, the energy management strategy presented in this paper is realistically implemented onto a real fuel cell E-REV. Simulation and dynamometer test results prove that the proposed instantaneous optimization energy management strategy can dramatically improve fuel economy performance and adaptability under a broad range of driving conditions compared to rule-based strategies.

Driver Intention Analysis for a Through-the-Road Solar Hybridized Car

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In last decade, Hybrid Electric Vehicles (HEV) have emerged as real alternatives to engine-driven vehicles, in order to reduce fuel consumption and emissions. But their market share is still limited, as their impact on global fossil fuel demand and CO2 production. In parallel, the possibility of upgrading conventional vehicles to HEV is gaining interest.

A research work on the development of a kit for converting a conventional vehicle into a Through-The-Road (TTR) Hybrid Solar Vehicle (HSV) has been recently performed at the University of Salerno, where flexible solar cells, an additional Lithium-Ion battery and two electrically driven wheel-motors have been mounted on a FIAT Punto. Preliminary studies performed by simulation have shown the technical and economic feasibility of this solution.

In the proposed vehicle, the control of wheel motors is performed via a Vehicle Management Unit (VMU), which in turn reads data from the OBD port. In order to develop an effective and safe control strategy for wheel-motors, a precise real-time knowledge of the Driver Intention is required.

In the paper, a set of mathematical models using data measured only by the OBD port are developed and integrated into a fuzzy logic model. A first release of the control system has been implemented and successfully validated on real driving cycles on a FIAT Punto.

Multi-Objective Optimization of Fuel Cell Hybrid Vehicle Powertrain Design - Cost and Energy

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The scope of this study is to optimize the powertrain of a fuel cell powered hybrid electric vehicle and plug-in hybrid electric vehicle, aiming to minimize the cost, minimize fuel consumption, and maximixe all-electric range (AER). A genetic algorithm (GA) was used to perform single objective optimization, and a non-dominated sorting genetic algorithm (NSGA-II) to perform multi-objective optimization. Both algorithms were programmed in MATLAB. The cost, fuel consumption and AER were optimized by the GA individually, and the couples cost and fuel consumption, and cost and AER, were evaluated by the NSGA-II. In order to optimize the vehicle powertrain, not only the fuel cell, electric motor, and battery, are sized but different component models are also considered, including different battery chemistries (Lithium and Nickel-metal hydride). The battery charge sustaining level is also an optimization variable. The vehicle design is evaluated by a vehicle simulation software, ADVISOR which is connected to the optimization algorithms. The designed vehicles are simulated in a real measured driving cycle in Lisbon downtown (LisbonDt) and in the official European driving cycle NEDC. The vehicles must comply to several performance constraints, such as maximum speed, acceleration, and maximum electric range (only for plug-in vehicle). The developed methodology main objective is to present a possible best vehicle option regarding a specified objective and conditions.

Adaptive Energy Management Strategy Calibration in PHEVs Based on a Sensitivity Study

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This paper presents a sensitivity analysis-based study aimed at robustly calibrating the parameters of an adaptive energy management strategy designed for a Plugin Hybrid Electric Vehicle (PHEV). The supervisory control is developed from the Pontryagin's Minimum Principle (PMP) approach and applied to a model of a GM Chevrolet Volt vehicle. The proposed controller aims at minimizing the fuel consumption of the vehicle over a given driving mission, by achieving a blended discharge strategy over the entire cycle. The calibration study is conducted over a wide set of driving conditions and it generates a look-up table and two constant values for the three controller parameters to be used in the in-vehicle implementation. Finally, the calibrated adaptive control strategy is validated against real driving cycles showing the effectiveness of the calibration approach.

Modular Methodology to Optimize Innovative Drivetrains

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IFP Energies nouvelles

In this paper, an integrated simulation-based methodology demonstrating feasibility and performance of several electric-hybrid concepts is developed. Several advanced tools are coupled to define the specifications of each component of the hybrid powertrain, to select the most promising hybrid architecture and finally to assess the proposed powertrain with regard to CO2 and pollutants emissions.

Concurrent minimization of NOx and CO2 emissions enables to find the best compromise to fulfil Euro 6 standards while lowering fuel consumption. This stage consists in an iterative co-optimization of the power split strategies between the electric drive and the Diesel engine and of the engine settings (injection pressure, EGR rate, etc.). The methodology combines optimal control laws and optimization methodology based on global statistical models using single-cylinder design of experiments. After several iterations, this method allows to find the optimal NOx/CO2 trade-off curve. This enables to choose those settings and power split laws that satisfy Euro 6 standards without a NOx-dedicated aftertreatment device, or using an SCR-type aftertreatment device (with higher raw NOx emissions), while simultaneously minimizing fuel consumption.

The proposed methodology, combined with powerful tools, facilitates the optimization and the assessment of a large diversity of innovative drivetrains.

Impact of Hybrid and Electric Mobility in a Medium-Sized Historic City

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The goal of the investigation is the evaluation of the environmental impact of hybrid and electric mobility in Lecce, a city of about 100,000 inhabitants in southern Italy. The investigation starts from the definition of specific driving cycles for the University campus and Lecce city center under different conditions of traffic and weather. The data acquired in this way are used to evaluate the performance of four typologies of vehicles: a gasoline city car (Smart Fortwo), the corresponding electric version (Smart ED), three range extenders and a plug-in hybrid electric vehicle operating with blended discharge. The simulation of the different power trains is performed with AVL-Cruise and validate through comparison with literature results on the European driving cycle. Particular relevance is given to CO2 emissions that are calculated with a well-to-wheel approach taking into account the average levels of emissions of the national electric grid and with a Life Cycle Assessment methodology.

HYBUS: A New Hybrid Bus for Urban Public Transportation

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Nowadays the increasing demand for sustainable mobility has fostered the introduction of innovative propulsion systems also in the public transport sector in order to achieve a significant reduction of pollutant emissions in highly congested urban areas. Within this context this paper describes the development of the HYBUS, an environmental friendly hybrid bus for on-road urban transportation, which was jointly carried out by Pininfarina and Politecnico di Torino in the framework of the AMPERE project.

The first prototype of the bus was built by integrating an innovative hybrid propulsion system featuring a plug-in series architecture into the chassis of an old IVECO 490 TURBOCITY. The bus is 12 meters long and has a capacity of up to 116 passengers in the original layout. The project relied on a modular approach where the powertrain could be easily customized for size and power depending on the specific application. Furthermore this flexibility could pave the way to a significant reduction of investment costs since it could allow the revamping of obsolete vehicles in the fleet of public transportation companies, extending their end of life.

After a preliminary description of the main features of the hybrid architecture, the paper assesses, through numerical simulations, the fuel economy potential of the vehicle in real world driving conditions. The promising results of this study led to the development of the abovementioned prototype which was extensively tested in the city of Genoa, Italy, an urban context which is extremely demanding because of its routes featuring a continuously variable altitude and significant grades. The experimental data collected during the test campaign confirmed the simulations forecasts, highlighting significant fuel economy benefits.

Viking 45 Electric HybridDesign, Construction and Analysis: A Quest for the $10 million Progressive Automotive X Prize

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Faculty and undergraduate students at the Vehicle Research Institute developed the parallel electric hybrid Viking 45 to compete in the Progressive Automotive X Prize. The contest challenged auto manufacturers to build vehicles that could achieve a gasoline equivalent fuel efficiency of 2.35 liter per 100 km while meeting a subset of U.S. Federal Motor Vehicle Safety Standards (FMVSS) and U.S. Environmental Protection Agency (EPA) emission standards. The contest offered a $10 million purse to encourage participation.

Viking 45 features a 50 kW, three cylinder gasoline engine coupled with a 23 kW electric motor. A 9.6 kWh lithium polymer battery pack allows the vehicle to travel more than 100 km at 100 km/hr. Carbon fiber composite vacuum assisted resin transfer techniques were developed to demonstrate the potential for low volume (10,000 units/year) production. The monocoque chassis demonstrated carbon fiber honeycomb for impact attenuation structures to manage front and side impacts. These materials enabled the test weight of the vehicle, with driver to be 789 kg. The vehicle achieved a top ten finish out of 136 vehicles entered.

Comparison between a Diesel and a New 2-Stroke GDI Engine on a Series Hybrid Passenger Car

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The internal combustion engine (ICE) for a series hybrid vehicle must be very compact, fuel efficient reliable and clean; furthermore it should possess excellent NVH features; finally, the cost should be as low as possible.

An unconventional but not exotic solution, potentially ideal to fulfill all the above mentioned requirements, is represented by a 2-Stroke externally scavenged GDI engine, without poppet valves. BRC (Cherasco, Italy) and PRIMAVIS (Turin, Italy) are currently developing an engine of this type, incorporating a patented rotary valve for the control of the charge induced to cylinder. The development is supported by extensive CFD simulations, which are able to predict all the main engine performance characteristics.

The paper analyzes, from a theoretical point of view, the installation of the engine on an electric vehicle, previously optimized for a small Diesel engine (Smart 0.8 l CDi). For a straight comparison between the Diesel and the 2-Stroke GDI engine, all the vehicle components are the same. Furthermore, the operating points employed for battery charging correspond to the same values of brake power.

The 4-S Diesel and the 2-S GDI engine are compared from several point of views: fuel economy in the European driving cycle, capability to comply with stringent emissions regulations, cost, overall dimensions, weight, etc. It is found that the new 2-Stroke engine can possess the advantages of the Diesel in terms of fuel efficiency, while maintaining the compactness and cost effectiveness of the best SI Range Extenders.

Improving the Overall Efficiency of a Pneumatic-Combustion Hybrid Engine by Adding an Intermediate Heated Tank

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Several works have previously shown that the concept of pneumatic-combustion hybrid engine is an interesting alternative to the Electric Hybrid Vehicle, by leading to equivalent fuel savings for a probable lower cost. However, these studies have shown that the thermal insulation of the tank is a problem. Indeed, due to its size and its location, the adiabaticity of the pneumatic tank cannot be guaranteed. During a regenerative braking (pneumatic pump mode) the hot and pressurized air that is send to the tank cools, pressure drops and density increases. When reusing the air in pneumatic motor mode, the mass necessary to fill the cylinder is greater than the one that would have been necessary if the air was not cool at its stay in the tank. This phenomenon is the major cause to the quite low regenerative efficiency that has been observed on a prototype engine. This paper proposes and evaluates a solution to this problem by using an intermediate air tank heated by the exhaust gases while the engine operates in the conventional combustion mode. The proposed concept is developed in detail and 0D thermal and thermodynamic modeling is proposed. The fuel savings, for the NEDC and WLTP driving cycles under several thermal initial states of the intermediate tank, are estimated by numerical simulations. Finally, the influence of the intermediate heated tank size is investigated.

Design, Development and Control of a Self-Tracking Photovoltaic Roof for a Road Vehicle

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In last years, increasing fleet electrification, improvement in solar panel efficiency and reduction in their costs are concurring toward an increasing attention to the integration of photovoltaic in road vehicles. As in fixed plants, the adoption of solar tracking systems would allow to enhance the solar contribution. But a mobile solar systems for a car must have specific features, due to space constraints and to specific exigencies of a mobile application such as instabilities, energy and aerodynamic losses. Due to these reasons, they should operate only in parking mode.

A kinematic model of mobile solar roof, as a parallel robot, has been developed and used to optimize the roof geometry; the benefits of a mobile roof, in terms of solar energy gain at different latitudes and months, have been assessed. A second prototype of solar tracking roof with two degrees of freedom has been then realized, to overcome some mechanical problems.

In order to detect the relative position of the sun and to achieve the best roof orientation, a model based control strategy has been developed, using sky images detected by a small camera. The control system has been successfully validated over experimental data.

In order to assess the economic feasibility of the project, a preliminary study on payback value has been performed. The comparison of a fixed horizontal roof and a solar tracking roof on a hybrid vehicle has shown that a significant reduction in payback occurs with the adoption of a mobile solar roof.

A Model to Assess the Benefits of an After-Market Hybridization Kit based on Realistic Driving Habits and Charging Infrastructure

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Despite the recent commercial success of HEVs, their market share is still insufficient to produce a significant impact on energy consumption on a global basis. Moreover, it is unlikely that, in next few years, the scenario will drastically change, since relevant investments on production plants would be needed and the market does not seem to provide the expected growth for such technologies. Therefore, the possibility of upgrading conventional vehicles to hybrid electric vehicles is gaining interest. Among the diverse options for hybridization, researchers are focusing on electrification of rear wheels in front-driven vehicles, by adopting in-wheel motors and adding a lithium-ion battery. Thus, the vehicle is transformed in a Through-The-Road parallel hybrid electric vehicle.

This paper presents an energy-based model, developed in Matlab/Simulink environment, of a conventional vehicle hybridized by means of such conversion kit. The model has a modular approach, where different powertrain configurations are considered, specifically with different battery sizes, different in-wheel motors power, with/without plug-in capabilities. An additional level of complexity comes from the opportunity to integrate flexible PV panels into the hybridization kit.

In order to assess the benefits of the proposed kit with respect to the conventional vehicle, the analysis was performed over a variety of realistic driving cycles to reflect common driving habits. Results show that driver habits (in terms of driving style and distance driven), and the availability of charging infrastructure play an important role in fuel economy of the vehicle, thus making one configuration more convenient than others.

Diesel Engine Technologies Enabling Powertrain Optimization to Meet U.S. Greenhouse Gas Emissions

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The world-wide commercial vehicle industry is faced with numerous challenges to reduce oil consumption and greenhouse gases, meet stringent emissions regulations, provide customer value, and improve safety. This work focuses on the new U.S. regulation of greenhouse gas (GHG) emissions from commercial vehicles and diesel engines and the most likely technologies to meet future anticipated standards while improving transportation freight efficiency.

In the U.S., EPA and NHTSA have issued a joint proposed GHG rule that sets limits for CO2 and other GHGs from pick-up trucks and vans, vocational vehicles, semi-tractors, and heavy duty diesel engines. This paper discusses and compares different technologies to meet GHG regulations for diesel engines based on considerations of cost, complexity, real-world fidelity, and environmental benefit. In addition, the paper describes powertrain integration aspects for vocational and semi-tractor engines with technologies including advanced SCR, waste heat recovery (Rankine) cycles and downspeeding. Innovation in component technology coupled with system integration is enabling engine manufactures to move forward with the development of high efficiency clean diesel products with a long term goal of reaching a greater than 50% brake thermal efficiency (BTE) for the engine plus aftertreatment system.

Emission Reduction Technologies for the Future Low Emission Rail Diesel Engines: EGR vs SCR

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The EU emission standards for new rail Diesel engines are becoming even more stringent. EGR and SCR technologies can both be used to reduce NOx emissions; however, the use of EGR is usually accompanied by an increase in PM emissions and may require a DPF. On the other hand, the use of SCR requires on-board storage of urea. Thus, it is necessary to study these trade-offs in order to understand how these technologies can best be used in rail applications to meet new emission standards.

The present study assesses the application of these technologies in Diesel railcars on a quantitative basis using one and three dimensional numerical simulation tools. In particular, the study considers a 560 kW railcar engine with the use of either EGR or SCR based solutions for NOx reduction. The NOx and PM emissions performances are evaluated over the C1 homologation cycle.

The simulation results indicate that either EGR or SCR based solutions can be used to achieve Stage IIIB NOx limits for the 560 kW engine, with an acceptable trade-off regarding BSFC in the case of EGR solutions. In the case of EGR, though, a DPF is necessary to meet Stage IIIB PM limits. Furthermore, SCR based solutions have the potential to go beyond the Stage IIIB NOx limit by scaling up the size of the SCR device and the on-board urea storage.

Simultaneous Reduction of Soot and NO_x Emissions by Means of the XHCPC Concept: Complying with the Heavy Duty EURO 6 Limits without Aftertreatment System

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Due to concerns regarding pollutant and CO2 emissions, advanced combustion modes that can simultaneously reduce exhaust emissions and improve thermal efficiency have been widely investigated. The main characteristic of the new combustion strategies, such as HCCI and LTC, is that the formation of a homogenous mixture or a controllable stratified mixture is required prior to ignition. The major issue with these approaches is the lack of a direct method for the control of ignition timing and combustion rate, which can be only indirectly controlled using high EGR rates and/or lean mixtures.

Homogeneous Charge Progressive Combustion (HCPC) is based on the split-cycle principle. Intake and compression phases are performed in a reciprocating external compressor, which drives the air into the combustor cylinder during the combustion process, through a transfer duct. A transfer valve is positioned between the compressor cylinder and the transfer duct. The compressor runs with a fixed phase delay with respect to the combustor. As a consequence, during the combustion process, air moves from the compressor cylinder to the combustor cylinder. Contemporary with the air transfer, fuel is injected into the transfer duct, evaporates and mixes with the air, bringing about the conditions needed for homogeneous combustion.

This paper relates to CFD study of a Heavy Duty HCPC engine that provides ultra-clean combustion and diesel-like indicated thermal efficiency. As a matter of fact the HCPC Heavy Duty engine can comply with EURO 6 regulations without complicated and expensive aftertreatment systems.

An Assessment of the Bottoming Cycle Operating Conditions for a High EGR Rate Engine at Euro VI NO_x Emissions

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This paper investigates the application of a Bottoming Cycle (BC) applied to a 10-litre (L) heavy duty Diesel engine for potential improvements in fuel efficiency. With the main thermodynamic irreversibility in the BC due to the temperature difference between the heat source and the working fluid, a proper selection of the working fluid and its operating condition for a given waste heat is the key in achieving high overall conversion efficiency. The paper reviews a fluid selection methodology based on thermodynamic/thermo-physical and environmental/safety properties. Results are presented using seven pure, dry, isentropic and wet working fluids (synthetic, organic and inorganic) operating with expansion starting from the saturated vapour, superheated vapour, supercritical phase, saturated liquid, and two-phase.

Efficiency improvements by recovering Charge Air Coolers (CAC) and Exhaust Gas Recirculation (EGR) cooler heat on two engine platforms were calculated. The first platform operating at Euro 6 engine out NOx emissions levels and the second platform operating with Euro 5 engine out NOx emissions coupled with a 80% efficient selective catalytic reduction system. Performance and heat rejection data for the 10L platforms were derived from experimental measurements on an advanced 2L single cylinder research engine which was used to determine the trade-off between thermal efficiency and regulated/unregulated emissions. Results indicate a potential improvement of 5.1% and 6.3% in engine power for a cruise (B50) and high load (C100) condition, with a technically feasible BC operating at subcritical mode with minimum superheat.

Partial Admission Impulse Turbine for Automotive ORC Application

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The analysis of the energetic losses in a combustion engine shows that one-third of the chemical energy is lost as heat through the exhaust gas. Prior investigations have shown that an exhaust-gas driven Organic Rankine cycle (ORC) is suitable for the recovery of some of that energy. One of the essential components in such an ORC is the expansion machine. An investigation of the suitability of a turbine for this application is presented in this conceptual study.

The concept is investigated for a heavy-duty truck application and a passenger-car application. On the basis of predefined design points, a thermodynamic analysis is performed to determine a suitable working fluid and the best process parameters.

A single-stage partially admitted impulse turbine shows the best performance at tolerable rotational speeds for the resulting thermodynamic boundary conditions. However, the high pressure ratio requires supersonic blade profiles in order to handle high flow velocities and achieve a high efficiency. To cover the part-load and overload operating points as well, a variable partial admission is included to increase the operating range. The concluding performance predictions are made using CFD simulations, computing flow over 360° of the circumference. Circumferential parts of the stator which are not admitted are closed by walls to simulate the loss due to ventilation.

Based on the resulting blade design a conceptual design for a prototype is presented. Different possibilities for bearings and seals are discussed. A CAD model is presented of a prototype of realistic size and weight.

Lamborghini Approach to Engine Downsizing Engine Friction Modeling

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Downsizing, down speeding and hybridization are becoming a standard in the automotive industry. This paper was initiated to answer Automobili Lamborghini R&D's question: what does downsizing mean In technical literature downsizing is often referred to as reducing displacement and, sometimes, cylinders. Through a methodological approach, analysis and experimental activities Automobili Lamborghini, with FEV's support, shows that downsizing in terms of engine friction reduction means only reduction of displacement. Using the Aventador V12 6.5 liter engine as a baseline, two 4.3 liter engines were designed, a V8 and a V12.

The engine friction losses of these two engines were calculated all over the engine speed range and during the NEDC cycle utilizing a simulation tool and verified through FEV's "Strip-Method" database.

This approach gives us the holistic understanding on engine components design and which technologies should be introduced for the next Lamborghini engine generation.

Development and Validation of a Five Stroke Engine

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Internal combustion engine development is mainly driven by new emission regulations and fuel cost. The introduction of hybrid power trains allows the development of highly efficient non-traditional internal combustion engines. One way of increasing thermal efficiency while avoiding issues like high mechanical stress or knock, is to realize different expansion and compression strokes. Different solutions exist such as the Miller/Atkinson cycle or the five stroke engine.

A 5-stroke turbo-charged port-injection spark-ignition engine has been developed in the present study for use as a range extender or series-hybrid main power source. Its development and design are based on 0D/1D model and experimental results have been compared with the engine model. The 5-stroke engine is a three-cylinder in which two cylinders, called high pressure (HP) cylinders, perform a four-stroke cycle with a volumetric compression ratio of 8:1 and alternatively a second expansion of the burnt gases is performed in the third cylinder, called low pressure (LP) cylinder with a volumetric compression ratio of 30:1, the overall expansion ratio being 12.7:1.

The boost pressure delivered by the turbocharger is controlled by a particular innovative system called “smart wastegate”, consisting in two differently controlled exhaust valves, one feeding the turbine, the other bypassing the latter.

The engine develops 32.5 kW for an engine of 4000 rpm. BSFC is 226 g/kWh which corresponds to a global efficiency of 36.1 %.

The engine parts and technology are standard and allow cost effective development of the concept as no special component with special development is needed. Moreover, the version studied consists of a multi-point port-injection system and a two valve combustion chamber.

Development of Thermal Modeling in Support of Engine Cooling Design

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The growing interest on environmental issues related to vehicles is pushing up the research on reciprocating internal combustion engines which seems to be endless and able to insure to combustion engines a long future. Euro standards imposed a significant reduction of pollutant emissions and were the stimulus to favor the conception of technologies which represented real breakthroughs; the recent directives on greenhouse gases emissions further reinforced the concept of reducing fuel consumption and, consequently, carbon dioxide emissions.

So, new technological efforts have to be made on internal combustion engines in order to achieve this additional target: several technological options are already available or under studying, but only a few of these are suitable, in particular, in terms of costs attendance per unit of CO2 saved.

Among these technologies, a revision of engine cooling system seems to have good potentiality. In fact, the cooling system remained substantially unchanged during years and a number of innovations are close to be on the market. They do not consider yet an integration between the engine cooling system with the other vehicle thermal needs, in order to improve comfort and increase transient requirements.

Concerning this chance, the Authors present a physically consistent mathematical model that describes the main phenomena about heat transfer on engine cooling circuits. The model was created in a modular way and it is an evolution of previous works that can solve the thermo-hydraulic field of an engine cooling system and can identify control strategies.

Thanks to this, model novel opportunities of engine cooling systems can be studied in terms of integration among thermal requirements. In particular, the integration of a liquid cooled charge air cooler is considered and warm-up time reduction is achieved, with benefits on fuel consumption and emissions.

Fuel Injection and Combustion Processes: Modeling

Fuel Injection and Combustion Processes: Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Preparation, Structure Analysis, and Engine Performance Test of Triethylene Glycol Monomethyl Ether Cottonseed Oil Monoester as Biodiesel

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Biodiesels, which are produced through the transesterification reaction of fatty acids with alcohols, are promising clean alternative fuels in substitution of conventional diesel fuels. In this paper, a novel biodiesel, triethylene glycol monomethyl ether cottonseed oil monoester (TGMECOM), was developed. It was synthesized through transesterification of refined cottonseed oil and triethylene glycol monomethyl ether (TGME) with KOH as catalyst. Its chemical structure was characterized through FTIR, 1H NMR and GC-MS analyses. To investigate the engine performance of TGMECOM, tests on a two-cylinder DI diesel engine were conducted with different concentrations blended into diesel fuel. The results indicate that, compared to diesel fuel, TGMECOM has higher cetane number and oxygen content. For TGMECOM, the combustion timing of engine is advanced, ignition delay is shortened, and the combustion is improved. As the TGMECOM fraction increased in the TGMECOM-diesel blends, the brake thermal efficiency of engine is remarkably increased and a maximal reduction of the smoke and NOx by 54.6% and 39.3%, respectively, can be reached.

Deterioration of Diesel Particulate Filters in Relation to CI Engine Fueled with Biodiesel

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The paper presents results illustrating the effect on Diesel particulate filters (DPF) in relation to rapeseed methyl ester (RME) and animal tallow methyl ester (TME) compared to Diesel (EN590). Measurements were performed in an engine test cell using a modern common rail light duty CI engine running at five different load points for more than 330 hours. Regulated and non-regulated gaseous emission such as NOx and NO2 were monitored before and after the DPF to characterize the catalytic activity. Detailed investigation was also carried out concerning the ash balance in relation to engine lubricant additives and fuel contribution.

Results showed an increase in NO2 engine out emission when the engine was fueled with biodiesel. However, the balance point temperature for the catalyst was significantly decreased illustrating the opportunity to optimize the catalytic surface correspondingly with increasing amount of biodiesel being regulatory implemented. According to the soot and ash loading analysis of the DPF the engine oil was the major contributor to accumulation of ash in the DPF.

Engine Performances and Emissions of Second-Generation Biofuels in Spark Ignition Engines: The Case of Methyl and Ethyl Valerates

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As an alternative to second generation ethanol, valeric esters can be produced from lignocellulose through levulinic acid. While some data on these fuels are available, only few experiments have been performed to analyze their combustion characteristics under engine conditions. Using a traditional spark ignition engine converted to mono-cylinder operation, we have investigated the engine performances and emissions of methyl and ethyl valerates. This paper compares the experimental results for pure valeric esters and for blends of 20% of esters in PRF95, with PRF95 as the reference fuel. The esters propagate faster than PRF95 which requires a slight change of ignition timing to optimise the work output. However, both the performances and the emissions are not significantly changed compared to the reference. Accordingly, methyl and ethyl valerate represent very good alternatives as biofuels for SI engines. Future studies will focus on testing these esters in real application engines and performing endurance tests.

Literature Study and Feasibility Test Regarding a Gasoline/EHN Blend Consumed by Standard CI-Engine Using a Non-PCCI Combustion Strategy

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A literature and experimental study was done to create an overview of the behavior of gasoline combusted in a CI-engine. This paper creates a first overview of the work to be done before implementing this Gasoline Compression Ignition concept in a multi-cylinder engine.

According to literature the gasoline blend will have advantages over diesel. First the shorter molecular chain of the gasoline makes it less prone to soot. Second the lower density gives the gasoline a higher nozzle exit speed resulting in better mixing capabilities. Third the lower density and higher volatility lets the spray length decrease. This lowers the chance of wall-impingement, but creates worse mixing conditions looking from a spray point of view. The CO and HC emissions tend to increase relative to operation with diesel fuel, NOx emissions largely depend on the choice of combustion strategy and could be influenced by the nitrogen bound to the EHN molecule that is used as an ignition improver.

Tests on a standard 2.4l 5-cylinder Euro 4 compression ignition engine showed it was fully capable of running on the chosen gasoline blend 95 RON + 5 vol% 2-EHN in every selected load-point. Load-points varied from idle to 10.5 bar BMEP at 1850 RPM. The standard injection strategy was not adjusted for the characteristics of gasoline. Emission measurements showed a decrease in soot and efficiency, and increases in NOx and CO2. At low load points the HC and CO emissions increased, at higher load points the difference was smaller or negligible.

A First Implementation of an Efficient Combustion Strategy in a Multi Cylinder Two-Stage Turbo CI-Engine Producing Low Emissions While Consuming a Gasoline/EHN Blend

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A Gasoline Compression Ignition combustion strategy was developed and showed its capabilities in the heavy duty single cylinder test-cell, resulting in indicated efficiencies up to 50% and low engine out emissions applying to EU VI and US 10 legislations while the soot remained at a controllable 1.5 FSN. For this concept a single-cylinder CI-engine was used running at a lambda of 1.6 and EGR levels of 50% and a modified injection strategy. Part of this strategy was also the use of a gasoline blended with an ignition improver, giving the blend a cetane number in the range of regular diesel; 50. In this paper a step is taken towards implementation of this combustion concept into a multi-cylinder light duty standalone CI-engine.

A standard CI-engine was modified so that its gas-exchange system could deliver the requested amounts of EGR and lambda. A long-route EGR system was installed, furthermore a two stage turbocharger system delivered the boost and increased the overall engine efficiency. A blend of gasoline RON 87 and 5 vol.% EHN was tested and with a cetane number of 55 it showed the right auto-ignition capabilities.

Injection sweeps regarding: EGR amount, rail pressure, timing main combustion peak, separation between pilot and main injection and pilot amount were performed. These sweeps resulted in an optimal injection strategy for this test engine in two engine load points both at 6 bar BMEP but at 1000 and 1500 rpm. As requested the soot emissions remained below 1.5 FSN, the NOx levels were at 2.82 and 3.20 g/kWh for 1000 and 1500 rpm respectively. Efficiency for the engine load point at 1000 rpm was 34.4 % for the load point at 1500 rpm this was 23.4% due to the excessive pressure loss over the engine created by the modified gas-exchange system.

Experimental Characterization of Diesel Combustion Using Glycerol Derived Ethers Mixtures

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In this paper the characteristics of a mixture of glycerol-based ethers usable in a compression ignition engine are investigated, in terms of efficiency and emissions. Alternative pathways for the energetic exploitation of biodiesel derived glycerol became of increasing interest as the biodiesel production was increased worldwide. Because of its detrimental physical and chemical properties, raw glycerol is hardly usable in conventional internal combustion engines (ICE). However, etherification of glycerol with tert-butyl alcohol and isobutylene allows obtaining a mixture mainly composed of higher glycerol ethers (GEM) suitable for compression ignition engines. Thus, the aim of this research study was to test a mixture of mono-, di- and tri-tert-butyl ethers of glycerol in blend with a commercial diesel fuel in a compression ignition engine, evaluating the fuel efficiency and the impact on the pollutant emissions.

The tests were performed on a single cylinder research engine derived from a Euro5 compliant four cylinder engine. The test methodology considers the comparison among three fuel blends: 1) a mixture consisting of 90% v/v diesel and 10% v/v of GEM; 2) a blend consisting of 80% v/v diesel and 20% v/v of GEM; 3) a reference diesel. The tests were carried out in five characteristic key points of the NEDC emission homologation cycle (New European Driving Cycle). These points allow estimation of the blends impact on the performance of a real four-cylinder engine (one cylinder of which is represented by the research engine) over the NEDC.

The results have shown the possibility to burn the diesel/GEM blends without significant impact on combustion characteristics and efficiencies while, due to the oxygen content of the GEM, important benefits are obtained in terms of NOx-PM trade-offs and emission particles at the exhaust. At medium-high load conditions there is a maximum decrease of about 70% in terms of PM emissions compared to a slight increase of NOx. At low load conditions, a maximum increase of HC and CO of about 50% has been detected.

Styrofoam Precursors as Drop-in Diesel Fuel

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Styrene, or ethylbenzene, is mainly used as a monomer for the production of polymers, most notably Styrofoam. In the synthetis of styrene, the feedstock of benzene and ethylene is converted into aromatic oxygenates such as benzaldehyde, 2-phenyl ethanol and acetophenone. Benzaldehyde and phenyl ethanol are low value side streams, while acetophenone is a high value intermediate product. The side streams are now principally rejected from the process and burnt for process heat. Previous in-house research has shown that such aromatic oxygenates are suitable as diesel fuel additives and can in some cases improve the soot-NOx trade-off.

In this study acetophenone, benzaldehyde and 2-phenyl ethanol are each added to commercial EN590 diesel at a ratio of 1:9, with the goal to ascertain whether or not the lower value benzaldehyde and 2-phenyl ethanol can perform on par with the higher value acetophenone. These compounds are now used in pure form. In future work, real streams, which are rich of these compounds, but contain various other chemicals as well, will be used.

Experiments have been performed on a heavy duty (12.6L) diesel engine, of which one cylinder is a dedicated test cylinder. The results demonstrate that the emissions and efficiencies are more or less comparable for all aromatic oxygenates. Afterwards, the results are compared against neat diesel. It was found that, depending on operation conditions, either the efficiency of the oxygenates was higher, while the emissions where comparable to diesel or the emissions decreased dramatically with comparable efficiencies as diesel. Accordingly, compared to neat diesel, both the high- and low-value styrene streams yield overall positive engine behavior in all measured operating conditions.

Experimental Investigation of Diesel Engine Fueled with Jatropha Oil Blend with Ethanol

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Dwindling petroleum reserves and alarming level of air pollution has been an issue of great concern in recent times and researchers across the world are experimenting on variety of renewable fuels for meeting the future energy demands. Within the gamut of alternative fuels, biofuels are the most promising and have the potential to mitigate climate change and lease a new life to existing IC engines. The vegetable oils are having immense potential in this context and have been used either in neat or modified form by large number of researchers. Jatropha curcus is a perennial plant and bears non edible oil. The plant is drought tolerant and has been cultivated all over the arid and semi-arid areas for reforestation. In the present study, blends of jatropha oil and ethanol have been prepared in 5, 10, 15 and 20% (v/v) and evaluation of important properties of blends has been carried. The results show that properties are quite similar to diesel fuel. Performance and emission characteristics were evaluated for straight vegetable jatropha ethanol (SVJE) blends. Engine performance (brake specific energy consumption, brake thermal efficiency) and emissions (CO, HC, NOx, and smoke opacity) were measured to evaluate the behavior of the diesel engine running on SVJE blends. It has been found that at part load condition, the brake thermal efficiency and brake specific energy consumption of blends of SVJE were insignificant. HC, CO emissions and smoke opacity were reduced at part load condition. However, there was a decrease in NOx in case of SVJE diesel blends at full load condition.

Locomotive Emissions Measurements for Various Blends of Biodiesel Fuel

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The objective of this project was to assess the effects of various blends of biodiesel on locomotive engine exhaust emissions. Systematic, credible, and carefully designed and executed locomotive fuel effect studies produce statistically significant conclusions are very scarce, and only cover a very limited number of locomotive models. Most locomotive biodiesel work has been limited to cursory demonstration programs. Of primary concern to railroads and regulators is understanding any exhaust emission associated with biodiesel use, especially NOx emissions.

In this study, emissions tests were conducted on two locomotive models, a Tier 2 EMD SD70ACe and a Tier 1+ GE Dash9-44CW with two baseline fuels, conventional EPA ASTM No. 2-D S15 (commonly referred to as ultra-low sulfur diesel - ULSD) certification diesel fuel, and commercially available California Air Resource Board (CARB) ULSD fuel. A single batch of soy-based B100 was blended with the EPA and CARB diesel fuels to yield 5 percent and 20 percent by volume blends of fuels. A randomized test matrix was used to perform triplicate tests on each of the six test fuels (EPA0, CARB0, EPA5, CARB5, EPA20, and CARB20).

The results of these emissions test results were analyzed to determine the statistical relevance of any difference in emissions among fuels. General emissions and fuel economy trends for biodiesel seen in other studies and in other applications were seen in this study. Higher blend levels of biodiesel were associated with lower carbon monoxide and particulate matter, and higher levels of nitrogen oxides and fuel consumption. Diesel fuel with 20 percent biodiesel often resulted in statistically significant differences from the fuel with 0 percent or 5 percent biodiesel. The difference between 0 percent and 5 percent biodiesel was generally not statistically significant. Different trends between the locomotives could be explained by differences in emissions certification levels, combustion cycle (4-stroke vs. 2-stroke), and lubricating oil consumption.

Real-World On-Road Exhaust Emissions from an Ordinary Gasoline Car Operated on E85 and on Butanol-Gasoline Blend

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Bioethanol, produced from renewable sources, is promoted as a fuel in higher concentrations in newer flexible fuel engines, and in lower concentrations in the general fleet. Introduction of a blend of 85% ethanol with gasoline (E85) at a competitive price in the Czech Republic has, however, spontaneously resulted in this fuel being used in “ordinary” engines not adapted for this fuel. This study investigates the operation of a typical gasoline car with fuel injection and three-way catalyst on gasoline, E85, and additionally on a blend of 85% n-butanol with gasoline, as butanol features better material compatibility than ethanol. The car was equipped with a portable, on-board emissions monitoring system and driven along a route comprising city and rural roads, including hills. Multiple runs were made on each fuel to verify test-to-test repeatability. The engine control unit has remarkably well adapted itself, over tens of km of driving, to both E85 and n-butanol by increasing the fuel injector pulse width, so that the engine was operated mostly at stoichiometric ratio on all fuels. Exhaust temperatures at tailpipe were comparable for all fuels. Operation on E85 and n-butanol blend has resulted, compared to gasoline, in no adverse effects on HC, lower emissions of CO and higher emissions of NOx, likely resulting from changes in air-fuel ratio. E85 had no effects on particle mass and reduced particle length (indicator of nanoparticles), while n-butanol has increased particle mass and had no adverse effects on particle length.

Knock Resistance Increase through the Addition of Natural Gas or LPG to Gasoline: An Experimental Study

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Bi-fuel spark ignition engines, nowadays widely spread, are usually equipped with two independent injection systems, in order run the engine either with gasoline or with gaseous fuel, which can be Natural Gas (NG) or Liquefied Petroleum Gas (LPG). These gases, besides lower cost and environmental impact, are also characterized by a higher knock resistance with respect to gasoline that allows to adopt a stoichiometric proportion with air also at full load. Gasoline, on the other hand, being injected as liquid, maintains higher volumetric efficiency and hence higher power output. As a compromise solution, it could be desired to exploit the advantages of both gasoline and gas (NG or LPG), thus performing a Double-Fuel injection: as already experimented by the authors [1, 2], the addition of gaseous fuel to the gasoline/air mixture increases knocking resistance, allowing to run the engine with both “overall stoichiometric” mixture (thus lowering fuel consumption and emissions) and better spark advance (which increases engine efficiency) even at full load: the results showed high improvements in engine efficiency without noticeable power losses respect to the pure gasoline operation. Since no references have been found in literature on the Octane Number of both NG-gasoline and LPG-gasoline blends, the authors decided to experimentally determine the knock resistance increase due to gaseous fuel addition to normal air-gasoline mixtures. A wide experimental campaign has been carried out in order to evaluate the correlation between the gaseous fuel-gasoline mixture composition and its overall knock resistance measured in terms of Motor Octane Number (MON). To this purpose, a CFR engine was endowed with two independent injection systems in order to realize mixtures with different proportion between gaseous fuels and gasoline and control the overall air-fuel ratio. The experimental results presented in this paper are quite innovative and will be fundamental for future study on the simultaneous combustion of gaseous fuel and gasoline. The experimental results showed that the relationship between the mixture MON and gaseous fuel concentration in the blend is not linear and is quite different between NG-gasoline and LPG-gasoline blends.

Piston Cleanliness via Fuel Additive Technology

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This work compared the piston deposit ratings in an engine when it was run on gasoline with a high concentration of deposit control additive (DCA) versus gasoline with a low concentration of additive. The additives came from different sources and contained detergents with different functional groups. The engine was a Ford V-8 PFI engine, which is used in ASTM D6593, the Sequence VG test. The experimental procedure followed the ASTM protocol, except for the fuel, which was treated with additives.

Deposit ratings were better, at 95% confidence, in the tests using a high concentration of additive versus the tests using a low concentration.

Well-to Wheel Greenhouse Gas Emissions of LNG Used as a Fuel for Long Haul Trucks in a European Scenario

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The EU Commission's "Clean Power for Transport" initiative aims to break the EU's dependence on imported oil whilst promoting the use of alternative fuels to reduce greenhouse gas emissions. Among the options considered is the use of liquefied natural gas (LNG) as a substitute for diesel in long haul trucks. It is interesting to ask how the lifecycle greenhouse gas (GHG) emissions of LNG compare with conventional diesel fuel for this application.

The LNG available in Europe is mainly imported. This paper considers the "well-to-tank" emissions of LNG from various production routes, including: gas production, treatment and liquefaction, shipping to Europe, terminal, distribution and refuelling operations. "Tank-to-Wheel" emissions are considered for a range of currently-available engine technologies of varying efficiency relative to diesel.

If LNG is used in a direct-injection engine having the same efficiency as a diesel engine, the "well-to-wheel" GHG emissions are typically around 19% lower than conventional diesel, or around 17% lower than diesel containing 7% FAME (B7).

Different sources of LNG may have higher or lower savings, depending on the efficiency of liquefaction and the shipping distance. In the best cases, the WtW reduction may be as high as 25%.

Some natural gas engines in the market are significantly less efficient than diesel engines. GHG emissions increase with reducing engine efficiency and in some cases in some cases, the gas engine could have higher WtW emissions than an equivalent diesel engine.

Stoichiometric Natural Gas Combustion in a Single Cylinder SI Engine and Impact of Charge Dilution by Means of EGR

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In this paper experimental results of a medium duty single cylinder research engine with spark ignition are presented. The engine was operated with stoichiometric natural gas combustion and additional charge dilution by means of external and cooled exhaust gas recirculation (EGR).

The first part of this work considers the benefits of cooled EGR on thermo-mechanical stress of the engine including exhaust gas temperature, cylinder head temperature, and knock behaviour. This is followed by the analysis of the influence of cooled EGR on the heat release rate. In this context the impact of fuel gas composition is also under investigation. The influence of increasing EGR on fuel efficiency, which is caused by a changed combustion process due to higher fractions of inert gases, is shown in this section. By application of different pistons a relationship between the piston bowl geometry and the flame propagation has been demonstrated. Unstable combustion due to increasing charge dilution could be shifted to higher EGR rates by means of adapted piston geometry. By increasing EGR a correlation between the required advancement of spark timing and the process of heat release is shown. These relationships are finally compared to lean natural gas combustion.

Experimental Analysis of a Natural Gas Fueled Engine and 1-D Simulation of VVT and VVA Strategies

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The paper deals with experimental testing of a natural gas fueled engine. Break Specific fuel Consumption (BSFC), Average Mass Flow Rate, Instantaneous Cylinder Pressure and some wall temperatures have been measured at some full and part load operating conditions. The results of this experimental activity, still in progress, have been used to calibrate a 1D-flow engine's model. Then the effects of some VVA strategies have been theoretically studied through the validated model. With the aim of maximizing the full load engine's torque, a genetic algorithm was used to calculate the optimized intake and exhaust valves timing angles. Various VVA strategies were compared at part-load in order to reduce brake specific fuel consumption.

Comparative Study of Ignition Systems for Lean Burn Gas Engines in an Optically Accessible Rapid Compression Expansion Machine

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Ignition systems for large lean burn gas engines are challenged by large energy deposition requirements to ensure stable and reliable inflammation of the premixed charge. In this study, two different ignition systems are investigated experimentally: ignition by means of injecting a small amount of diesel spray and its subsequent autoignition is compared to the ignition with an un-scavenged pre-chamber spark plug over a wide range of engine relevant conditions such as methane equivalence ratios and thermomechanical states. The ignition behavior as well as the combustion phase of the two systems is investigated using an optically accessible Rapid Compression Expansion Machine (RCEM). Filtered OH-chemiluminescence images of the ignition and combustion were taken with a UV intensified high speed camera through the piston window. Pressure signals along with filtered photomultiplier signals of the total emitted light for three different radicals (OH, CH, C2) were recorded to study the effects of ignition system and operating conditions on the early combustion phase.

Ignition with a pre-chamber spark plug was seen to accelerate the early combustion phase in the main chamber due to the turbulence generated by the flame jets, but following the dissipation of this initial turbulence slower flame propagation was observed. Higher temperatures and equivalence ratios (Φ) lead to increased turbulence generation of the flame jets as well as shorter delays between spark timing and entrance of the jets into the main combustion chamber. Similar trends with respect to temperature and pressure conditions were observed in the case of Diesel pilot ignition. However, the ignition delays of the pilot spray increased at higher levels of methane in the ambient gas. Generally, the flame/ignition jets generated by pilot injection provide a more stable and stronger ignition source than those achieved by means of pre-chamber spark plug ignition.

Hydrogen-CNG Blends as Fuel in a Turbo-charged SI Ice: ECU Calibration and Emission Tests

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This paper reports the results of experimental tests performed at ENEA (Italian National Agency for New Technologies, Environment and Sustainable Development) in its "Casaccia" Energy Research Center to evaluate the energetic and environmental performances of a Heavy-Duty Compressed Natural Gas (HD CNG) engine fuelled with a hydrogen-methane blend of 15% in volume. A lean burn Mercedes 906 LAG engine has been optimized properly calibrating ECU engine maps regarding both ignition advance and air to fuel ratio (AFR). It was therefore possible to correct ignition advance to take into account the faster combustion speed given by the hydrogen content of the fuel mixture. Equivalence ratio (Lambda) has instead been modified in order to minimize the NOx emissions. All the tests were performed on a steady engine test-bed focusing the attention on the most important parts of the engine maps. The target of the activity was the reduction of energy consumption and CO2 emissions, still catching targets on pollutant emissions to getting the homologation of the engine in the same environmental category of the original one.

Experimental results showed a reduction of CO2 variable with the ignition advance: decreasing the ignition advance timing the advantages are reduced. A reduction of CO2 of about 9% can be observed, for the same overall levels of pollutant emissions.

After the calibration procedure the engine has been object of formal EU homologation and is running on a city bus since the start of 2013. Results about the on-road experimental campaign (which will last 150.000 km) will be published in future.

Soot Emission Reduction from Post Injection Strategies in a High Pressure Direct-Injection Natural Gas Engine

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Compression ignition engines, including those that use natural gas as the major fuel, produce emissions of NOx and particulate matter (PM). Westport Inc. has developed the pilot-ignited high-pressure direct-injection (HPDI) natural gas engine system. Although HPDI engines produce less soot than comparable conventional diesel engines, further reductions in engine-out soot emissions is desired. In diesel engines, multiple injections can help reduce both NOx and PM. The effect of post injections on HPDI engines was not studied previously. The present research shows that late injection of a second gas pulse can significantly reduce PM and CO from HPDI engines without significantly increasing NOx or fuel consumption. In-cylinder pressure measurements were used to characterize the heat release resulting from the multiple injections. Experiments showed that most close-coupled split injection strategies provided no significant emissions benefit and less stable operation. However, post injection of 15-20% of the fuel 1.5-2.5 ms after the end of the first injection can reduce PM and CO by over 80%. Using this strategy has only a small effect on other emissions and fuel consumption. Methane emission is reduced about 25%, NOx changes is almost within the variability of results, maximum pressure of cylinder increases within 5bar and fuel consumption will increase about 1%. Based on the literature for diesel engines, we expect that enhanced mixing due to the second injection and increased local temperature within the cylinder may be major contributors to the soot reductions.

Effect of the Shape of the Combustion Chamber on Dual Fuel Combustion

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The effect of the shape of the bowl on the combustion process and emissions of a Natural Gas - Diesel dual fuel engine is analyzed. The simulation of the dual fuel combustion is performed with a modified version of the KIVA3V code where diesel is treated as the main fuel and a further reacting specie is introduced as methane (CH4). The auto-ignition of the pilot is simulated with a modified version of the Shell model and the first stage of the combustion, related to the pilot burning process, is simulated with the Characteristic Time Combustion model. When the temperature of the mixture reaches a certain threshold, a kernel of combustion is initialized. Until the kernel reaches a nominal radius the combustion of CH4 is prevented. The combustion of CH4 is simulated with a turbulent characteristic time too. Numerical models were chosen as a compromise between accuracy and computational time. The model has been validated with comparison to experimental data including in-cylinder pressure traces and tailpipe emissions. The numerical analysis has been performed with respect to a single cylinder diesel engine converted to dual fuel combustion. The results of the investigation showed that the conversion rate of CH4 can be increased by optimizing the bowl profile.

Influence of Ethanol-gasoline Blended Fuels on Cold Start Emissions of a Four-stroke Motorcycle. Methodology and Results

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The aim of this study is to investigate the effect of ethanol-gasoline mixtures on cold emissive behavior of commercial motorcycles. For the newly sold motorcycles, equipped with a three-way catalyst and electronic mixture control, CO and HC cold additional emissions, if compared with those exhausted in hot conditions, represent an important proportion of total emissions. On the other hand, ethanol is known as potential alcohol alternative fuel for spark ignition engines, which can be blended with gasoline to increase oxygen content and then to decrease emissions. From this explanations, a research on cold start emissions of motorcycles using ethanol-gasoline mixtures was conducted. In this specific study, a motorcycle (belonging to the Euro-3 legislative category) was operated on a chassis dynamometer and driven according to the ECE driving cycle to analyze the exhaust cold extra emissions of CO and HC, while the ethanol was mixed with unleaded gasoline in three different percentages (10, 20 and 30 % v/v). Results of the tests and the application of a calculation procedure, designed to model the cold start transient behavior of motorcycles, indicate that CO and HC cold start extra emissions using ethanol-gasoline blended fuels decrease compared to the use of unleaded gasoline.

Improved Thermal Efficiency Using Hydrous Ethanol Reforming in SI Engines

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The internal combustion engines waste large amounts of heat energy, which account for 60% of the fuel energy. If this heat energy could be converted to the output power of engines, their thermal efficiency could be improved.

The thermal efficiency of the Otto cycle increases as the compression ratio and the ratio of specific heat increase. If high octane number fuel is used in engines, their thermal efficiency could be improved. Moreover, thermal efficiency could be improved further if fuel could be combusted in dilute condition.

Therefore, exhaust heat recovery, high compression combustion, and lean combustion are important methods of improving the thermal efficiency of SI engines.

These three methods could be combined by using hydrous ethanol as fuel. Exhaust heat can be recovered by the steam reforming of hydrous ethanol. The reformed gas including hydrogen can be combusted in dilute condition. In addition, it is cooled by directly injecting hydrous ethanol into the engine. In other words, it is possible to burn at a high compression ratio.

Hydrous ethanol can be efficiently converted from biomass during refinement because the energy during distillation can be reduced.

Using hydrous ethanol is effective from both perspectives of refining and using it.

We examined improvements to thermal efficiency by using hydrous ethanol that was reformed in SI engine. The thermal efficiency of these systems is 1.5 times that of conventional SI engines from calculations. The thermal efficiency of these systems in test engines is 1.18 times that of conventional SI engines.

Fuel Injection and Combustion Processes: Modeling

Fuel Injection and Combustion Processes: Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Advanced Numerical and Experimental Techniques for the Extension of a Turbine Mapping

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1D codes are nowadays commonly used to investigate a turbocharged ICE performance, turbo-matching and transient response. The turbocharger is usually described in terms of experimentally derived characteristic maps. The latter are commonly measured using the compressor as a brake for the turbine, under steady "hot gas" tests. This approach causes some drawbacks:

- each iso-speed is commonly limited to a narrow pressure ratio and mass flow rate range, while a wider operating domain is experienced on the engine;
- the turbine thermal conditions realized on the test rig may strongly differ from the coupled-to-engine operation;
- a "conventional" net turbine efficiency is really measured, since it includes the effects of the heat exchange on the compressor side, together with bearing friction and windage losses.

In the present work, advanced experimental techniques aiming to extend the pressure ratio and mass flow rate ranges are summarized and results are compared to conventional test-rig findings.

A recently developed 1D turbine model is described basing on the solution of the flow equations inside the stationary and rotating ducts composing the device. The model is tuned with reference to experimental data collected on the conventional test-rig for a variable geometry turbine (VNT) and a mixed-flow waste-gated turbine (WGT). Then, for the WGT, the model is applied to extend the base map. The results very well agree to the experimental map obtained on the advanced test-rig.

The turbine model is finally used to provide the actual turbine aerodynamic efficiency, which does not account for compressor heat exchange, bearing friction and windage losses. The results are moreover validated against literature derived 3D CFD simulation findings.

The model hence shows the potential to overcame the limitations of a conventional test-rig for a turbine mapping.

Validation of a 1D Compressor Model for Performance Prediction

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In the present paper, a recently developed centrifugal compressor model is briefly summarized. It provides a refined geometrical schematization of the device, especially of the impeller, starting from a reduced set of linear and angular dimensions. A geometrical module reproduces the 3D geometry of the impeller and furnishes the data employed to solve the 1D flow equations inside the rotating and stationary ducts constituting the complete device. The 1D compressor model allows to predict the performance maps (pressure ratio and efficiency) with good accuracy, once the tuning of a number of parameters is realized to characterize various flow losses and heat exchange.

To overcome the limitations related to the model tuning, unknown parameters are selected with reference to 5 different devices employing an optimization procedure (modeFRONTIER™). A unique set of tuning constants is identified by the optimizer, which is able to provide, in most of cases, a good agreement with the experimental maps of each compressor.

To verify the reliability of the previously selected parameters, the tuned model is employed to compute the performance map of an additional compressor of different geometry, not included in the tuning procedure. The predicted map shows a good agreement with the experimental one.

The proposed model can hence be very helpful in providing with good accuracy a first estimate of the performance maps of a centrifugal compressor, only basing on its geometry, and in absence of manufacturer data.

Experimental Validation of Vanes with Reduced Vaneless Space to Improve Transient Behavior of Variable Geometry Turbines

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To increase the efficiency of a Variable Geometry Turbine at low massflow rates the vaneless space of the vanes is reduced. It is researched if this modification can reduce turbo lag. A turbine with modified vane ring is installed in the exhaust of a naturally aspirated engine and wide open throttle accelerations are performed to test the turbine performance.

The new (reduced vaneless space) vane configuration induced a lower exhaust backpressure which allowed the engine to accelerate faster. The acceleration from 1500 to 3000 RPM was an average of 8 % faster for the new vane configuration. This in turn increased the massflow rate through the turbine which caused the power available to the turbine to be similar in compared vane rings. The initial turbine speeds was lower for the new vane configuration but it quickly caught up with the conventional configuration because the turbine acceleration was higher. The turbine efficiency was higher for the new vane configuration in most cases. The mean increase in turbine efficiency during the initial acceleration was 4 %. The turbine efficiency at the end of the acceleration was similar for both vane configurations.

These experiments indicate that it is probable that decreasing the vaneless space in a variable geometry turbine will increase turbine performance during vehicle acceleration.

Experimental Efficiency Characterization of an Electrically Assisted Turbocharger

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Electrically assisted turbochargers consist of standard turbochargers modified to accommodate an electric motor/generator within the bearing housing. Those devices improve engine transient response and low end torque by increasing the power delivered to the compressor. This allows a larger degree of engine downsizing and down-speeding as well as a more efficient turbocharger to engine match, which translates in lower fuel consumption. In addition, the electric machine can be operated in generating mode during steady state engine running conditions to extract a larger fraction of the exhaust energy. Electric turbocharger assistance is therefore a key technology for the reduction of fuel consumption and CO2 emissions.

In this paper an electrically assisted turbocharger, designed to be applied to non-road medium duty diesel engines, is tested to obtain the turbine and electrical machine efficiency characteristics. The radial turbine is of the variable geometry type where the mass flow characteristics are changed by varying the vanes angle. The motor/generator is of the switched reluctance type and has a maximum speed of over 135,000 rev/min.

The turbine and the motor/generator have been characterized with two different experiments. The turbine has been tested in cold flow on a specifically built dynamometer available at Imperial College. This allowed extending the turbine maps available from the manufacturer and to separate the bearing and heat transfer losses from the aerodynamic performance. To test the electrical machine, a prototype of the assisted turbocharger has been modified by removing the compressor and by placing the bearing housing on gimbal bearings. By measuring the speed, the reaction torque on the bearing housing and the electrical power, the efficiency of the electrical machine has been calculated.

Turbine testing results show a peak turbine efficiency of 69% at a velocity ratio of 0.65 with 60% vane opening. Results in the electrical machine testing have shown peak efficiency exceeding 90% at 120.000 rev/min with a maximum shaft power of 3.5 kW in motoring mode and 5.4 kW in generating mode.

Temperature Estimation of Turbocharger Working Fluids and Walls under Different Engine Loads and Heat Transfer Conditions

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Turbocharger performance maps, which are used in engine simulations, are usually measured on a gas-stand where the temperatures distributions on the turbocharger walls are entirely different from that under real engine operation. This should be taken into account in the simulation of a turbocharged engine. Dissimilar wall temperatures of turbochargers give different air temperature after the compressor and different exhaust gas temperature after the turbine at a same load point. The efficiencies are consequently affected. This can lead to deviations between the simulated and measured outlet temperatures of the turbocharger turbine and compressor. This deviation is larger during a transient load step because the temperatures of turbocharger walls change slowly due to the thermal inertia. Therefore, it is important to predict the temperatures of turbocharger walls and the outlet temperatures of the turbocharger working fluids in a turbocharged engine simulation.

In the work described in this paper, a water-oil-cooled turbocharger was extensively instrumented with several thermocouples on reachable walls. The turbocharger was installed on a 2-liter gasoline engine that was run under different loads and different heat transfer conditions on the turbocharger by using insulators, an extra cooling fan, radiation shields and water-cooling settings. The turbine inlet temperature varied between 550 and 850 °C at different engine loads.

The results of this study show that the temperatures of turbocharger walls are predictable from the experiment. They are dependent on the load point and the heat transfer condition of the turbocharger. The heat transfer condition of an onengine turbocharger could be defined by the turbine inlet temperature, ambient temperature, oil heat flux, water heat flux and the velocity of the air around the turbocharger. Thus, defining the heat transfer condition and rotational speed of the turbocharger provides temperatures predictions of the turbocharger walls and the working fluids. This prediction enables increased precision in engine simulation for future work in transient operation.

Performance Development of a New Tier 4 Final Engine Family below 56 kW

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This paper describes the design and performance development of the new Kohler / Lombardini KDI engine range which is a family of 3 and 4 cylinder, in line, water cooled engines covering the power range 37 - 56 kW. The paper covers the following aspects:

- Performance and economy
- Exhaust emissions over legislative cycles
- Deterioration factor test results
- Effect of fuel quality on emissions

Analysis of Nozzle Coking Impact on Emissions and Performance of a Euro5 Automotive Diesel Engine

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The present paper reassumes the results of an experimental study focused on the effects of the nozzle injector's coking varying the flow number (FN); the performance and emissions of an automotive Euro5 diesel engine have been analyzed using diesel fuel. As the improvement of the diesel engine performance requires a continuous development of the injection system and in particular of the nozzle design, in the last years the general trend among OEMs is lowering nozzle flow number and, as a consequence, nozzle holes size. The study carried out moves from the consideration that a reduction of the nozzle holes diameter could increase the impact of their coking process.

For this purpose, an experimental campaign has been realized, testing the engine in steady state in three partial load operating points, representative of the European homologation driving cycle, and in full load conditions. Three sets of injectors with different flow number (480 cc/30s, 390cc/30s, 300cc/30s) have been used for the experimental campaign; in a first phase new injectors have been used, then, after an accelerated coking procedure of the same injectors, the tests have been repeated to compare the results. The impact of the different FN and coking grade on the engine behaviour has been investigated performing exhaust gas recirculation ratio and lambda sweeps, at partial and full load engine conditions, respectively.

The study has evidenced the benefits of the FN reduction on smoke emissions especially at low load conditions. Also as expected, it has been observed a general deterioration of engine performance in the tests carried out after the injectors' coking procedure, that is evidenced by an increase of smoke, CO and HC; moreover the results have shown a greater tendency to suffer the effects of coking for the nozzle with lower FN.

Impact on Performance, Emissions and Thermal Behavior of a New Integrated Exhaust Manifold Cylinder Head Euro 6 Diesel Engine

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The integration of the exhaust manifold in the engine cylinder head has received considerable attention in recent years for automotive gasoline engines, due to the proven benefits in: engine weight diminution, cost saving, reduced power enrichment, quicker engine and aftertreatment warm-up, improved packaging and simplification of the turbocharger installation. This design practice is still largely unknown in diesel engines because of the greater difficulties, caused by the more complex cylinder head layout, and the expected lower benefits, due to the absence of high-load enrichment. However, the need for improved engine thermomanagement and a quicker catalytic converter warm-up in efficient Euro 6 diesel engines is posing new challenges that an integrated exhaust manifold architecture could effectively address.

A recently developed General Motors 1.6L Euro 6 diesel engine has been modified so that the intake and exhaust manifolds are integrated in the cylinder head. Extensive CAD/CAE/CAM analyses have been employed in order to guide the design of the overall surface and the water cooling jacket that surround the exhaust manifold of the new engine version, and thus to be able to improve the low-frequency thermal fatigue resistance of the head.

The thus obtained prototype engine head has been tested on a highly-dynamic test bench at the Politecnico di Torino in order to characterize performance, emissions and thermal behavior in comparison to the baseline production engine.

The results have generally been very promising and have shown the possibility of maintaining the same performance rating over the overall engine speed range as well as comparable emissions and brake specific fuel consumption in steady-state conditions. Furthermore, appreciably faster engine and aftertreatment warm-up

have been recorded due to the higher heat fraction that is transferred to the coolant and to the more favorable exhaust gas enthalpy management. The latter benefit is in fact very interesting as far as the control of HC and CO emissions within the NEDC homologation is concerned.

A Tridimensional CFD Analysis of the Lubrication Circuit of a Non-Road Application Diesel Engine

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The aim of this paper is the analysis of a Diesel engine lubrication circuit with a tri-dimensional CFD technique. The simulation model was built using Pumplinx®, a commercial code by Simerics Inc.®, developed and optimized for predicting oil flow rates and cavitation phenomena. The aim of this paper is, also, to show that this code is able to satisfactorily model, in a very “economic” way, an unsteady hydraulic system such as the lubrication circuit

First of all, an accurate model of a lubrication circuit oil pump will be described. The model was validated with data from an experimental campaign carried out in the hydraulic laboratory of the Industrial Engineering Department of the University of Naples.

Secondly, the oil pump model was coupled with a tri-dimensional model of the entire lubrication circuit, in order to compute all the hydraulic resistances of the network and the oil consumption rate of the circuit components

Model Based Control for Dual EGR System with Intake Throttle in New Generation 1.6L Diesel Engine

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Honda developed a new generation 1.6L diesel engine as a part of technologies for high driving performance and good fuel economy. This new engine is equipped on Civic (C Segment, 5 doors), launched as a new European model in 2013. This engine has some technologies achieving both good fuel economy and low emission, and met Euro5 emission regulation. And the Civic achieved CO2emission of 94 g/km in NEDC, a reduction of 14.5% in CO2 emission against the previous diesel engine of Honda. [1]

This engine has the dual EGR system composed of HP-EGR and LP-EGR, one of the technologies introduced to increase fuel efficiency. In this paper, some issues for the dual EGR system control and countermeasures for them will be described.

In order to control each EGR mass flow, two or more valves (HP-EGR valve, LP-EGR valve and intake throttle) should be regulated cooperatively. So the model based control which is multi input-multi output (MIMO) system is introduced, and operates some valves simultaneously. In the dual EGR system, the ratio of LP-EGR flow and HP-EGR flow should be controlled. So the logic which guarantees minimum differential pressure to LP-EGR was introduced. And then LP-EGR flow indicates lag and dead-time characteristics because LP-EGR passage is very long. In this case HP-EGR which has higher response is compensated, and achieves accurate EGR control. This model based control is used in the rich combustion mode also in order to realize the cooperative control of an intake shutter and HP-EGR valve. Introducing the model based control realizes good control accuracy of EGR flow regardless of the dual EGR using some valves.

Research on the UML-based Modeling of Embedded Software for Diesel Engine Control System

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The method and steps for software modeling of the embedded control systems for diesel engine based on UML are described in this paper. In order to meet the software function and the features of the system, object-oriented modeling for diesel engine embedded control software system has been implemented. Requirements are depicted by use case diagram and the logic structure is depicted by class diagram. According to the domain knowledge and the class diagram, the sequence diagram and state diagram are developed to describe the dynamic behavior of the system. The level of software development has been enhanced to the system level by software modeling. It focuses on the automotive field, and can be easy to grasp the problem from the overall perspective and discover software design problems at the early stage. It is also convenient to solve the problems caused by the change of requirements. The model has an excellent flexibility so that it can be applied to different software platforms. This method provides strong support to make the open architecture and reusability of the embedded software for diesel engine control come true.

Comparison of Numerical and System Dynamics Methods for Modeling Wave Propagation in the Intake Manifold of a Single-Cylinder Engine

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The automotive industry is striving to adopt model-based engine design and optimization procedures to reduce development time and costs. In this scenario, first-principles gas dynamic models predicting the mass, energy and momentum transport in the engine air path system with high accuracy and low computation effort are extremely important today for performance prediction, optimization and cylinder charge estimation and control.

This paper presents a comparative study of two different modeling approaches to predict the one-dimensional unsteady compressible flow in the engine air path system. The first approach is based on a quasi-3D finite volume method, which relies on a geometrical reconstruction of the calculation domain using networks of zero-dimensional elements. The second approach is based on a model-order reduction procedure that projects the nonlinear hyperbolic partial differential equations describing the 1D unsteady flow in engine manifolds onto a predefined basis.

The two models are compared against experimental data obtained from a single cylinder engine for motorcycle applications. The results presented allow one to establish a trade-off between accuracy, stability and computation time for each solution method, in light of potential applications to engine performance simulation.

Development of an Integrated Design Tool for Real-Time Analyses of Performance and Emissions in Engines Powered by Alternative Fuels

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Development of computationally fast, numerically robust, and physically accurate models to compute engine-out emissions can play an important role in the design, development, and optimization of automotive engines powered by alternative fuels (such as natural gas and H2) and fuel blends (such as ethanol-blended fuels and biodiesel-blended fuels). Detailed multidimensional models that couple fluid dynamics and chemical kinetics place stringent demands on the computational resources and time, precluding their use in design and parametric studies. This work describes the development of an integrated design tool that couples a fast, robust, physics-based, two-zone quasi-dimensional engine model with modified reaction-rate-controlled models to compute engine-out NO and CO for a wide variety of fuel-additive blends. This integrated tool was designed to evaluate engine performance and emissions on the order of a typical engine cycle (25 -50 milliseconds) to enable its use for real-time control and optimization.

As an illustrative example, this tool was used to study the engine-out NO and CO in a natural gas engine. The engine-out CO and NO predicted by the model showed good agreement with experimental data. The performance and emission computations for a single engine cycle were completed in about 8 milliseconds.

Neural Model for Real-Time Engine Volumetric Efficiency Estimation

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Increasing the degrees of freedom in the air path has become a popular way to reduce the fuel consumption and pollutant emissions of modern combustion engines. That is why technical definitions will usually contain components such as multi or single-stage turbocharger, throttle, exhaust gas recirculation loops, wastegate, variable valve timing or phasing, etc. One of the biggest challenges is to precisely quantify the gas flows through the engine. They include fresh and burnt gases, with trapping and scavenging phenomena. An accurate prediction of these values leads to an efficient control of the engine air fuel ratio and torque. Fuel consumption and pollutant emissions are then minimized.

In this paper, we propose to use an artificial neural network- based model as a prediction tool for the engine volumetric efficiency. Results are presented for a downsized turbocharged spark-ignited engine, equipped with inlet and outlet variable valve timing. The calibration process that is used in this study only requires steady-state operating points. The validation stage was conducted on both steady-state and vehicle transients. Model prediction is in very good agreement with experimental results while keeping a very low calibration effort and matching embedded computational requirements. The conclusion stresses that thanks to their generic structure, neural models offer an interesting potential for generalization to even more complex technical definitions.

Towards On-Line Prediction of the In-Cylinder Pressure in Diesel Engines from Engine Vibration Using Artificial Neural Networks

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This study aims at building efficient and robust artificial neural networks (ANN) able to reconstruct the in-cylinder pressure of Diesel engines and to identify engine conditions starting from the signal of a low-cost accelerometer placed on the engine block. The accelerometer is a perfect non-intrusive replacement for expensive probes and is prospectively suitable for production vehicles. In this view, the artificial neural network is meant to be efficient in terms of response time, i.e. fast enough for on-line use. In addition, robustness is sought in order to provide flexibility in terms of operation parameters. Here we consider a feed-forward neural network based on radial basis functions (RBF) for signal reconstruction, and a feed-forward multi-layer perceptron network with tan-sigmoid transfer function for signal classification. The networks are trained using measurements from a three-cylinder real engine for various operating conditions. The RBF neural network is trained with time series from in-cylinder pressure signals and vibration signals measured on a cylinder which is distant from the one in which the pressure signal is measured. The accuracy of the predicted pressure signals is analyzed in terms of mean square error and in terms of a number of pressure-derived parameters. The location of the accelerometer has little influence on the accuracy of the reconstruction. This is confirmed also by the fact that the perceptron network, constructed in the second part of the work, is able to distinguish, from the accelerometer signal, among motored and fired conditions for any of the cylinders. Here, training data are again composed of time series obtained from the accelerometer, plus the corresponding target classes (fired/non-fired). Despite of the noisy character of the vibration signal and the distance from the cylinders, the perceptron network classifies correctly almost 100% of the signals.

A Methodology to Enhance Design and On-Board Application of Neural Network Models for Virtual Sensing of NO_x Emissions in Automotive Diesel Engines

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The paper describes suited methodologies for developing Recurrent Neural Networks (RNN) aimed at estimating NOx emissions at the exhaust of automotive Diesel engines. The proposed methodologies particularly aim at meeting the conflicting needs of feasible on-board implementation of advanced virtual sensors, such as neural network, and satisfactory prediction accuracy. Suited identification procedures and experimental tests were developed to improve RNN precision and generalization in predicting engine NOx emissions during transient operation. NOx measurements were accomplished by a fast response analyzer on a production automotive Diesel engine at the test bench. Proper post-processing of available experiments was performed to provide the identification procedure with the most exhaustive information content. The comparison between experimental results and predicted NOx values on several engine transients, exhibits high level of accuracy.

CFD and FEM Analysis of a New Engine for Light Transportation Vehicles

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An engine head of a common rail direct injection engine with three in line cylinders for Light Transportation Vehicle (LTV) applications has been analyzed and optimized by means of uncoupled CFD and FEM simulations in order to assess the strength of the components. This paper deals with a structural stress analysis of the cylinder head considering the thermal loads computed through an CFD simulation and a detailed FV heat-transfer analysis.

The FE model of the cylinder head includes the contact interaction between the main parts of the cylinder head assembly and it is subjected to the gas pressure, thermal loads and the effects of bolts tightening and valve springs. The results, in term of temperature field, are validated by comparing with those obtained by means of experimental analyses. Then a fatigue assessment of the cylinder head has been performed using a multi-axial fatigue criterion.

Development of a Fast, Robust Numerical Tool for the Design, Optimization, and Control of IC Engines

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This paper discusses the development of an integrated tool for the design, optimization, and real-time control of engines from a performance and emissions standpoint. Our objectives are threefold: (1) develop a tool that computes the engine performance and emissions on the order of a typical engine cycle (25-50 milliseconds); (2) enable the use of the tool for a wide variety of engine geometries, operating conditions, and fuels with minimal user changes; and (3) couple the engine module to an efficient optimization module to enable real-time control and optimization.

The design tool consists of two coupled modules: an engine module and an optimization module. The engine module consists of three components: a two-zone quasi-dimensional engine model to compute the temporal variation of temperature and pressure during the compression and power stroke, a thermal model to compute the cyclic variation of the engine wall temperature, and a reaction-rate-controlled emission model to compute engine-out NO and CO. The optimization solver is an extension of the model-based, derivative-free POUNDER and is designed to limit the number of engine model evaluations. The outputs of the engine model, thermal model, and emissions model can be used for optimizations under various design constraints.

By more thoroughly using the output from the simulations, our optimization scheme reduces the number of simulation evaluations by two orders of magnitude compared with parameter sweeps and one order of magnitude compared with the standard black-box optimizer in MATLAB. These results highlight the proposed tool's potential for use in design, optimization, and real-time control of engines.

Combined Modeling of Thermal Systems of an Engine in the Purpose of a Reduction in the Fuel Consumption

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The tightening restrictions, in terms of fuel consumption, have pushed the vehicle manufacturers and equipment suppliers into searching for innovative ways to reduce the carbon dioxide emissions. Along with the ameliorations added to the engine itself, additional systems are grafted to the engine in order to keep up with the ever-changing laws.

Isolating the impact on the fuel consumption of an added system, by on board testing, is a complicated task. In this case, using simulation modeling allows the reduction of delays related to prototyping and testing. This paper presents modeling of various thermal systems in a vehicle and their interactions to evaluate the fuel consumption using AMESim software.

As means to reduce the CPU cost of the model (calculation time), without decreasing its predictability, engine modeling has been done by two steps: high frequency model and mean value model. While the first model is used to characterize the engine indicated work, exhaust losses and thermal losses, the second model is integrated in a complete vehicle model where the additional thermal systems are connected. From these additional systems, the model contains: the cooling system, lubricating system, EGR (Exhaust Gas Recirculation) and charged air cooling system.

Using this model helps evaluating the cost of each system in terms of fuel consumption. Comparing different cooling systems architectures is possible. Furthermore, the impact of air shutters on both the aerodynamics and the thermal stability of the engine is studied.

Application of an Integrated CFD Methodology for the Aerodynamic and Thermal Management Design of a Hi-Performance Motorcycle

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Though CFD methods have become very popular and widespread tools in the early as well as more advanced automotive design stages, they are still not so common in the motorcycle industry branch. The present work aims at the development of a comprehensive simulation environment, based on the open-source finite volume toolbox OpenFOAM®, for the aerodynamic and thermal fluxes optimization of a full motorcycle-and-rider geometry. The paper is divided in two parts: in the first one, the OpenFOAM® code is evaluated for a cold flow aerodynamic analysis, using a slightly simplified version of the Aprilia RSV4 motorbike geometry; in the second one, a mixed reduced scale-full scale methodology is proposed for the simultaneous assessment of aerodynamic forces and heat transfer performances of the engine cooling system. Results have been compared against other well established commercial CFD packages and, where available, with experimental measurements.

Vehicle Dynamics Modeling for Real-Time Simulation

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This paper presents a 14 degrees of freedom vehicle model. Despite numerous software are nowadays commercially available, the model presented in this paper has been built starting from a blank sheet because the goal of the authors was to realize a model suitable for real-time simulation, compatible with the computational power of typical electronic control units, for on-board applications. In order to achieve this objective a complete vehicle dynamics simulation model has been developed in Matlab/Simulink environment: having a complete knowledge of the model's structure, it is possible to adapt its complexity to the computational power of the hardware used to run the simulation, a crucial feature to achieve real-time execution in actual ECUs.

Passive Fault-Tolerant Performance of 4WID/4WIS Electric Vehicles Based on MPC and Control Allocation

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The passive fault-tolerant performance of the integrated vehicle controller (IVC) applied on 4WID/4WIS Electric Vehicles has been investigated in this study. The 4WID/4WIS EV is driven independently by four in-wheel motors and steered independently by four steering motors. Thanks to increased control flexibility of the over-actuated architecture, Control Allocation (CA) can be applied to control the 4WID/4WIS EVs so as to improve the handling and stability. Another benefit of the over-actuated architecture is that the 4WID/4WIS Electric Vehicle has sufficient redundant actuators to fight against the safety critical situation when one or more actuators fail.

The integrated vehicle control (IVC) approach is composed of two parts, i.e. a motion controller which is based on the Model Predictive Control (MPC) to determine the generalized forces/moments in order to track the desired vehicle motion; a control allocator which adopts Control Allocation (CA) method and distributes the generalized forces/moments among four wheels aiming at maximizing the vehicle-road grip margin.

The MPC-based integrated vehicle controller is robust to parameter uncertainties and external disturbances. The actuator failure can be considered as a sort of disturbances. The integrated vehicle controller can handle the actuatorfailure situation maintaining the desired vehicle motion while the controller configuration is not necessary to be reconfigured. The proposed IVC controller has the passive fault-tolerant performance which does not need the fault detection and diagnosis mechanism so that the control system is simple and has no diagnosis time delay.

The passive fault-tolerant performance of the proposed IVC controller has been confirmed through simulations. Simulations have shown that once the actuator fails, the IVC controller can still maintain the desired vehicle motion. The IVC controller ensures the desired vehicle dynamics after driving motor failures which verify the passive fault-tolerant performance of the proposed IVC controller. In this way, the proposed passive fault-tolerant controller improves the post-fault safety, stability and maneuverability of the 4WID/4WIS EVs.

A New Optical Sensor for the Measurement of the Displacement of the Needle in a Common Rail Injector

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Since the needle displacement exerts a fundamental influence in the operation of a Common Rail Diesel injection equipment, an accurate measurement of the instantaneous position of the control piston is crucial for a more thorough analysis of the behavior of the injectors, in particular when multiple injections are employed. Moreover, the development of a cheap instrumentation would allow to enlarge the Diesel engine on-board equipment with an instrumentation for the diagnosis of the injector operation.

Eddy current sensors have been traditionally used in lab activities to measure the position of the needle inside the injector; apart from its high cost, the scientific literature clearly shows their inadequacy, given the presence of electromagnetic disturbance: the current pulse which controls the opening of the injector nozzles generates electromagnetic fields which strongly affect the acquisition of data.

Many attempts have been made either to solve the interference occurring during the measures or to propose a displacement transducer whose operation is not influenced by electromagnetic interference.

The sensor that will be proposed in this paper (Patent filing October 2012, under submission for PCT extension) follows the latter line: it is an optical transducer which joins the simple and very cheap construction with the employment of a reliable physical principle for measuring the needle lift.

The paper provide all technical and scientific details of the operation of the proposed sensor, as well as a wide proposition of experimental applications aiming at assessing its capability of detecting also multiple injections.

Diesel Combustion Analysis via Block Vibration during Engine Transient Operation

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To ensure compliance with emerging Diesel emission standards and demands for reduced fuel consumption, the optimization of the engine operation is imperative under both stationary and real operation conditions.

This issue imposes a strict control of the combustion process that requires a closed-loop algorithm able to provide an optimal response of the engine system not only to warm-up, accelerations, changes in the slope of the road, etc., but also to engine aging and variations of fuel properties.

In this paper, with the final purpose of accomplishing an innovative control strategy based on non intrusive measurement, the engine block vibration signal is used to extract useful information able to characterize the in-cylinder pressure development during the combustion process.

In the previous research activity, the same methodology was applied to stationary operation of the engine. In such a condition, it demonstrated to work not only with standard diesel fuel, but also with biodiesel blends. This paper focuses on the application of the technique when the engine is operating under transient conditions.

In the research, a small displacement two-cylinder Diesel engine equipped by high pressure common rail (HPCR) fuel injection systems was used. The results of engine speed and torque transient tests are presented to highlight the reliability of the method in the optimization of the combustion process not only to obtain better engine performance, but also to reduce the smoke emissions.

In-Cylinder Pressure based Modeling for Injection Parameters by PCA with Feature Correlation Analysis

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Modern Diesel engines have become complex systems with a high number of available sensor information and degrees of freedom in control. Due to recent developments in production type in-cylinder pressure sensors, there is again an upcoming interest for in-cylinder pressure based applications. Besides the standard approaches, like to use it for closed loop combustion control, also estimation and on-board diagnostics have become important topics. Not surprising in general the trend is to utilize those sensors for as many tasks as possible.

Consequently this work focuses on the estimation of the injection parameters based on the indicated pressure signal information which can be seen as first step of a combustion control based on desirable indicated pressure characteristics which may be utilized for e.g. the minimization of NOx emissions.

Currently the acquisition of the cylinder pressure traces can be done in real-time by fast FPGA (Field Programmable Gate Array) based systems. However, a crucial part of such cylinder pressure based approaches is to extract the information of the cylinder pressure traces since the raw pressure signals are often available with a resolution of 0.5 CAD and thus per engine cycle 1440 data points are recorded. To post process this information different data reduction techniques are available. Whichever technique used, two differing tasks have to be concerned, on one hand the number of inputs should be as low as possible to keep the model structure simple, but still the significant information should be preserved. However, the number of necessary quantities, e.g. in the case of principle component analysis (PCA) the so called features, cannot be straightforward determined and may depend on the modeled quantity or model type.

To this end in this work a PCA reduction approach is extended to tackle three different issues: First, the optimal amount of features for the start of the main injection and the main injection amount are determined by data analysis. And second it is analyzed, whether an identical number of features and amount of parameters is applicable for both injection parameter models. The last issue considers if a direct relation between a certain feature and the injection parameters are detectable.

Investigation of Combustion Process in a Small Optically Accessible Two Stroke SI Engine

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The improvement in engines efficiency and reduction of emissions is the permanent aim of engine industry in order to meet European standards regulation. To optimize small internal combustion engines it is necessary to improve the basic knowledge of thermo-fluid dynamic phenomena occurring during the combustion. This paper describes the combustion process in an optically accessible two-stroke spark-ignition engine used in a commercial 43 cm3 chainsaw. Two different feeding systems were tested: standard and CWI one.

The engine head was modified in order to allow the visualization of the combustion using endoscopic system coupled with a high spatial resolution ICCD camera. Flame front propagation was evaluated through an image processing procedure. The image visualization and chemiluminence allowed to follow the combustion process from the spark ignition to the exhaust phase at high engine speed. All the optical data were correlated with engine parameters and exhaust emissions.

The effect of the injection system on deposits formed by fuel accumulation and on the flame front propagation and unburned hydrocarbons emission was investigated. The use of CWI system allowed a fast and efficient injection and a reduction of unburned hydrocarbon emissions and specific fuel consumption. However it causes a worsening in combustion stability probably due to a less homogeneous distribution of the fuel as observed by optical means.

3D-CFD Virtual Engine Test Bench of a 1.6 Liter Turbo-Charged GDI-Race-Engine with Focus on Fuel Injection

Marco Chiodi, Antonella Perrone, Paolo Roberti, Michael Bargende
FKFS
Alessandro Ferrari, Donatus Wichelhaus
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In the last years motorsport is facing a technical revolution concerning the engine technology in every category, from touring car championships up to the F1. The strategy of the car manufacturers to bring motorsport engine technology closer to mass production one (e.g. turbo-charging, downsizing and direct injection) allows both to reduce development costs and to create a better image and technology transfer by linking motorsport activities to the daily business.

Under these requirements the so-called Global Race Engine (GRE) concept has been introduced, giving the possibility to use one unique engine platform concept as basis for different engine specifications and racing categories.

In order to optimize the performance of this kind of engines, especially due to the highly complex mixture formation mechanisms related to the direct injection, it is nowadays mandatory to resort to reliable 3D-CFD simulations.

In this paper the contribution of intensive CFD simulations within the engine development process will be shown, in particular some issues regarding the injection modeling and its influence on the prediction of the mixture formation, the combustion and the global engine performance will be analyzed.

Fuel Injection and Combustion Processes: Modeling

Fuel Injection and Combustion Processes: Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

The Development of a Simulation Tool for Monitoring Heavy-Duty Vehicle CO2 Emissions and Fuel Consumption in Europe

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Following its commitment to reduce CO2 emissions from road transport in Europe, the European Commission has launched the development of a new methodology for monitoring CO2 emissions from heavy-duty vehicles (HDV). Due to the diversity and particular characteristics of the HDV sector it was decided that the core of the proposed methodology will be based on a combination of component testing and vehicle simulation. A detailed methodology for the measurement of each individual vehicle component of relevance and a corresponding vehicle simulation is being elaborated in close collaboration with the European HDV manufacturers, component suppliers and other stakeholders. Similar approaches have been already adopted in other major HDV markets such as the US, Japan and China.

In order to lay the foundations for the future HDV CO2 monitoring and certification software application, a new vehicle simulation software was developed, Vehicle Energy Consumption calculation Tool (henceforward VECTO). VECTO aims to serve as a platform that will incorporate the findings of current research activities in the field of HDV fuel consumption simulation and serve as a pilot for future upgrades and developments of the software application to be included in the European regulation. Emphasis was put from the very beginning on features that are of importance to HDV in order to reflect realistically both the actual vehicle CO2 emissions during operation and the competitive advantages of various fuel/CO2 saving technologies of the vehicles.

This paper describes the simulation tool, its key characteristics and summarizes the most important future updates that are under investigation. In addition a first validation of its performance against real world measurement data is presented. The tool was also benchmarked against three widely available commercial vehicle simulators. Results suggest good ability to reproduce tests but further developments are still necessary in order to accurately reflect the real world fuel consumption of modern HDVs.

Exhaust Emissions from European Market-Available Passenger Cars Evaluated on Various Drive Cycles

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AECC, the Association for Emissions Control by Catalyst, conducted a test program to compare the newly developed World-harmonized Light vehicles Test Cycle (WLTC) with the current European regulatory New European Drive Cycle (NEDC) and the cold-start Common Artemis Driving Cycle (CADC).

Vehicle engines and aftertreatment technologies were selected to cover a wide range of future systems. Six European commercially available passenger cars were chosen: three Euro 5 Gasoline Direct Injection cars, two Euro 6 Diesel cars and a Euro 5 non-plug-in gasoline hybrid car. The hybrid car was tested with three different battery state of charge: nominal, minimum charge, and maximum charge.

Investigations on the test temperature were also conducted by comparing emissions at 25°C and at −7°C. Regulated gaseous emissions (HC, CO, NOx) and particulate mass and particles number were measured, together with additional pollutants such as CH4, NO2 and ammonia.

The study isolated cycle-to-cycle effects on emissions for each vehicle by normalizing the test mass in all tests to the draft WLTP (World-harmonized Light vehicles Test procedure) Global Technical Regulation (gtr). Because of the higher inertia used, emissions results obtained on the regulatory NEDC can deviate from type-approval emissions for each tested vehicle.

Comparison of emissions results obtained on NEDC and WLTC tends to show that WLTP may bring more realistic CO2 emissions from the higher vehicle inertia included in the test procedure (closer to real mass of vehicle) but most likely not from its drive cycle pattern, even if it is more transient.

Thermal Management Strategies for SCR After Treatment Systems

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While the Diesel Particulate Filter (DPF) is actually a quasi-standard equipment in the European Diesel passenger cars market, an interesting solution to fulfill NOx emission limits for the next EU 6 legislation is the application of a Selective Catalytic Reduction (SCR) system on the exhaust line, to drastically reduce NOx emissions.

In this context, one of the main issues is the performance of the SCR system during cold start and warm up phases of the engine. The exhaust temperature is too low to allow thermal activation of the reactor and, consequently, to promote high conversion efficiency and significant NOx concentration reduction. This is increasingly evident the smaller the engine displacement, because of its lower exhaust system temperature (reduced gross power while producing the same net power, i.e., higher efficiency).

The proposal of the underlying work is to investigate and identify optimal exhaust line heating strategies, to provide a fast activation of the catalytic reactions on SCR. The main constrain is to limit the potential fuel consumption increase, and possibly to even increase global efficiency, and the chosen application is a small EU5-compliant diesel engine.

After an initial investigation, the research has been focused on main combustion control parameters, rather than on post-oxidation processes associated with late injections, in an effort to reduce eventual fuel penalties. The effect of each relevant engine control parameter has been analyzed on the test bench, observing the results in terms of exhaust system temperature and fuel efficiency. After this preliminary identification phase, different calibration strategies have been tested on the vehicle, executing several NEDC cycles. The most relevant comparisons are illustrated and critically discussed in the paper.

Improved Sulfur Resistance of Noble Metal Catalyst for Lean-Burn Natural Gas Applications

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Natural gas and biogas alone or in combination with conventional liquid fuels (dual-fuel applications) are advanced alternative solutions to diesel and gasoline in the future. Burning of natural- or biogas produces less CO2 emissions per energy unit, and particulate matter emissions can also be reduced compared to more traditional liquefied fuels. This decrease in engine out emissions can be utilized as a tool to meet tightening emission limits and to improve the air quality locally in the areas with big challenges especially related nitrogen oxide and particulate emissions.

In the present study the focus was on the development of catalytic emission control technology for both mobile and stationary lean-burn natural gas applications. Main activities were related to the oxidation catalyst and its improvements towards sulfur poisoning and to enhance methane light-off performance. Combination between oxidation catalyst and selective catalytic reduction (SCR) to reduce NOx emissions from especially dual-fuel engines is discussed as well.

The study showed that catalytic washcoat composition played an important role in methane oxidation. Methane combustion activity and sulfur resistance were improved by modifying chemical composition of the catalyst to optimize adsorption properties and support-active site interactions. Sulfur resistance of the catalyst was improved by modifying washcoat with acidic raw material, since it may change sulfur adsorption properties of the catalyst. Washcoat modification enabled also reduction in the noble metal loading which reduces significantly the cost of the catalyst.

Fuel-Cut Based Rapid Aging of Commercial Three Way Catalysts - Influence of Fuel-Cut Frequency, Duration and Temperature on Catalyst Activity

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In order to quantify fuel-cut aging effects on commercial bimetallic Pd/Rh three-way catalysts (TWCs), supported on cerium-zirconium promoted alumina, full-size automotive catalysts were exposed to accelerated fuel-cut aging on an engine test bench, with a variation in temperature, fuel-cut frequency and fuel-cut duration. After aging, samples of the catalysts were tested in a laboratory environment for Light-off temperature (T50), Specific surface area (BET), Dispersion of noble metals and changes in the oxidation state of Pd and Rh.

The catalytic tests showed clear deactivation of the aged samples and influence on the TWC's properties. The light off temperature and noble metal dispersion were found to be a clear function of oxygen exposure to the catalysts, i.e. fuel-cut frequency and duration, while the specific surface area was found to be a function of fuel-cut frequency. No changes in oxidation states of Pd and Rh could be detected. The variation in temperature had the lowest influence on the TWC properties among the varied parameters.

Performance and Emission Characteristics of Isobutanol-Diesel Blend in Water Cooled CI Engine Employing EGR with EGR Intercooler

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The increasing rate of fossil fuel depletion and large scale debasement of the environment has been a serious concern across the globe. This twin problem of energy crises has caused researchers to look for a variety of solutions in the field of internal combustion engines. In this current scenario the issue of fuel availability has increased the use alternative fuels, especially alcohol derived fuels. Alcohol-diesel blends can be been seen as a prominent fuel for CI engine in the near future. Previous research on the use of alcohol as an alternative fuel in CI engines is restricted to short branch alcohols, such as methanol and ethanol. Despite their comparable combustion properties longer chain alcohols, such as butanol, isobutanol and pentanol have been barely investigated. In the present study performance and emission characteristics of an isobutanol-diesel blend was studied. One of the major problems encountered by isobutanol in CI engines is its low cetane rating. The blending of isobutanol in diesel helps in overcoming this problem. This fuel shows several advantages, such as reduced CO, NOx and PM emissions, low corrosive nature and low solubility in water. In the present study the test fuel used was 10% isobutanol by volume in diesel fuel. The test engine used for the present study was a single cylinder 4-stoke CI engine with exhaust gas recirculation (EGR) using EGR intercooler. Among various NOx reduction strategies, viz. selective catalytic reduction (SCR), fuel additives, retarded injection and exhaust gas recirculation (EGR), EGR was chosen in the present experimentation. Study was also done to study the effect of using an EGR intercooler on performance and emission of the engine. Seven parameters, viz. Brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), Exhaust gas temperature, Unburned Hydrocarbon emission (UHC), Carbon monoxide Emission (CO), Oxides of nitrogen emission (NOx) and Smoke opacity were determined at all the operating conditions. IB10 was found to have a higher BTE compared to diesel. Also NOx and CO emissions were low, but higher UHC emissions were recorded. Using EGR with an intercooler was more effective in reducing NOx compared with EGR without an intercooler. However, employing an intercooler reduced BTE and increased other emissions.

Potential of Advanced, Combined Aftertreatment Systems for Light-Duty Diesel Engines to Meet Upcoming EU and US Emission Regulation

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The modern DI-diesel engine represents a valuable platform to achieve worldwide tightened CO2 standards while meeting future strengthened emission regulations in the EU and the US. Due to the simultaneous, partially contrary legal demands, new integrated and combined systems are required to allow best overall performance within the upcoming legal frames concerning pollutant emission reduction and minimization of CO2 output. As extended emission relevant areas in the engine map have to be respected in view of RDE and PEMS scenarios in EU, but also facing the LEVIII standards in the US, comprehensive and synchronized technical solutions have to be engineered. Based on furthermore optimized combustion systems with improved combustion efficiency, meaning also lowered exhaust gas temperatures, especially refined and tailored emission control systems are demanded. Besides possible realizations regarding integrated DPF and SCR (SDPF) functionalities on one substrate, also the combination with advanced LNT technology features beneficial aspects. To point out benefits and challenges of combined systems with relatively low complexity a simulative study was performed in this paper. For the European market conventional SCR as well as alternative SDPF concepts have been comparatively investigated for a 2.0L Diesel engine in WLTP cycle. It is shown that SDPF shows an improved thermal behaviour in comparison to the SCR based EAS layout. This is due to lower overall thermal mass within EAS, which leads to increased NOx conversion efficiency. However, a significant amount of required conversion efficiency can only be gained by catalyst heating measures. For the US market the application of a Passive NOx Adsorber (PNA) in combination with conventional SCR was studied for a 3.0L Diesel engine in FTP cycle. The simulation results point out that the PNA is in principle a valuable technology improving the NOx aftertreatment. However, the intended task of the PNA buffering NOx at cold start is only sufficient in case of low initial PNA NOx load at engine start. Therefore a somehow active operation of the PNA is required resulting in increased control logic algorithms and fuel economy penalty.

Cold Start Thermal Management with Electrically Heated Catalyst: A Way to Lower Fuel Consumption

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Recent engine development has been mainly driven by increased specific volumetric power and especially by fuel consumption minimization. On the other hand the stringent emission limits require a very fast cold start that can be reached only using tailored catalyst heating strategy.

This kind of thermal management is widely used by engine manufactures although it leads to increased fuel consumption. This fuel penalty is usually higher for high power output engines that have a very low load during emission certification cycle leading to very low exhaust gas temperature and, consequently, the need of additional energy to increase the exhaust gas temperature is high.

An alternative way to reach a fast light off minimizing fuel consumption increase is the use of an Electrical Heated Catalyst (EHC) that uses mechanical energy from the engine to generate the electrical energy to heat up the catalyst. Following this thermal management strategy the energy input can be tailored according to the component need and the energy loss in the system can be minimized. Moreover, the efficiency of such systems can be further optimized using for example brake energy recuperation or advanced thermal management.

The present work describes the different engine management strategies tested by Ferrari to find the best compromise between fuel consumption and emission reduction.

Influence of the Washcoat Structure in the Performance of Automotive Three Way Catalysts

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Transport limitations inside the porous washcoat layer have an important influence in the light-off and overall conversions even in the case of relatively thin layers used in automotive three way catalysts (TWC). The porous structure of the washcoat layer is controlled at two levels: i) at the level of mesoporous structure, which can be determined by the use of specific synthesis techniques (e.g., sol-gel or pore-templating method), and ii) at the level of macroporous structure, which is influenced by the particle size distribution of mesoporous in a slurry that has undergone a specific thermal treatment. This paper investigates the influence of the washcoat structure in the performance of automotive TWC. Furthermore, the article presents a method that allows to quantify the magnitude of the reaction resistance (chemical kinetics), internal mass transfer resistance (washcoat diffusion), and external mass transfer resistance on the TWC conversions. From experimental data gathered at different operating temperatures (from light-off to 1100 K) and applying the developed methodology for resistances quantification, it was found that the internal mass transfer limitations play a major role in the TWC conversions. The main conclusions from this study are: i) the effective diffusivity strongly depends on the washcoat layer structure, which in turn depends on its preparation process; ii) the resistance quantification analysis reveals that the lower effective diffusivity interval is more adequate for the TWC used in the present investigation, which also indicates that the TWC washcoat has a low percentage of macropores; and iii) to decrease the relevance of the internal mass transfer limitation requires an increase in the effective diffusivity and/or a thinner washcoat layer.

Experimental Investigation on Three Different Ceramic Substrate Materials for a Diesel Particulate Filter

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Three different ceramic substrate materials (Silicon Carbide, Cordierite and Aluminum Titanate) for a Diesel Particulate Filter (DPF) for a European passenger car diesel engine have been experimentally investigated in this work.

The filters were soot loaded under real world operating conditions on the road and then regenerated in two different ways that simulate the urban driving conditions, which are the most severe for DPF regeneration, since the low exhaust flow has a limited capability to absorb the heat generated by the soot combustion.

The tests showed higher temperature peaks, at the same soot loading, for Cordierite and Aluminum Titanate compared to the Silicon Carbide, thus leading to a lower soot mass limit, which in turn required for these components a higher regeneration frequency with draw backs in terms of fuel consumption and lube oil dilution. On the other hand Cordierite and Aluminum Titanate could guarantee a lower thermal loss across the DPF, thus allowing the attainment of higher temperature levels and consequently of higher efficiencies of an SCR system placed downstream of the DPF.

Improved Soot Combustion in DPF Catalyzed by Ceria Nanofibers: The Importance of Soot-catalyst Contact

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Ceria nanofibers were synthesized as soot oxidation catalysts. The morphology of the catalyst was tailored to maximize the contact between the soot particles and the catalyst. Of the synthesized catalysts, the fibrous shape was the most active toward soot oxidation: the peak combustion temperature was reduced from 600°C (non-catalytic combustion) to 375°C during tight contact, 428°C during prolonged loose contact (see detailed definition in the text), and 553°C during loose contact. These results were compared to a very active ceria catalyst generated using the Solution Combustion Synthesis method and characterized by its high porosity and SSA surface. However, although the nanofibers have one fifth of the BET that the nanopowders obtained with SCS have, they display almost the same activity under tight conditions and considerably better activity during prolonged loose contact: their peak temperature was 31°C lower than the peak temperature for SCS-obtained nanopowders during the latter. This encourages us to investigate the interaction between the morphology and real contact conditions between the catalyst and soot in Diesel Particulate Filters (DPF) and to tailor the DPF catalytic support toward enhancing this contact while maintaining the low pressure drop associated with the catalytic layer.

Diesel Engine Biofuelling: Effects of Ash on the Behavior of the Diesel Particulate Filter

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The use of biodiesels is an effective way to limit greenhouse emissions and partly limit the dependence on fossil primary sources. Biodiesel fuels also show interesting features in terms of PM-NOx emissions trade-off that appears more favorable toward an optimized control of the Diesel Particulate Filter (DPF). In fact, the DPF, which is the assessed aftertreatment technology to reduce PM emissions below the limits, suffers from fuel consumption penalization or excessive exhaust system backpressure, as a function of the frequency of the regeneration process. On the other side, issues such as the impact of the higher ash content of biodiesel on the DPF performance have also to be better understood.

In the given scenario, an experimental study on a DEUTZ 4L off-road Diesel engine coupled to a DOC-DPF (Diesel Oxidation Catalyst-Diesel Particulate Filter) system is proposed in this paper. Experimental data have been gathered at the engine test bench of the University of Rome Tor Vergata to validate a model of the DPF, including ash related effects, and by adding a special sampling unit to collect particles. To that final aim, collected particulate has been examined via an experimental TGA (Thermo-Gravimetric Analysis) to measure ash content of particles emitted with B30 distilled biodiesel blend from Waste Cooking Oil (WCO), and compare it with a commercially available fossil fuel (B06). The multiple effects, in terms of lower regeneration activation energy, lower PM emissions and higher ash content, have been analyzed under repeated equivalent Non Road Transient Cycles (NRTCs), proving that the positive effects more than counterbalance the negative ones while using the B30 fuel.

Grey Box Control Oriented SCR Model

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Although SCR is a well established technology for many applications, it is still a field in which several new approaches and components are being tested. Control is a critical issue, as the conflicting requirements of NOx abatement and very small NH3 slip need to be met. Besides empirical solutions, model based controls have been proposed and are probably the technology of choice, also in view of the combination with monitoring functions. However, SCR models are typically based on First Principles (FP), i.e. on global chemical equations and reaction rate equations, and require precise calibration. Still, their performance for the control of dynamic processes is limited, or a high detail, much a priori information, e.g. on the actual SCR reaction rates, are needed. Frequently, this information is not available or reliable, and this is particularly true when components are changed or modified during the development process, so that typically a re-design is needed.

Against this background, this paper proposes a grey box approach, in which a simple first principle model is used as basic model, without assuming any special information on the physical parameters, (e.g. the above mentioned actual SCR reaction rates). On the contrary, these parameters, in particular the actual reaction rates are to be determined by an optimization technique using measurements under real operation conditions on a test bench with the engine and the whole exhaust after treatment system. In order to account for those effects which are not properly modeled by the simple first principle approach, an extension of the model using an output error model is shown to attain satisfactory performance for the complete operation ranges of the SCR. Finally, the whole model was experimentally validated in a dynamical test cycle and under different dynamical operating conditions.

NO_x Reduction with the Combinations on LNT and SCR in Diesel Applications

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Stricter emission limitations for NOx and particulates in mobile diesel applications will require the combinations of active aftertreatment methods like Diesel Particulate Filters (DPF), Selective Catalytic Reduction (SCR) with urea and Lean NOx Trap (LNT) in the 2010's. A new concept is the combination of LNT+SCR, which enables on-board synthesis of ammonia (LNT), which is then removed on the SCR catalyst. The main application for this kind system will be light-duty vehicles, where LNTs are already used and the low temperature deNOx is a main target. That combinatory system was investigated by developing and selecting PtRh/LNT and SCR catalysts for that particulate application, where the maximum temperature may reach 800°C and SCR should proceed without NO2 assistance. Pt-rich, PtRh/LNT with reasonable high loadings above 80g/cft resulted in a high NOx efficiency in the experimental laboratory conditions which created also on LNTs a higher NH3 concentration for the SCR unit. The SCR catalyst with copper as an active metal (Cu- SCR) showed the good durability up to 800°C and a wide operation window without the NO2 assistance. Fe-SCR and VSCR catalysts were more dependent on NO2, which is not present after LNT and DPF. An optimized concept had an air injection after LNT to keep SCR condition always lean side, where the SCR reaction was promoted by oxygen with a high selectivity without NH3 emissions. The simulations in reaction conditions and system design resulted in the proposals for the optimal design and main reaction mechanism.

The Evaporation and Spray Wall Interaction Behavior of Urea Water Solution (UWS) in Selective Catalytic Reduction (SCR) Systems of Modern Automobiles

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The Selective Catalytic Reduction (SCR) based on Urea-Water-Solution (UWS) injection is an effective technique to reduce the nitrogen oxides (NOx) emitted from the exhaust gases of diesel engines. The evaporation characteristics obtained for single Urea-Water-Solution (UWS) droplet using CFD code AVL FIRE is compared with experimental values. 3D numerical model of the injection of UWS and its interaction with the exhaust gas flow and exhaust tubing is developed. The model accounts for all relevant processes appearing from the injection point to the entrance of the SCR catalyst, especially during evaporation and thermolysis of droplets, hydrolysis of isocyanic acid in gas phase, heat transfer between wall and droplets and spray/wall-interaction. The spray wall deposition is found to be varying with temperature and residence time. The simulated results of variation of wall deposition, film deposition area, evaporated mass with respect to residence time are compared at temperatures 573K and 623K.

Experimental Investigation of Multi-In-Cylinder Pyrometer Measurements and Exhaust Soot Emissions Under Steady and Transient Operation of a Heavy-Duty Diesel Engine

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Future engine emission legislation regulates soot from Diesel engines strictly and requires improvements in engine calibration, fast response sensor equipment and exhaust gas aftertreatment systems. The in-cylinder phenomena of soot formation and oxidation can be analysed using a pyrometer with optical access to the combustion chamber. The pyrometer collects the radiation of soot particles during diffusion combustion, and allows the calculation of soot temperature and a proportional value for the in-cylinder soot density (KL).

A four-cylinder heavy-duty Diesel engine was equipped in all cylinders with prototype pyrometers and state of the art pressure transducers. The cylinder specific data was recorded crank angle-resolved for a set of steady-state and transient operating conditions, as well as exhaust gas recirculation (EGR) addition and over a wide range of soot emissions. A continuously operating gas sampling photo acoustic soot sensor was used for measuring the exhaust gas soot concentration.

A correlation of cylinder specific pyrometer measurements and corresponding tail pipe soot concentrations for a set of operating conditions was developed including variability of start of injection, engine load and speed, injection pressure and EGR. The correlation matches the in-cylinder soot concentration at the end of the combustion well with exhaust pipe soot emissions. In transient operation, the predicted soot emissions showed immediate response on changing engine load, speed and their combination whereas the soot concentration sampled in the exhaust stream was delayed due to gas mixing. The agreement between the two measurement methods was good. Furthermore a qualitative analogy between soot temperature and cylinder specific EGR rate was found.

Comparison of Particulate Matter Emissions from Different Aftertreatment Technologies in a Wind Tunnel

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Stringent emission regulations have forced drastic technological improvements in diesel after treatment systems, particularly in reducing Particulate Matter (PM) emissions. Those improvements generally regard the use of Diesel Oxidation Catalyst (DOC), Diesel Particulate Filter (DPF) and lately also the use of Selective Catalyst Reduction (SCR) systems along with improved engine control strategies for reduction of NOx emissions from these engines. Studies that have led to these technological advancements were made in controlled laboratory environment and are not representative of real world emissions from these engines or vehicles. In addition, formation and evolution of PM from these engines are extremely sensitive to overall changes in the dilution process. In light of this, the study of the exhaust plume of a heavy duty diesel vehicle operated inside a subsonic environmental wind tunnel can give us an idea of the dilution process and the representative emissions of the real world scenario.

The subsonic environmental wind tunnel used for this study is capable of accommodating a full-sized heavy-duty truck and generating wind speeds in excess of 50mph. It was specifically designed and built by West Virginia University (WVU) to characterize the exhaust plume emitted of heavy duty vehicles. A 3 dimensional gantry system allows spanning the test section and sample regions in the plume with accuracy of less than 5mm. The gantry system was equipped with engine exhaust gas analyzers and Particulate Matter (PM) sizing instruments.

The investigation involves three different heavy-duty Class-8 diesel vehicles equipped with after-treatment technologies, representative of legacy and modern truck fleets in the USA. The three vehicles investigated are representative of three emission regulation standards, namely a US-EPA 2007 compliant, a US-EPA 2010 compliant and a baseline vehicle without any after-treatment technologies as pre US-EPA 2007, respectively.

The testing procedure includes three different vehicle speeds: idling, 20mph, and 35mph.

The vehicles were tested on WVU's medium-duty chassis dynamometer, with the load applied to the truck reflecting the road load equation at the respective vehicle test speed. Wind tunnel wind speed and vehicle speed were maintained in close match during the entire test.

Results show that, the cross-sectional plume area increases with increase in distance away from tailpipe. Also indicating the cooling and dilution of the exhaust begins at close proximity to the tailpipe. The rate of cooling and dilution are greatest in early stages of the dilution process for the areas with high turbulence intensity, where strong mixing phenomena occurs. On the other hand, the core of plume observes a slower cooling and dilution rate. This difference is reflected in the PM formation and evolution of these two distinct regions, as shown by the particle size distributions and number concentrations.

Assessment of Low Levels of Particulate Matter Exhaust Emissions Using Low-Cost Ionization-Type Smoke Detectors

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Traditional smoke opacity measurement, performed on diesel engines during regular emissions inspections, sensitive primarily to larger particles of elemental carbon, is very little sensitive to nanoparticles and to semi-volatile “organic carbon” particles. For this reason, it no longer suffices as a high emitter detection tool for modern vehicles with a particle filter or for advanced low-emissions technology where semi-volatile organic particles are the dominant fraction of particulate matter. This paper investigates the potential of common low-cost ionization type smoke detectors, produced in mass quantities for fire detection in buildings, as a tool to measure particle emissions in vehicular exhaust. Two ionization chambers were used to measure both raw and diluted exhaust of various engines powered by diesel fuel and biofuels under laboratory conditions as well as on the road. Laboratory results suggest that the ionization chamber signal correlates best to total particle length, with correlation to number and mass dependent on particle size distribution. Particle filter regeneration events were clearly discerned from the ionization chamber readings. With detection limits on the order of 0.1 mg/m3 and 106 particles/cm3 in raw exhaust, the method appears to be sufficiently sensitive for inspection of vehicles equipped with particle filters and for preliminary measurements of particle emissions from modern engines.

Applicability of the Pegasor Particle Sensor to Measure Particle Number, Mass and PM Emissions

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The Pegasor Particle Sensor (PPS) has been earlier presented by Ntziachristos et al. (SAE Paper 2011-01-0626) as a novel small and robust instrument that can be directly installed in the exhaust line to measure exhaust particles without any dilution. The instrument is based on the electrical detection of aerosol. It is increasingly being used to measure exhaust particles from engines and vehicles with different exhaust configurations. In this study, a number of tests have been conducted using two sensors in parallel, one directly installed in the tailpipe and one installed in the CVS, side by side to the PM sampling filter. Aim of the study was to make recommendations on the proper use of the sensor and to check how the sensor signal compares to particulate mass, soot concentration, and particle number. A first finding is that external heating has to be provided to the sensor to avoid condensation. Second, very good linearity of the sensor signal is established for all three particle concentrations examined. The only exception was PM at very low concentrations, where positive adsorption artifacts determine the mass collected on the filter. Also, the original calibration provided with the sensor offers a satisfactory match with the absolute level of mass and number measured with other instruments. Improving this requires either specific calibration of the sensor for a particular emission source, or, at least, knowledge of the particle size distribution.

Development of In-Situ, Full Stream, Laser Induced Incandescence Technique for Measurement of Transient Soot Emissions

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The Laser Induced Incandescence technique (LII) is a sensitive optical method for reliable spatially and temporally resolved measurement of particulate matter (PM) concentration. This technique appears to be suitable for measurement of fast transient PM emissions, from diesel engines, which forms the main fraction of total emissions during standardized test cycles. However, the existing commercial LII devices require modifications in the exhaust gas flow, dilution, sampling cell, or it measure only in a partial stream. This article presents the development of a laser based optical setup - LII for rapid in-situ measurement of PM concentrations during the combustion process of a diesel production engine. The presented LII setup is suitable for direct in-situ, full stream, measurements of soot emissions without needs of dilution or a sampling cell. The focus of this paper is to measure static and transient PM emissions at tail pipe of an EURO 5 passenger car 2l diesel production engine by LII. A comparison of the LII approach with commercial devices based on photo-acoustic principle, opacity and filter blackening is also given. Results obtained from the fast in-situ LII device can help in better understanding of PM emissions and support dynamic emission modeling as well as control design for development of virtual PM sensors.

Real Time Emissive Behaviour of a Bi-Fuel Euro 4 SI Car in Naples Urban Area

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An experimental campaign was carried out to evaluate the influence of CNG and gasoline on the exhaust emissions and fuel consumption of a bi-fuel passenger car over on-road tests performed in the city of Naples. The chosen route is very traffic congested during the daytime of experimental measurements. An on-board analyzer was used to measure CO, CO2, NOx tailpipe concentrations and the exhaust flow rate. Throughout a carbon balance on the exhaust pollutants, the fuel consumption was estimated. The exact spatial position was acquired by a GPS which allowed to calculate vehicle speed and the traffic condition was monitored by a video camera. Whole trip realized by the vehicle was subdivided in succession of kinematic sequences and the vehicle emissions and fuel consumption were analyzed and presented as value on each kinematic sequence. Moreover, throughout a multivariate statistical analysis of sequences, the driving cycles characterizing the use of vehicle were identified.

Finally, comparison between regulated emissions of CNG and gasoline configurations was performed qualitatively by the analysis of speed and emission profiles belonging to the same cluster of cycles. Frequency distribution of mean values of CO2, CO, NOx emissions, and fuel consumptions, respectively with CNG and gasoline fuel type are presented. They are very well differentiated, both in the range of values than in the mode of frequency distribution. Particularly CO2 emissions relative to gasoline fuel show a range of higher values respect on CNG fuel. Related to CO emissions, values obtained with CNG fuel also result much low. Concerning NO emissions, the richer combustion occurring when CNG is fuelled, due to different ECU tuning respect to gasoline, discourages the production of NOx.

Moreover it was realized a statistical distribution analysis evaluating emission and fuel consumption mean values in each cluster. This analysis allows to compare emission and fuel consumption distribution between two different fuel types in the same traffic condition. To better underline difference due to fuel type, some statistical moments such as mean, standard deviation and range of regulated emissions are presented, cluster by cluster, to better evaluate the dispersion for each subgroup. The reducing effect computed in pair on each subgroup is clearly evident and repeatable.

Emissions of Light Duty Vehicle Tested under Urban and Extraurban Real-World Driving Conditions with Diesel, Animal Fat Biodiesel and GTL fuels

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Universidad de Castilla La Mancha

Regulated gaseous emissions and particle concentrations, with commercial diesel fuel, animal fat biodiesel and gas to liquid (GTL) fuel from a Low Temperature Fischer-Tropsch process, have been studied. Tests were carried out in a light duty vehicle (Nissan Qashqai, 110 kW, Euro 4) equipped with variable geometry turbocharger (VGT), cooled exhaust gas recirculation (EGR), common rail with split fuel injection strategy, diesel oxidation catalyst (DOC) and diesel particle filter (DPF). Vehicle tests were carried out at real-world driving conditions. Specific emissions, in g/km, were determined separately for two test circuits (urban and extraurban). Results show that the use of alternative fuels reduced THC and CO emissions compared to diesel fuel while only slight differences were observed in NOx emissions and in particle number concentration. However, since the vehicle was operated under different operating modes than those included in NEDC (out of the optimized zone of the engine map), specific emissions were generally different than those established in Euro 4 normative.

Low Ambient Temperature Cold Start Emissions of Gaseous and Solid Pollutants from Euro 5 Vehicles featuring Direct and Indirect Injection Spark-Ignition Engines

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Spark ignition (SI) engines are susceptible to excess emissions at low ambient temperatures. Direct injection leads to the formation of particulate matter (PM), and direct injection spark ignition (DISI) engines should show greater PM emissions at low ambient temperatures. This study compares excess emissions of gaseous and solid pollutants following cold start at a low ambient temperature and the standard test temperature. Euro 5 passenger cars were tested on a chassis dynamometer within BOSMAL's climate-controlled test chamber, according to European Union legislation (−7°C over the urban driving cycle (UDC), and at 25°C). Two vehicles were also tested over the entire New European Driving Cycle (NEDC). Emissions of regulated compounds and carbon dioxide were analyzed; particulate emissions (both mass and number) were also measured, all using standard procedures. Over the UDC, changes in emissions of hydrocarbons (HC), carbon monoxide (CO), and CO_2 were unequivocal; the situation for oxides of nitrogen (NO_x) was somewhat more complex. Over the entire NEDC, excess emissions were observed (though much larger for the UDC). The increase in CO_2 emissions over the entire NEDC was 17% for the MPI vehicle and 15% for the DISI vehicle. DISI particle number emissions increased by 50%; DISI particle mass by >600%. A simple mathematical correction for the difference in ambient temperature was applied to the results. Excesses are greatest following start-up, but persist for hundreds of seconds. The temperature of the intake air had a measurable effect on certain emissions, even after the engine had been running for some time.

Greenhouse Gas Emissions of MY 2010 Advanced Heavy Duty Diesel Engine Measured Over a Cross-Continental Trip of USA

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The study was aimed at assessing in-use emissions of a USEPA 2010 emissions-compliant heavy-duty diesel vehicle powered by a model year (MY) 2011 engine using West Virginia University's Transportable Emissions Measurement System (TEMS). The TEMS houses full-scale CVS dilution tunnel and laboratory-grade emissions measurement systems, which are compliant with the Code of Federal Regulation (CFR), Title 40, Part 1065 [1] emissions measurement specifications. One of the specific objectives of the study, and the key topic of this paper, is the quantification of greenhouse gas (GHG) emissions (CO2, N2O and CH4) along with ammonia (NH3) and regulated emissions during real-world operation of a long-haul heavy-duty vehicle, equipped with a diesel particulate filter (DPF) and urea based selective catalytic reduction (SCR) aftertreatment system for PM and NOx reduction, respectively.

The TEMS was additionally outfitted with an MKS MultiGas® 2030-HS high-speed FTIR to quantify NH3 and N2O, along with other compounds of interest, at a frequency of 5 Hz. One of the salient features of the study is the continuous measurement of N2O and NH3 concentrations at high temporal resolution while driving across the US.

A Mack heavy-duty Class8 tractor, powered by a MY 2011, 12.8 liter diesel engine, equipped with a DOC-DPF and a urea-SCR NOx aftertreatment system was used to transport the TEMS, and ancillary measurement systems. The study was conducted over a total distance of 2,450 miles driven between Morgantown, WV and Riverside, CA, with a gross vehicle weight (GVW) of 67,000 lbs. The chosen route represented varying topography and driving conditions that included the Appalachian

Mountains, flat regions of the mid-west, high altitudes of the Rocky Mountains and the busy highways of Southern California.

Results show the effect of road grade, ambient operating conditions, and on-board diagnostics (OBD) related to DPF and SCR aftertreatment systems on the GHG emissions and regulated constituents. Specifically, the results show the measured payload-distance specific CO2 emissions of a USEPA 2010 emissions-compliant Class 8 heavy-duty engine is higher than MY 2014 vehicle standards by 11% over the entire trip. The brake specific GHG emissions were lower than MY 2017 & later engine standards by a wide margin. However, the simulation tool (GEM) resulted in 13% higher CO2 emissions than measured over the entire trip. The brake specific NOx emissions were an order of magnitude higher when the engine was operating at altitudes greater than 5,500 ft.

Experimental Investigation on Use of Jatropha Oil Ethyl Easter and Diesel Blends in Small Capacity Diesel Engine

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Biodiesel in has gained great momentum in last few years and has been a subject of vast research all around the globe. Bulk of the research work carried out so far has been confined to production of methyl esters of vegetable oil that is known as biodiesel in the transesterification process. In the present study, jatropha oil ethyl ester (JOEE) was prepared using transesterification process with ethanol and KOH as a catalyst. The evaluation of important physico-chemical properties was carried and the properties were found within acceptable limits of ASTM/EN standards. A small capacity diesel engine was fuelled with different blends of JOEE and diesel and various performances, emission and combustion characteristics were evaluated. The results suggested that brake thermal efficiency was increased and emissions of carbon monoxide, hydrocarbons and smoke opacity were found lower for JOEE blend confirming better combustion due to the oxygenated fuel and higher cetane rating. However, an upward trend was observed in case of oxides of nitrogen for ethyl ester. The combustion studies suggested that in cylinder pressure in case of JOEE blends was lower as compared to diesel fuel and heat release analysis confirmed small ignition delay for JOEE diesel blends than diesel fuel. Therefore, 20% blend of JOEE in diesel may be recommended in an unmodified diesel engine to be directly applied which shall result in improved performance and combustion parameters and emissions of CO and HC at the penalty of marginal increase in NOx emissions.

Experimental Investigation of Orange Peel Oil Methyl Ester on Single Cylinder Diesel Engine

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The rising cost and exponential depletion of crude oil in international market has provided an opportunity for the researchers to evaluate the utilization and suitability of various renewable fuels. Amongst variety of alternative fuels, biofuels have the potential to mitigate the vulnerability and the adverse effects of use of fossil fuels. Vegetable/plant oil is better proposition as alternative fuel for diesel engine having much advantage over other alternative fuels. Orange oil from its peel has a huge potential and can be used as an alternate fuel at the most economical purchase rate. In the present investigation experiments were carried out to evaluate performance and emission characteristics of Orange peel oil methyl ester blends (OPOME) (10%, and 20% by volume) on unmodified diesel engine. The properties of these blends were found to be comparable to diesel and confirming to both the American and European standards. Engine performance (brake specific energy consumption, brake thermal efficiency) and emissions (CO, HC, NOx, and smoke density) were measured to evaluate the behavior of the diesel engine running on biodiesel and diesel. It has been found that at peak load condition the brake thermal efficiency of 20% blend of OPOME is higher than that diesel. Emissions of HC and CO were found to be reduced with increase in OPOME percentage compared to diesel confirming better combustion due to the oxygenated fuel. However, there was substantial increase in NOx in case of OPOME compare to diesel. From overall analysis it may be concluded that Orange peel oil biodiesel showed better performance and emission characteristics than that of diesel and used as a fuel in unmodified single cylinder diesel engine.

Investigations of Changes of the 2-Stroke Scooters Nanoparticles in the Exhaust- and CVS-System

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Nanoparticle emissions of two 2-stroke scooters were investigated along the exhaust and the CVS (Constant Volume Sampling) systems. Two configurations were tested: regular full-flow dilution configuration (denoted as “closed”) and also a modified sampling configuration (denoted as “open”).

The scooters represent two distinct modern technologies. One scooter had direct injection TSDI*) (Two-Stroke Direct Injection). The other had a carburettor. Depending on the technology, the scooters produce different kind of aerosols (state-of-oxidation and SOF content). Moreover, the scooters were operated with and without oxidation catalyst.

The tests were performed at two constant vehicular speeds (20 km/h and 40 km/h). The measuring procedures are those established during the previous research of the Swiss Scooter Network. The nanoparticulate emissions were measured using SMPS (Scanning Mobility Particle Sizer) and DC (Diffusion Charging) sensors.

The most important results are:

The changes of the particle size distributions (PSD) of the aerosol, along the exhaust and CVS systems, are influenced by the average gas temperature and particle count (PC) concentration, which result after the different dilution steps and cooling down in the connecting pipe.

The “open” variant of exhaust gas sampling has a dilution step, with unfiltered ambient air, directly after tailpipe. This stops agglomeration, decreases diffusion losses*) and increases nanoparticle (NP) concentration. There is also lower postoxidation of CO and HC. Some spontaneous condensates, due to the temperature drop, are postulated.

The “closed” variant exhibits stronger decrease of SMPS PCs, along the gas path, than in the open variant. This is due to the higher temperatures and concentrations in the closed system, which enable more intense agglomeration effects, thermophoresis-

and diffusion losses.

The NP concentrations are always higher in the “open” variant.

The type of sampling: “open” or “closed”, as well as the sampling position in the exhaust installation, significantly influence the measured nanoparticle emissions.

The authors recommend NP tailpipe sampling with strong “atmospheric” dilution and the closed CVS system for gaseous emission components. That would be best suited solution for possible legislated measurement systems of the nanoaerosol from 2-stroke gasoline engines, with lost oil lubrication.

Benchmark Comparison of Commercially Available Systems for Particle Number Measurement

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Measurement of particle number was introduced in the Euro 5/6 light duty vehicle emissions regulation. Due to the complex nature of combustion exhaust particles, and to transportation, transformation and deposition mechanisms, such type of measurement is particularly complex, and regression analysis is commonly used for the comparison of different measurement systems.

This paper compares various commercial instruments, developing a correlation analysis focused on PN (Particle Number) measurement, and isolating the factors that mainly influence each measuring method. In particular, the experimental activity has been conducted to allow critical comparisons between measurement techniques that are imposed by current regulations and instruments that can be used also on the test cell. The paper presents the main results obtained by analyzing instruments based on different physical principles, and the effects of different sampling locations and different operating parameters.

The main instruments that have been critically analyzed during this project are: Horiba MEXA 2000 SPCS Particle Counter installed on a CVS tunnel; AVL APC 489 installed directly on the exhaust gas flow; AVL Smart Sample 478 GEM 140 (Mini CVS tunnel) + AVL APC 489; Cambustion DMS 500 installed directly on the exhaust gas flow; AVL MicroSoot Sensor 483 installed directly on the exhaust gas flow. The tests have been carried out on a prototype vehicle equipped with a GDI engine, both under steady-state conditions and during the New European Driving Cycle (NEDC), while comparing the effects of different dilution factors, different engine calibration datasets, and different positions of the various instruments.

Dynamical Nonlinear Particulate Matter Estimation Based on Laser Induced Incandescence Measurements

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Measurements of transient emissions become more important due to the increasing contribution of transient operation to the total tail pipe emissions. While for many quantities measurement devices with response time in the range of few milliseconds exist, the same is not true for particulate matter(PM).

Pulsed Laser Induced Incandescence (LII) is widely used in experimental setups and may offer a viable approach also for production engines, but the specific nature of LII raises doubts on the quantitative precision achievable by the method, especially in transient operation. Indeed, there are two main problems in particular for dynamic measurements. On one side, the emitted laser power must be high enough to excite a sufficiently large number of particles within the observed area, but not as high to destroy them, and varying engine operating conditions imply changes in the number and size distribution of the particles as well. On the other side, during transients, flow conditions will vary, the particle flow may become less homogenous and changes in the gas velocity can make the time synchronization more difficult.

Against this background, a LII measurement system has been setup at the JKU in Linz. The LII measurement system has been setup with a high power laser system. Measurements of the particulate emissions have been recorded for a transient cycle using this setup, and in parallel the AVL Micro Soot Sensor and the AVL Opacimeter. As the paper shows, strong nonlinear relations prevent the use of simple correlation methods to parameterize the LII output to reconstruct the particulate flow, but by using a robustified polynomial approach a law could be determined which handles this task. The reconstructed results not only achieve the same dynamical performance and exactitude of the AVL Micro Soot Sensor, but also retain many dynamical effects which are qualitatively confirmed by opacity measurements.

Optical Studies about the Influence of Diesel Engine Operating Parameters on the Physicochemical Properties of Emitted Soot Particles

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This paper describes the influence of diesel engine operating parameters not only on the properties of the emitted soot particles but also on the whole engine chain of events, which was visualized by optical measurement techniques.

The vapor and liquid phase of the injected diesel spray was observed simultaneously by laser-induced exciplex florescence (LIEF) to analyze mixture formation up to the visible start of combustion. The soot formation and oxidation process was evaluated by detecting a spectral range of the soot luminescence and the OH radical. The electrical mobility particle diameter as well as the primary particle size of the emitted soot particles were analyzed by a Scanning Mobility Particle Sizer (SMPS) and by High-Resolution Transmission Electron Microscopy (HR-TEM). Finally, the results were combined to examine the influence of injection pressure, injection timing, boost pressure and engine speed on mixture formation, combustion and the properties of the engine out soot particles. All measurements were carried out on an optically accessible single-cylinder diesel engine.

The study shows a strong influence of injection pressure, injection timing and boost pressure as well as of engine speed on combustion, soot formation and oxidation and in particular on properties of the emitted diesel soot particles. Advanced injection and boost pressures as well as higher engine speeds lead to smaller primary particles and to smaller electrical mobility particle diameters and lower particle numbers. This is caused by the enhanced mixture formation resulting in a different soot formation and soot oxidation process during combustion. Different intensities of soot oxidation tends to affect smaller primary particle sizes for a SOI next to the TDC and cause smaller electrical mobility particle diameters and lower particle numbers for early injection events.

Detailed Morphological Properties of Nanoparticles from Gasoline Direct Injection Engine Combustion of Ethanol Blends

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Detailed properties of particulate matter (PM) emissions from a gasoline direct injection (GDI) engine were analyzed in terms of size, morphology, and nanostructures, as gasoline and its ethanol blend E20 were used as a fuel. PM emissions were sampled from a 0.55L single-cylinder GDI engine by means of a scanning mobility particle sizer (SMPS) for size measurements and a self-designed thermophoretic sampling device for the subsequent analyses of size, morphology and nanostructures using a transmission electron microscope (TEM). The particle sizes were evaluated with variations of air-fuel equivalence ratio and fuel injection timing. The most important result from the SMPS measurements was that the number of nucleation-mode nanoparticles (particularly those smaller than 10 - 15 nm) increased significantly as the fuel injection timing was advanced to the end-of-injection angle of 310° bTDC. In variation of fuel injection timing, no consistent fuel dependence was found for the total number of particles. The TEM morphology examination revealed the presence of those small nanoparticles, clearly discerned from large aggregate particles. Both nano-sized and large aggregate particles appeared to be agglomeration of a number of nearly-spherical primary particles, where the size of aggregate particles was dependent on the size of primary particles. In the TEM nanostructure examination, particles from gasoline combustion exhibited graphitic structures, regardless of fuel injection timing. However, the nanostructures of E20-derived particles were changed to amorphous as the injection timing was advanced to 310° bTDC. It was finally concluded that those results from SMPS and nanostructure analyses for the 310° bTDC injection timing are caused potentially by the increased amount of unburned hydrocarbons or volatile organics due to fuel impingement at that early fuel injection timing.

Characteristics of Exhaust Emissions from a Heavy-Duty Diesel Engine Retrofitted to Operate in Methane/Diesel Dual-Fuel Mode

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The need for a cleaner and less expensive alternative energy source to conventional petroleum fuels for powering the transportation sector has gained increasing attention during the past decade. Special attention has been directed towards natural gas (NG) which has proven to be a viable option due to its clean-burning properties, reduced cost and abundant availability, and therefore, lead to a steady increase in the worldwide vehicle population operated with NG. The heavy-duty vehicle sector has seen the introduction of natural gas first in larger, locally operated fleets, such as transit buses or refuse-haulers. However, with increasing expansion of the NG distribution network more drayage and long-haul fleets are beginning to adopt natural gas as a fuel. Traditionally, natural gas engines are operated over an Otto-cycle employing a stoichiometric combustion strategy, and using sparkplugs to ignite the fuel and a three-way catalyst (TWC) to mitigate emissions of NOx, CO as well as HC. Alternatively, combusting NG in a Diesel engine would result in higher combustion efficiencies, inherent to the Diesel-cycle, thus, reduce fuel consumption and therefore, further amplify the CO2 emissions benefits of NG.

In this regard, 'retrofit kits' have been developed in order to convert standard Diesel engines into Diesel-NG dual-fueled engines by taking advantage of the auto-ignition properties of Diesel fuel. These technologies basically substitute a given amount of energy delivered by the Diesel fuel with NG that is being injected into the intake-runners leading to the combustion chambers. The NG substitution rate primarily depends on engine operating modes (i.e. speed and torque) and specific engine calibrations and is seamlessly adjustable. Therefore, particulate matter (PM) as well as gaseous emissions are expected to differ when the engine is being operated in dual-fuel mode as compared to conventional diesel fuel operation only.

The primary objective of this study was to experimentally investigate the physical and chemical properties of the emissions products from a heavy-duty Diesel engine (HDDE) after conversion to Diesel-CNG dual-fueled operation.

To this aim, a 11.9L Mack AC 460P (MY 2005) HDDE equipped with a conversion kit for dual-fuel operation has been evaluated over the 13-mode European Stationary Cycle (ESC) and Federal Test Procedure (FTP) at West Virginia University's Engine and Emissions Research Laboratory (EERL). Particulate matter emissions were sampled using the gravimetric filter method and characterized in terms of particle number concentrations and size distributions utilizing a Differential Mobility Spectrometer (DMS) from Cambustion (model DMS-500). Data were collected using two different sampling systems, namely through a constant volume sampling system (CVS) and a custom-made double mini-dilution system using ejector-type dilutors allowing to sample directly from the exhaust stack. Results showed a significant reduction of oxides of nitrogen and carbon dioxide emission levels at the expenses of hydrocarbons and carbon monoxide which, on the contrary, increased drastically. Particulate matter emission levels experienced an increase when operating the engine in dual-fuel mode. This fact together with the increased emissions of hydrocarbons and carbon monoxide suggested a deterioration of the quality of combustion.

Prevention of Backflow in a intake pipe on two stroke SI engine on Handheld products

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Most of the handheld application are equipped with a Two stroke SI engine. The advantage of this engine are known but one of the problem of this application is the reliability of the filter. One of the main problem of this part is due to the backflow of the fuel.

A crankcase scavenge two stroke engine with piston controlled ports has inevitable backflow of inlet charge at low speed in case where the inlet port timing id designed to be suitable for high speed operation.

This paper describes an attempt that was made to prevent the backflow by a fluid device which has diode characteristics, namely fluid diode. The results of prevention of backflow, the effect on the acceleration and improvement of the delivery ration at low speed is provided showing the experimental data and field tests.

Turbocharging Approaches for Formula 1 2014

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The FIA regulations for Formula 1 Racing in 2014 bring a change in paradigm from naturally aspirated engines to turbocharged engines. This brings a technology into the prime class of Motorsports that has taken a dominant role in on-highway propulsion.

Formula 1 always has claimed the role of developing advanced technologies for motor vehicles that eventually would make it to customer cars. In that respect already implemented systems for energy recovery like KERS, now called MGU-K, i.e. motor-generator unit for kinetic energy, are complemented by a system for energy recovery for improved turbocharger response, which in the regulations is called MGU-H, i.e. a motor-generator unit for storing heat energy.

The green aspect is brought into racing by limiting the fuel rate to a maximum flow rate of 100 kg/h, which in turn puts emphasis on rigorously optimizing the engine system for efficiency, as this is the only way of getting more power out of the propulsion unit.

Among the numerous changes the new regulations bring for the new season, the presentation will focus on potential approaches regarding the interaction of the turbocharging system, its heat energy recovery system and the combustion engine for maximizing power output.

On-road Emission Factors of Particulate Matter Pollutants for Light-Duty Vehicles Based on Urban Street Driving Conditions

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An on-road sampling campaign was conducted on two major surface streets (Wilshire and Sunset Boulevards) in Los Angeles, CA, to characterize PM components including metals, trace elements, and organic species for three PM size fractions (PM10-2.5, PM2.5-0.25, and PM0.25).

Fuel-based emission factors (mass of pollutant per kg of fuel) were calculated to assess the emissions profile of a light-duty vehicle (LDV) traffic fleet characterized by stop-and-go driving conditions that are reflective of urban street driving.

Emission factors for metals and trace elements were highest in PM10-2.5 while emission factors for PAHs and hopanes and steranes were highest in PM0.25. PM2.5 emission factors were also compared to previous freeway, roadway tunnel, and dynamometer studies based on an LDV fleet to determine how various environments and driving conditions may influence concentrations of PM components.

The on-road sampling methodology deployed in the current study captured substantially higher levels of metals and trace elements associated with vehicular abrasion (Fe, Ca, Cu, and Ba) and crustal origins (Mg and Al) than previous LDV studies. The semi-volatile nature of PAHs resulted in higher levels of PAHs in the particulate phase for LDV tunnel studies (Phuleria, H. C., M. D. Geller, et al. (2006). “Size-resolved emissions of organic tracers from light-and heavy-duty vehicles measured in a California roadway tunnel.” Environmental Science & Technology 40(13): 4109-4118) and lower levels of PAHs in the particulate phase for freeway studies (Ning, Z., A. Polidori, et al. (2008). “Emission factors of PM species based on freeway measurements and comparison with tunnel and dynamometer studies.” Atmospheric Environment 42(13): 3099-3114).

With the exception of a few high molecular weight PAHs, the current study's emission factors were in between the LDV tunnel and LDV freeway studies. In contrast, hopane and sterane emission factors were generally comparable between the current study, the LDV tunnel, and LDV freeway, as expected given the greater atmospheric stability of these organic compounds. Overall, the emission factors from the dynamometer studies for metals, trace elements, and organic species are lower than the current study. Lastly, n-alkanes (C19-C40) were quantified and alkane carbon preference indices (CPIs) were determined to be in the range of 1-2, indicating substantial anthropogenic source contribution for surface streets in Los Angeles.

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