SAE NAPLES SECTION

ICE2011

10th International Conference on Engines & Vehicles

September 11-15 @ Capri, Napoli

abstracts

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ICE2011

10th International Conference on Engines & Vehicles

editors

Rolf D. Reitz & Bianca Maria Vaglieco

SAE International™

ICE2011

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SI Combustion Modeling	**Fabio Bozza** *Università di Napoli Federico II (Italy)* **Gianluca D'Errico** *Politecnico of Milan (Italy)*

Fuel Injection and Combustion Process: Experiments

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Alternative and Advanced Power Systems

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Fuels and Lubricants

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Gaseous Fuels	**Gautam T. Kalghatgi** *Saudi Aramco (Saudi Arabia)*
Non-traditional use of fuels in engines	**Carlo Beatrice** *Istituto Motori - CNR (Italy)*
Nonpetroleum Based Fuels & Lubricants	**Vincenzo Mulone** *University of Rome Tor Vergata (Italy)* **Vittorio Rocco** *University of Rome Tor Vergata (Italy)*

Powertrain Technology

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Exhaust Aftertreatment, Emissions and Noise

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Preface

The growing transportation sector is considered to be one of the main reasons for failing to meet Kyoto emissions targets. In combination with the emission limits and new standards, the already very low CO_2 emission levels have to be further reduced in order to meet the Kyoto targets. Manufacturers of vehicles are under significant pressure to improve efficiency and to reduce exhaust emission levels. While dwindling fuel reserves and greenhouse gas emissions are motivating factors behind long-term interest in greater efficiency, ambient air quality standards and associated public health concerns have spurred the call for lower emissions. In order to achieve these objectives, new Internal Combustion Engine and Hybrid-Electric Vehicle technologies are being developed.
ICE2011, the 10th International Conference on Engine & Vehicles has been organized by the Istituto Motori – National Research Council of Italy (CNR), the Engine Research Center of University of Wisconsin-Madison and SAENA, the Italian Section of SAE International, to provide the ideal setting for interactions among representatives from research centers, academia and industry that are involved in the engine and vehicles fields.
To encourage intensive discussions about new results and research approaches for engine, vehicle and propulsion devices, 170 papers from around 30 countries have been selected after a peer review process conducted according to stringent SAE int. standards. These contributions cover a wide variety of aspects, from advanced internal combustion engines to hybrids vehicles, from liquid and gaseous fuels to alternative fuels, from innovative experimental diagnostics to the newest numerical methodologies for modeling, simulation and control. In addition, experts in these topics have been invited to deliver plenary lectures on the state of the art and future development trends for the disciplines associated with the conference.
We are very grateful to SAE Int. and in particular Gina Brandon, for their precious help and kindness.
We also thank all the Session and Sub-session Organizers for their availability and hard work, as well as all the authors and reviewers for their contributions. In addition, special thanks are due to the conference sponsors for their generous financial support.
Finally, a special note of appreciation is due to all those who contributed their enthusiasm, effort and time to the organization of ICE2011.

Bianca M. Vaglieco and Rolf D. Reitz

Plenary Lectures

Globally Harmonized Standards for Complex Systems

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

Policymakers and technologists alike are focusing on intelligent systems and electric-mobility as critical elements of safe and sustainable transportation. For effective implementation of such a highly integrated and complex system, standards are needed for the vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-grid (V2G) interfaces. Historically, national or regional standards were sufficient to meet the needs of the automotive industry. However, as the industry increasingly relies onglobal solutions, the global interface of technical standards is becoming evermore important. SAE International?s long and successful track record of developing timely and effective standards for the mobility industry is increasingly in demand by industry and governments around the world. This talk will explore the current state of standards for complex systems and the status of global harmonization efforts.

Powertrain Evolution: from Conventional to Alternative

L. Bernard
CRF / Fiat Powertrain (Italy)

Road transportation accounts for less than 23% of global GHG emissions, but it is assumed that independent personal mobility will continue to be a "must" in tomorrow's society. Therefore there is a strong request to reduce vehicle emissions, not only on a tank-to-wheel basis, but also taking into account "Life Cycle" emissions, from energy production to vehicle recycling. During the last fifteen years the automotive industry succeeded in reducing fleet average CO_2 emissions by more than 20%, with Fiat Group as leader in Europe in terms of lowest emissions values in the last four years.
We believe that small steps in emissions reduction, but in large scale of diffusion, are more efficient for global emissions reduction than big steps in very small scales. The renewal of the circulating fleet would, therefore, be the most efficient means of reducing overall emissions with an immediate effect.
In terms of noxious emissions, starting from the 90's the regulated levels of these emissions have been reduced by 50% every four to five years and the trend of the next years is to set regulated emissions values that will be more "Fuel Neutral". This means that there will be no significant difference in noxious emissions produced by gasoline, Diesel, CNG and LPG fuelled vehicles, independently from their intrinsic efficiency and CO_2 emission levels.
Considering the more conventional propulsion technologies, the most efficient thermodynamic cycle currently used for vehicle propulsion is the Diesel one, with about 20% better efficiency (and CO_2 emissions) than the alternative Otto cycle (e.g. gasoline engine). The lowest carbon-content, readily available, fuel is the Natural Gas (Methane) which results in around 23% lower CO_2 emissions compared to gasoline when used in conventional, Otto cycle, engines. New gasoline engine technologies, such as Electronic Valve Control (MultiAir), Downsizing, Direct Fuel Injection and Turbo-charging, render the modern gasoline engine very competitive in terms of CO_2 emissions towards the conventional Diesel and Natural Gas (CNG) engines. The introduction of these, available, new Spark Ignition engine technologies in CNG-fuelled vehicles further increases its intrinsic low-carbon benefit.
Alternative propulsion technologies, like Hybrid Electric Vehicle (HEV) reduce energy waste in particular city traffic conditions, but they are characterized by

still higher costs. The Plug-in Hybrid Electric Vehicles (PHEV) allow some vehicle autonomy in electric mode, but the energy storage system is more costly and they require electric energy re-charging facilities. The Battery Electric Vehicle (BEV) is a Zero Local Emissions vehicle but its energy storage capacity is still low and has a even higher cost.

Alternative fuels, in addition to Natural Gas and including bio-fuels, are already available or can be developed in the future with more efficient processes in comparison to the current first generation. The well-to-wheel CO_2 emissions analysis must however drive us in selecting the most efficient alternative fuel or energy source for the tomorrow propulsion systems.

Currently there is no single propulsion technology which can cure the global emissions problem in very short terms; the emissions issue, however, is actual and urgent and, therefore, every practical measure must be taken very soon. An intelligent mix of available and affordable technical solutions can, however, guarantee a significant leap forward.

Enhancing Real-World Benefits of the HCCI Engine: from Management of the Near-Wall Conditions to Vehicle Hybridization

Z. Filipi
The University of Michigan (USA)

Homogenous Charge Compression Ignition (HCCI) engines offer unparalleled potential for achieving high fuel efficiency while virtually eliminating NOx and soot emissions from the exhaust. However, due to minimum thermo-kinetic requirements for auto-ignition and excessive rates of pressure rise, the operability range of HCCI is limited. Extending the operating range is essential for achieving desired fuel economy improvements at the vehicle level. The integration and optimization of the powertrain system also play a role. The first part of this presentation offers the fundamental insight into possibilities for extending the operating range of the practical gasoline HCCI engine, and addresses the impact of Combustion Chamber Deposits (CCD). This is followed by a system-level study investigating the potential synergy between the HCCI technology and hybridization of the powertrain for a passenger car.

Establishing and subsequently improving the HCCI operating limits requires deep understanding of the thermal conditions in the cylinder. The early research has characterized the heat transfer process in the HCCI engine using experiments with heat flux probes mounted on both the cylinder head and the piston, and indicated an extraordinary sensitivity of burn rates to combustion chamber wall temperatures. In-depth studies led to a discovery of the effect of the combustion chamber deposits on near-wall phenomena and HCCI combustion. It is shown that peak burn rates in a fully conditioned combustion chamber, with equilibrium deposit thickness between 50-120 micrometres, can increase as much as 50%. Investigating the basic mechanism of this effect, and quantification of the impact on HCCI combustion and operating range, is necessary for developing a practical HCCI concept suitable for market introduction. Characterization of deposit properties and a methodology for in-situ measurements of CCD thickness enables dealing with this source of variability with a control system. In addition, full understanding of the deposit growth and its effect on HCCI combustion provides guidance for determining a desirable thermal barrier on the wall from the HCCI range standpoint.

Next, the focus shifts to the vehicle system level and real-life fuel economy benefits of HCCI. Looking at the big picture, HCCI operation significantly improves fuel efficiency at part load, while hybridization aims to reduce low load/low speed operation. Therefore, a key question arises: are the effects of these two technologies synergistic or overlapping? A simplified reasoning can lead to many pitfalls. Instead, a predictive Hybrid Electric Vehicle simulation is generated to enable a systematic analysis under realistic driving conditions. Three hybrid electric vehicle (HEV) configurations are explored, and knowledge gained through the investigation is used to propose a novel supervisory control strategy that maximizes benefits of combining a parallel “mild” HEV configuration with a dual-mode, SI-HCCI engine. The idea is to use the flexibility offered by HEV to maximize the time spent in the HCCI operating region, and minimize SI-HCCI mode transitions. The results provide a quantitative assessment of benefits and create a compelling case for a cost-effective e-HCCI solution for passenger car applications.

Gasoline-diesel “cocktail” – a potent recipe for cleaner, more efficient engines

R.D. Reitz, R.M. Hanson, D.A. Splitter, S.L. Kokjohn
Engine Research Center, University of Wisconsin-Madison (USA)

Diesel and gasoline fuels both bring unique assets and liabilities to powering internal combustion engines. The present research adopts “fast-response fuel blending,” in which the fuel injection is programmed to produce the optimal gasoline-diesel mix based on real-time operating conditions by blending the fuels within the combustion chamber. The strategy has been called Reactivity Controlled Compression Ignition (RCCI) and has been shown to allow a diesel engine to produce significantly lower NOx and Particulate Matter (PM) pollutant emissions than conventional engines, with up to 20% greater fuel efficiency as well.

The RCCI strategy has been implemented with port fuel injection to provide a premixed, less reactive fuel mixture (e.g., gasoline) using a conventional low-pressure, low-cost injection system. This is combined with optimized multiple low-pressure, in-cylinder higher-reactivity-fuel injections (e.g., diesel). With RCCI the engine operates at much lower combustion temperatures because of the improved control – as much as 40 percent lower than conventional engines – which leads to far less energy loss from the engine through heat transfer, thus increasing engine thermal efficiency. In addition, the customized fuel preparation controls the chemistry for optimal combustion, leading to less unburned fuel energy lost in the exhaust, and also fewer pollutant emissions being produced by the combustion process.

The development of the blending strategy was guided by advanced computer simulation models. As summarized in Fig. 1, the best results to-date have achieved as high as 59% percent thermal efficiency in a single-cylinder heavy-duty experimental test engine. The blending strategy can also be applied to automotive gasoline engines (GDI), which usually average a much lower 25% thermal efficiency. Here, the potential for fuel economy improvement is even larger than in the higher efficiency diesel engine.

In addition to high fuel efficiency, RCCI has been demonstrated to meet the US EPA’s 2010 NOx and PM emissions regulations without the need for exhaust after-treatment. Thus, RCCI can potentially displace use of selective catalytic reduction, in which the chemical urea (a second “fuel”) is injected into the exhaust stream to reduce NOx emissions. Other strategies, such as using large amounts of recirculated exhaust gas (EGR) to lower combustion temperatures to reduce NOx, can lead to high

PM. In this case, ultra-high high-pressure fuel injection is generally needed to reduce soot formation in the combustion chamber. This is not required with RCCI.
Exhaust after-treatment methods can be expensive and logistically complicated, and only address cleaning up emissions, not increasing fuel efficiency. The RCCI in-cylinder fuel blending strategy is less expensive and less complex, can use widely available fuels, and addresses both emissions and fuel efficiency at the same time. Application of the RCCI technology to vehicles does require separate tanks for both the diesel and gasoline fuels – but so does urea, which is carried in a separate tank. However, RCCI has also been successfully demonstrated using just one fuel, but where the direct injected fuel stream is doped with small quantities of cetane improver. In this case, the amount of ignition additive required is less than the urea needed for SCR technologies.

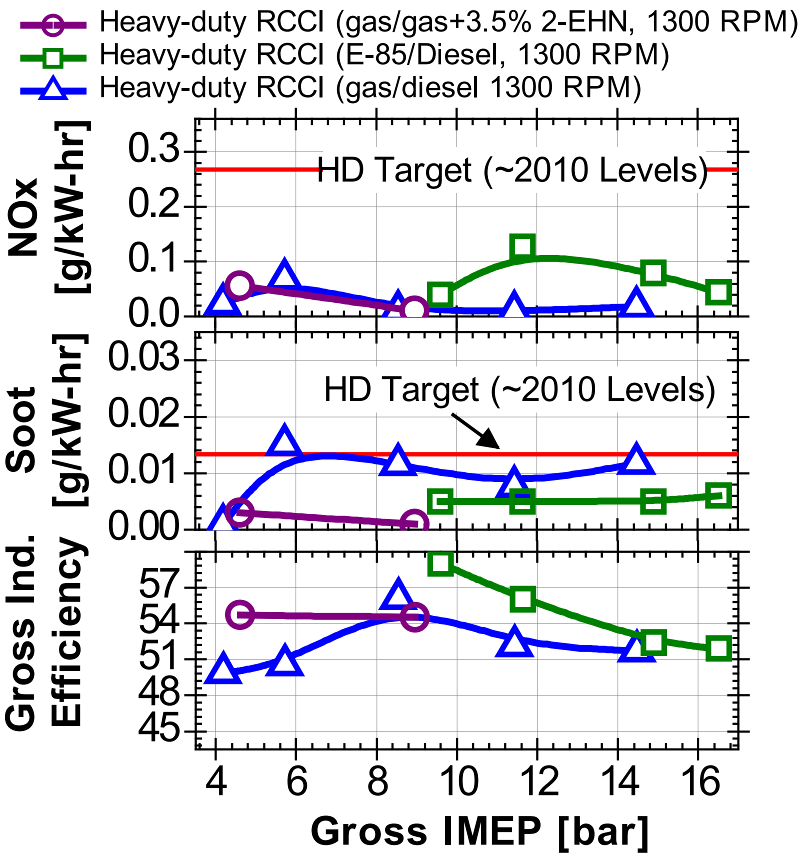

Figure 1 RCCI NOx and PM emissions and thermal efficiency as a function of engine load for a variety of fueling strategies in a heavy-duty diesel engine (fuels: premixed gasoline/DI diesel; premixed 85% ethanol-15% gasoline/DI diesel; premixed gasoline/DI gasoline doped with 3.5% 2-ethyl-hexyl-nitrate. Note that the 2-EHN amount is less than 0.5% of the total fueling rate).

Partially Premixed Combustion, PPC, - the next step after HCCI

B. Johansson
Lund University (Sweden)

A large faction of the fuel burned in the world is used in internal combustion engines. Traditionally there has been a trade-off between the locally harmful components and CO2 but some fifteen years ago IC engine combustion had a breakthrough with the usage of low temperature combustion, often called HCCI. For the first time it was possible to combine the high efficiency combustion from the diesel engine with ultra low emission of NOx and PM without catalytic after treatment. The presentation will start by showing some results with HCCI and discuss why HCCI should be applied and what the limitations of HCCI are.

Since HCCI have some severe limitations in practical operation, variations of the low temperature concept are studied. One such is Partially Premixed Combustion, PPC. With PPC the cylinder charge should not be fully homogeneous at the start of combustion but rather have a suitable stratification. This gives a spread in reactivity and hence a moderated burn rate. It will be shown that PPC can be generated with two injections in a more or less standard diesel engine geometry. With more fuel in the first, early, injection the charge is more homogeneous and the burn rate will be (too) high. With more fuel in the second injection, close to TDC, the combustion resembles a classical diffusion controlled process with a long slow post oxidation giving poor fuel efficiency. With the correct moderation between the two injections a ideal burn rate profile can be generated, resulting in very high indicated efficiency, up to 57%. In order to get the correct stratification at combustion start, the fuel reactivity and injection process must be matched. It will be shown that the best results are generated with a fuel having properties close to regular gasoline.

A U.S.A. perspective on vehicle electrification: Progress and challenges related to infrastructure and technology for vehicle-to-grid systems

G. Rizzoni
Center for Automotive Research, The Ohio State University (USA)

There is perhaps no better symbol of the twentieth century than the automobile. It is the dominant means of transport aspired to throughout the world. However, as demand for mobility continues to rise around the world, environmental and energy problems are rapidly making transportation as we know it unsustainable for our society. Thus, the role of the automobile in the future needs to be rigorously re-examined. Before looking ahead at how future energy needs might be met, the current state and a glimpse of the recent past are briefly analyzed: transportation systems, their development, and the needs established by the society that motivate the continuous expansion of such systems is outlined.

This presentation focuses on the use of electricity as a transportation energy source, and outlines how new and existing technologies could change work and driving patterns resulting in a different mix of vehicles and in a communication architecture serving as the backbone of the interaction between vehicles and utility grid. It is clear that embedded systems will play a prominent role in this development, and the aim of this presentation is to outline such possibilities.

Alternative fuels for transportation – The quest for the silver bullet...

T. Wallner
Argonne National Laboratory, Energy Systems Division (USA)

This presentation focuses on promising alternative fuels and propulsion systems from a U.S. perspective and attempts to shed light on current and anticipated trends. For more than a century almost exclusively crude oil based fuels have been used in the transportation sector worldwide. Only recently, mainly driven by environmental concerns, issues of dependence on foreign oil as well as related national security questions and in light of steadily increasing fuel prices, governments around the globe have started introducing alternative fuel road maps. Aside from a general push towards more efficient vehicles these roadmaps almost uniformly consist of increased production and utilization of alternative, domestically produced fuels such as ethanol and biodiesel as well as extended electrification of the vehicle fleet. Given that approx. 60% of energy is consumed in the light-duty sector, major drivers for wider utilization of alternative fuels, such as the Renewable Fuels Standard and E15 waiver for light-duty vehicles MY2001 and newer are identified, and actual trends in the U.S. vehicle fleet are analyzed. Further, information on market penetration and trends of alternatives such as CNG, LPG, and E85 and electricity are provided. Finally, barriers and challenges possibly delaying the introduction and success of alternative fuels such as lack of infrastructure are highlighted. Considering the wide range of consumer requirements, increasing cost of conventional fuels and challenges any new technology faces it appears likely that a larger variety of alternative fuels and powertrain solutions will be entering in the market place posing the question whether the quest for a silver bullet can be successful or whether a sustainable transportation scenario consists of multiple solutions.

Implications of internal combustion (IC) engine development trends for future fuels

Gautam T. Kalghatgi
Saudi Aramco (Saudi Arabia)

The primary development trend in IC engines is towards increasing efficiency. This has to be achieved while meeting emissions requirements, which could become even more stringent than they currently are. At the same time cost and complexity have to be kept in check.

Spark Ignition (SI) Engines: (SAE Paper# 2005-01-0239). Measures aimed at increasing the efficiency of SI engines such as downsizing and turbocharging lead to an increase in the pressure inside the cylinder for a given temperature. This will make knock more likely. The fuel needs to have sufficient anti-knock quality, measured by a combination of Research and Motor Octane Numbers, RON and MON, to enable such engines to run at their designed efficiencies. The RON and MON scales are based on primary reference fuels (PRF) whose autoignition chemistry is very different from that of practical fuels. As pressure increases for a given temperature, practical fuels become more resistant to knock compared to PRF. The result is that historically since the 1930s, as engines have become more efficient, the importance of MON has declined. Indeed in most modern cars for a given RON, a lower MON fuel has more resistance to knock. However current fuel specifications assume high MON to be important for knock resistance of the fuels. Thus in the U.S., anti-knock quality is defined by (RON+MON)/2 while in Europe there is a minimum MON specification of 85. This already has a distorting effect in the sense that refineries are spending more money and energy in making fuels that are arguably less suited for modern engines. This mismatch between fuel specifications and engine requirements will get more marked as engines become more efficient and fuel specifications will need to be changed to reflect the appetites of modern engines. Future turbocharged engines will also be more susceptible to pre-ignition which could then lead to extremely violent knock – superknock. Fuel effects on these abnormal combustion phenomena will need to be studied.

Compression Ignition (CI) Engines: In diesel engines NOx can be reduced by low-temperature combustion while soot can be reduced by promoting more pre-mixed combustion. However, diesel fuel ignites soon after injection into the cylinder making it very difficult to get premixed combustion. Indeed, the technology that makes diesel engines expensive and complicated is aimed at overcoming the difficulty presented by the low ignition delay of the diesel fuel e.g. high injection pressures. Recent work has shown that gasoline-like fuels that are resistant to autoignition make it significantly easier to achieve low NOx, low soot CI combustion. Moreover compared to today's gasolines the optimum fuel could have much lower octane number (RON 75-85) and lower volatility. In CI engines using such fuels, the injection system would have a low injection pressure, comparable to that of a direct injection SI engine and the after-treatment focus would be on HC and CO reduction rather than NO_x reduction. The engine would be at least as efficient, if not better, than current diesel engines. Thus future high efficiency CI engines could be simpler and cheaper than current diesel engines and prefer fuels that are easier to make than current fuels (e.g. SAE Paper#s 2007-01-006, 2010-01-2198, 2010-01-2206, 2010-01-0607).

A Future Fuels Scenario: In this long-term scenario, there will be a minority (40%?) of high RON / low MON fuels for efficient SI engines. Gasoline fuel specifications need to be brought in line with the requirements of modern engines. Components such as ethanol and isooctene would be important. The majority of the fuel (60%?) would be for the more efficient CI engines but would have a RON of 75-85 with no restrictions on fuel volatility. There would be little requirement for today's diesel fuels. Common fuel components could be used for both SI and CI engines increasing fuel blending flexibility. Current biodiesels with their high cetane numbers would be less attractive. The high cetane number of current gas-to-liquids (GTL) will not have a premium. The heavier components in the oil barrel need to be cracked but not upgraded.

High Performance from Small Engines – Boosting Systems and Combustion Development Methodology

C. Schernus
FEV Motorentechnik GmbH (Germany)
P. Adomeit, J. Ewald, S. Wedowski, A. Sehr, R. Weinowski
FEV Motorentechnik GmbH (Germany)

Future CO_2 legislation puts additional pressure on automotive manufacturers in developing more efficient powertrains. While hybridization of powertrains has its largest benefits in urban driving, its contribution to improve the mileage in highway driving is minimal. Apart from reducing vehicle rolling and wind resistance, the combustion engine efficiency plays a major role in lowering green house gas emissions in these driving conditions.
Aiming at fuel and cost efficient prime movers, downsizing of gasoline engines has been and still is a key technology. It combines the advantages of proven exhaust aftertreatment techniques with high power density. However, driving the specific torque and power higher and higher, new challenges relate to boosting systems, irregular combustion and oil dilution. This publication gives an overview about the research and development methodology involved to create high performance and highly efficient power plants for the next step of downsizing gasoline engines, which include experimental and computational analysis of pre-ignition propensity, mixture preparation and in-cylinder charge motion, but also turbocharging and EGR concepts.

Efficient Emission Reduction for Diesel Passenger Cars

P. Joachim
Centro Studi Componenti per Veicoli - Robert Bosch S.p.A. (Italy)

In order to comply with continuously increasing requirements from both, emission legislation and fuel economy enhancement, modern Diesel engines for passenger cars still offer a variety of measures, some of which will have to be employed in combination. Focus of this presentation is the importance of a highly flexible fuel injection system and an optimised injection strategy as direct measures to improve both, tailpipe emission as well as vehicle fuel economy. These improvements enable the introduction of additional indirect, very effective measures for fuel consumption reduction, such as downsizing and downspeeding, as well as such for simultaneous NOx-reduction, such as active $DeNO_x$-measures. Introduction of $DeNO_x$ introduces an additional degree of freedom in the system layout. This in turn can be used to upgrade the EU4/EU5 system basis to the targets for fuel consumption and emission at the lowest modification effort. Bosch Diesel injection technology and optimised combustion systems along with advanced control functionalities as the cylinder pressure based engine management inside the Bosch ECU pave the way to achieve the goal of fuel efficient emission reduction. Incorporating further indirect measures as hybrid drives will help to foster the Diesel on its position as powertrain with lowest CO_2 and an attractive total-cost-of-ownership.

Fuel Injection and Combustion Process _Modeling

Fuel Injection and Combustion Process _Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Modeling of Auto-Ignition and Combustion Processes for Dual-Component Fuel Spray

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Auto-ignition and combustion processes of dual-component fuel spray were numerically studied. A source code of SUPERTRAPP (developed by NIST),which is capable of predicting thermodynamic and transportation properties of pure fluids and fluid mixtures containing up to 20 components, was incorporated into KIVA3V to provide physical fuel properties and vapor-liquid equilibrium calculations. Low temperature oxidation reaction, which is of importance in ignition process of hydrocarbon fuels, as well as negative temperature coefficient behaviour was taken into account using the multistep kinetics ignition prediction based on Shell model, while a global single-step mechanism was employed to account for high temperature oxidation reaction. Computational results with the present multi-component fuel model were validated by comparing with experimental data of spray combustion obtained in a constant volume vessel. The results showed a good agreement in terms of spray tip penetration, liquid length, ignition delay and so on, for several kinds of dual-component fuels. Additional investigation into a combustion control methodology using dual-component fuel, which aims to mitigate combustion rate of premixed charge, was performed. Consequently, the feasibility of this approach was confirmed.

A Numerical Model for Flash Boiling of Gasoline-Ethanol Blends in Fuel Injector Nozzle

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Fuels are formulated by a variety of different components characterized by chemical and physical properties spanning a wide range of values. Changing the ratio between the mixture component molar fractions, it is possible to fulfill different requirements. One of the main properties that can be strongly affected by mixture composition is the volatility that represents the fuel tendency to vaporize. For example, changing the mixture ratio between alcohols and hydrocarbons, it is possible to vary the mixture saturation pressure, therefore the fuel vaporization ratio during the injection process. This paper presents a 1D numerical model to simulate the superheated injection process of a gasoline-ethanol mixture through real nozzle geometries. In order to test the influence of the mixture properties on flash atomization and flash evaporation, the simulation is repeated for different mixtures characterized by different gasoline-ethanol ratio. The Homogeneous Relaxation Model (HRM) is used as non-equilibrium two-phase model. As equation of state, the Peng Robinson equation is considered. Non-ideal thermodynamic properties are considered for the gasoline-ethanol blends. About the gasoline, a binary surrogate is used. The thermodynamic saturation properties of the multi-component blends are calculated by using fugacity and standard mixing rules for the cubical equation of state. The proposed 1D model is validated against experimental data available in literature. The simulation results reveal as the azeotropic behavior of the mixtures characterized by a medium-low ethanol concentration affected the mixture superheating degree influencing the flash evaporation and effervescent atomization outside the nozzle exit. These results can be used to improve initial condition for 3D CFD Lagrangian spray simulations especially when the spray targeting plays a fundamental role as for the Gasoline Direct Injection (GDI) engine.

Numerical Prediction of Erosive Cavitating Flows in Injection Equipment

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The paper demonstrates the capability of the commercial Computational Fluid Dynamics (CFD) code AVL FIRE to predict erosive effects due to cavitation. Such flows are of interest within the automotive and other internal combustion (IC) related industries using fuel injection components. Ability to predict such internal flows through CFD allows for improved engine efficiency, decreased emissions and shorter development cycles. Accurate modeling of cavitating flows is a prerequisite for the prediction of erosion effects and is described here. Driving force for erosive damage are the implosions of the bubbles generated due to cavitation and thereafter collapsing on the surface of the exposed material. Therefore, prediction of vapor generation and accurate transport of the bubbles are crucial. Investigated injector featured a single injector body in combination with two different needle (i.e. plunger) designs. The shape of the needle governed the nature of the flow through the injector. The fluid flow through the two different setups investigated in this study portrayed strong variance in flow aggressiveness leading to substantially differing erosion probability. First needle design showed practically no erosion damage on the needle surface, whereas the other showed strong damage. As a direct consequence, the durability of the first needle was proven superior to the latter. Presented numerical results are consistent with the experimental evidence for both, needle surface and injector body surface. Good agreement proves the applicability of the utilized numerical tool in the early design stage of injection components to distinguish between “safe” and “un-safe” component designs in terms of erosion probability. Consequently durability, efficiency and the emissions of considered engine configurations can be controlled.

Nozzle Flow and Cavitation Modeling with Coupled 1D-3D AVL Software Tools

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The paper is devoted to the coupled 1D-3D modeling technology of injector flow and cavitation in diesel injections systems. The technology is based on the 1D simulation of the injector with the AVL software BOOST-HYDSIM and 3D modeling of the nozzle flow with AVL FIRE. The nozzle mesh with spray holes and certain part of the nozzle chamber is created with the FIRE preprocessor. The border between the 1D and 3D simulation regions can be chosen inside the nozzle chamber at any position along the needle shaft. Actual coupling version of both software tools considers only one-dimensional (longitudinal) needle motion. Forthcoming version already includes the two-dimensional motion of the needle. Furthermore, special models for the needle tip contact with the nozzle seat and needle guide contact with the nozzle wall are developed in HYDSIM. The co-simulation technology is applied for different common rail injectors in several projects. It proved to be an efficient and user-friendly engineering tool. An example of piezoelectric common rail injector with a minisac nozzle is presented. Based on it, different numerical and technical aspects of the nozzle flow and cavitation modeling are discussed.

Numerical Simulation of Hollow-Cone Sprays Interacting with Uniform Crossflow for Gasoline Direct Injection Engines

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The interaction of fuel sprays with in-cylinder air flow is crucially important for the mixture preparation and subsequent combustion processes in gasoline direct injection (GDI) engines. In the present work, the experimentally validated computational fluid dynamics (CFD) simulations are performed to study the dynamics and physical insight of hollow-cone sprays interacting with a uniform crossflow. The basis of the model is the standard Reynolds-averaged Navier-Stokes (RANS) approach coupled to the Lagrangian treatment for statistical groups (parcels) representing the physical droplet population. The most physically suitable hybrid breakup models depicting the liquid sheet atomization and droplet breakup processes based on the linear instability analysis and Taylor analogy theory (LISA-TAB) are used. Detailed comparisons are made between the experiments and computations in terms of spray structure, local droplet diameter and velocity distributions. The computational results reveal the important features of the hollow-cone fuel spray in crossflow: the spray axis deflection by the crossflow is identified; the small droplets in the spray are displaced by the crossflow and transported to the downwind side; the vortical structure of the spray on the impacted side is significantly suppressed; there is a blockage effect of the spray on the crossflow in the near-nozzle field, and the counter-rotating vortex pair (CVP) owing to the interaction between the crossflow and the fuel spray is clearly captured. Furthermore, test cases with different crossflow velocities and at elevated ambient temperature are carried out to study the effects on spray characteristics and mixture formation. With higher crossflow velocity, the results show that the development of CVPs become slowly along the flow field, the secondary breakup is enhanced, and therefore a more uniform spray with smaller mean droplet diameter is produced. Additionally, the cumulative fuel vapor mass increases and the low temperature field within the normal spray cone shrinks, which means that the fuel/air mixing, fuel vaporization, and air utilization could be improved in the combustion chamber of GDI engines.

Lattice Boltzmann Simulation of a Cavitating Diesel Injector Nozzle

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The onset of cavitating conditions inside the nozzle of diesel injectors is known to play a major role on spray characteristics, especially on jet penetration and break-up. In this work, for the first time a Direct Numerical Simulation (DNS) based on the Lattice Boltzmann Method (LBM) is applied to study the fluid dynamic field inside the nozzle of a cavitating diesel injector. The formation of the cavitating region is determined via a multi-phase approach based on the Shan-Chen Equation of State and its most recent enhancements. The evolution of cavitation bubbles is followed and the characteristic numbers, i.e. Cavitation Number (CN) and discharge coefficient (Cd) are evaluated. The results obtained by the LBM simulation are compared to both numerical and experimental data present in literature.

Numerical Investigation on the Spray Characteristics and Combustion Process in a DI Diesel Engine at Reduced Temperature Combustion Condition

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In this paper, reduced temperature combustion has been investigated at high load condition of a direct injection diesel engine. A three dimensional CFD model for flow field, spray, spray-wall interactions, combustion and emissions formation processes have been used to carry out the computations. The combined effect of EGR temperature and EGR rate is analyzed to choose by consideration of engine performance. Then, the effect of injection timing and injection pressure is investigated to the improvement of mixture formation at high engine load condition. It reveals that combustion temperature is dramatically decreased by the increase of cold EGR to 25% rate. This characteristic influences on the increase of the liquid spray penetration and the decrease of indicated mean effective pressure (IMEP) and NOx emission associated with the increase of soot emission. Advance injection timing and high injection pressure together with applying 25% EGR lead to simultaneous reduction in NOx and soot formation compared with the base engine condition.

Modelling of Transport Phenomena in Diesel Sprays at Late-Cycle Post-Injection Conditions

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The development of Diesel sprays at late-cycle post-injection conditions is numerically investigated using a dense-particle Eulerian-Lagrangian stochastic methodology. Model validation takes place against experimental data available for injection into an optically accessible constant volume chamber using a single-hole injector nozzle. A parametric analysis on the effect of ambient temperature and density, injection duration and multiple injection strategy is performed to enlighten the development of the injected sprays for various post-injection strategies, with densities in the range of 1.2 - 3 kg/m3 and temperature in the range of 800 – 1400 K.s

Efficient Approach for Optimization of Piston Bowl Shape, Compression Ratio and EGR for DI Diesel Engine

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In order to meet emission norms, modern day diesel engines rely on methods of in cylinder emission reduction and expensive exhaust after treatment devices. Engine manufacturers across the world are finding it hard to maintain balance between customers' demand for better fuel consumption and obeying the stringent legislative emission regulations. Optimum combination of variables such as piston bowl shape, compression ratio, fuel injection and turbo charging systems precisely matched with engine, Exhaust Gas Re-circulation (EGR) rate etc can result in refined combustion leading to better engine out emissions as well as fuel efficiency. Optimization of piston bowl geometry and EGR rate would require a lot of experiments, which involves cost and time. If the numbers of variants of piston bowl shapes or EGR rates are more, so would be the expensive and require more testing time. Such approach proves to be inefficient in today's scenario, where minimizing the development time and expenses are the key objectives. In the present work, a approach based on 3D CFD simulation for optimization of piston bowl together with EGR rate is presented. Multidimensional CFD code "Engine Simulation Environment" i.e "ESE Diesel" of AVL-FIRE is used to run the simulations. The model is first validated with available engine measurements and then used for the optimization work. Three different shapes of piston bowl were selected for simulation. Combustion simulation was carried out to select optimum bowl shape. With the optimum bowl shape, simulation iterations were performed by varying EGR rate from 0 to 20%. NOx & exhaust soot trends are compared for different simulation model. Optimum bowl shape and EGR rate were decided based on the targets for specific fuel consumption, exhaust emissions, percentage of soot etc. Final combination of piston bowl shape and EGR rate was actually tested on engine. Test results in close conformity with simulation results were observed. A significant reduction in number of test experiments and the associated time and cost was experienced by following this simulation centric approach.

Numerical Assessment of Emission Sources for a Modified Diesel Engine Running in PCCI Mode on a Mixture of Gasoline and Diesel

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Premixed charge compression ignition (PCCI) is an interesting alternative to conventional diesel combustion, as it allows very low emission levels for part load operation. The difficult control of the onset of combustion is an obstacle to the implementation of PCCI. In a recent study, different mixtures of gasoline and diesel fuel have been used in a modified diesel engine to delay the ignition and thus to allow for a substantial premixing time. For these cases, very low levels of particulate emissions have been reported. However, the emissions of CO and NOx were considerably high. In this study, combustion and pollutant formation in the above mentioned modified diesel engine are simulated using the representative interactive flamelet (RIF) approach. A detailed chemical reaction mechanism for a mixture of n-heptane, iso-octane, toluene, and ethanol, serving as surrogate fuel for the diesel-gasoline blend, is used for the simulations. By systematic comparison of experimental and numerical results, an improved understanding of PCCI combustion is achieved and the origins of the CO and NOx emissions are identified. Finally, measures to reduce these emissions while keeping the low PM levels are suggested.

Computational Optimization of Reactivity Controlled Compression Ignition in a Heavy-Duty Engine with Ultra Low Compression Ratio

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Many studies have demonstrated ability of low temperature combustion to yield low NOx and soot while maintaining diesel-like thermal efficiencies. Methods of achieving low temperature combustion are numerous and range from using high cetane number fuels, like diesel, with large amounts of exhaust gas recirculation, to completely premixing a high octane number fuel, like gasoline, and approaching an HCCI-like condition. Both of the aforementioned techniques have relatively short combustion duration that results in very a rapid rate of heat release, and hence very rapid rates of pressure rise. This has been one of the major challenges for premixed, low temperature combustion at mid and high load. Reactivity Controlled Compression Ignition (RCCI) has been introduced recently, which is a dual fuel partially premixed combustion concept. In this strategy in-cylinder fuel blending is used to develop fuel reactivity gradients in the combustion chamber that result in a broad combustion event and reduced pressure rise rates. RCCI has been demonstrated to yield low NOx and soot with high thermal efficiency in a heavy-duty engine using a compression ratio of 16.1 at loads up to 15 bar gross IMEP. However, extension to full-load operation has proven to be difficult with a high compression ratio. The objective of this work was to optimize the engine with a low compression ratio of 11.7 using computational tools. The KIVA3V-CHEMKIN code, a multi-dimensional engine CFD model was coupled to a Nondominated Sorting Genetic Algorithm (NSGA II), which is a multi-objective genetic algorithm. Three engine operating conditions were investigated in this study, a low-load, mid-load, and a high-load point, 4, 9, and 23 bar gross IMEP, respectively. The goal of the optimization study was to simultaneously reduce six objectives, which are soot, NOx, unburned hydrocarbons, carbon monoxide, indicated specific fuel consumption, and the maximum pressure rise rate. The genetic algorithm was allowed to vary six engine design parameters, namely percent premixed gasoline, EGR fraction, and diesel direct injection parameters.

CFD Analyses on 2-Stroke High Speed Diesel Engines

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In recent years, interest has been growing in the 2-Stroke Diesel cycle, coupled to high speed engines. One of the most promising applications is on light aircraft piston engines, typically designed to provide a top brake power of 100-200 HP with a relatively low weight. The main advantage yielded by the 2-Stroke cycle is the possibility to achieve high power density at low crankshaft speed, allowing the propeller to be directly coupled to the engine, without a reduction drive. Furthermore, Diesel combustion is a good match for supercharging and it is expected to provide a superior fuel efficiency, in comparison to S.I. engines. However, the coupling of 2-Stroke cycle and Diesel combustion on small bore, high speed engines is quite complex, requiring a suitable support from CFD simulation. In this paper, a customized version of the KIVA-3v code (a CFD program for multidimensional analyses) has been used to address ports and combustion chamber design of a new project (a 3-cylinder 1.8L engine, with a power rating up to 150 HP). Multidimensional calculations have been supported by 1D engine cycle analyses, using GT-Power. Two types of combustion-scavenging system have been considered, both of them featuring direct injection: a configuration with exhaust poppet valves and another one with piston controlled ports. A development of both projects has been performed through a coupled 1d-3d computational approach. A first set of KIVA calculations has been performed, in order to characterize the scavenging and the port flow patterns of both configurations, considering three different operating conditions, representative an aircraft engine. Then, several combustion simulations have been run, for defining two chambers able to match the project goals (high fuel efficiency, limited in-cylinder peak-pressure). For the two best configurations, the most interesting calculation results are presented in the paper.

Diagnostics of Mixing Process Dynamics, Combustion and Emissions in a Euro V Diesel Engine

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An innovative approach to the study of combustion and emission formation in modern diesel engines has been applied to a EURO V diesel engine equipped with a indirect-acting piezo injection system. The model is based on the joint use of a predictive non stationary 1D spray model, which has recently been presented by Musculus and Kattke, and a diagnostic multizone thermodynamic model developed by the authors. The combustion chamber content has been split into homogeneous zones, to which mass and energy conservation laws have been applied: an unburned gas zone, made up of air, EGR and residual gas, several fuel/unburned gas mixture zones, premixed combustion burned gas zones and diffusive combustion burned gas zones. The 1D spray model enables the mixing process dynamics of the different fuel parcels with the unburned gas to be estimated for each injection pulse, therefore the equivalent ratio time-history of each mixture zone can be estimated. A separate set of zones has consequently been generated for each pulse, according to a similar conceptual approach to that introduced by Dec. A premixed burned gas zone is generated as combustion takes place. This zone progressively oxidizes the mixture zones of the pulse, until they are completely consumed. If the average equivalence ratio of the premixed burned gas zone is higher than unity, diffusive burned gas zones are generated to complete combustion. The global heat release rate is calculated on the basis of the experimental pressure signal, as the approach is of the diagnostic type. The main model results are the mass and temperature evolutions of the zones, along with the equivalence ratio values of the different mixture zones at the start of combustion. In the literature, this value has been shown to be significantly related to the soot formation rate. The diagnostic tool includes predictive submodels for the calculation of the pollutant emissions. In other words, NO formation is modeled by means of thermal Zeldovich and prompt mechanisms; CO is calculated via the Bowman equations; soot formation is modeled by means of an expression that is derived from Kitamura et al.'s results, in which an explicit dependence on the local equivalence ratio at the start of combustion is considered; soot oxidation is modeled via the Nagle-Strickland-Constable formulation; the THCs are calculated by accounting for the effects of spray overmixing, injector sac and hole volumes, and spray impingement. The model outcomes can be reported in the well-known -T diagrams, which offer a synthetic representation of the local

conditions during the fuel/unburned gas mixing processes and during combustion for each single injection pulse. The diagnostic approach has been applied to a EURO V diesel engine equipped with indirect-acting piezo injectors, at both medium low and medium-high load/speed conditions. The effects of EGR rate variations have been also investigated in order to assess the capability of the model to take the changes in the charge chemical composition into account. The main results have shown that the combustion of the pilot injection mainly occurs at stoichiometric/ lean premixed conditions, as it is responsible for NOx but not for soot formation. The main injection combustion initially occurs in rich premixed conditions, a result that confirms the Dec conceptual model. No spray impingement occurred in the analyzed data as far as THC formation is concerned, and the main contribution to THC emissions at the engine exhaust was due to the injector sac and hole volumes. However, the contribution of spray overmixing increased at medium-low loads. Finally, it has been confirmed that EGR is not an effective means of decreasing the average value at the start of combustion to reduce soot formation.

Reducing Fuel Consumption, Noxious Emissions and Radiated Noise by Selection of the Optimal Control Strategy of a Diesel Engine

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Despite the recent efforts devoted to develop alternative technologies, it is likely that the internal combustion engine will remain the dominant propulsion system for the next 30 years and beyond. Also as a consequence of more and more stringent emissions regulations established in the main industrialized countries, strongly demanded are methods and technologies able to enhance the internal combustion engines performance in terms of both efficiency and environmental impact. Present work focuses on the development of a numerical method for the optimization of the control strategy of a diesel engine equipped with a high pressure injection system, a variable geometry turbocharger and an EGR circuit. A preliminary experimental analysis is presented to characterize the considered six-cylinder engine under various speeds, loads and EGR ratios. The fuel injection system is separately tested on a dedicated test bench, to determine the instantaneous fuel injection rate for different injection strategies. The collected data are employed for tuning proper numerical models, able to reproduce the engine behaviour in terms of performances (in-cylinder pressure, boost pressure, air-flow rate, fuel consumption), noxious emissions (soot, NO) and radiated noise. In particular, a 1D tool is developed with the aim of characterizing the flow in the intake and exhaust systems and predicting the engine-turbocharger matching conditions, by including a short-route EGR circuit; a 3D model (AVL FireTM) is assessed to reproduce into detail the in-cylinder thermo-fluidynamic processes, including mixture formation, combustion, and main pollutants production; an in-house routine, also validated against available data, is finally developed for the prediction of the combustion noise, starting from in-cylinder pressure cycles. Obviously, data exchange between the codes is previewed. The overall numerical procedure is firstly checked with reference to the experimentally analysed operating points. The 1D, 3D and combustion noise models are then coupled to an external optimizer (Mode FRONTIERTM) in order to select the optimal combination of the engine control parameters to improve the engine performance and to contemporary minimize noise, emissions and fuel consumption. Under the hypothesis of a pilot-main injection strategy, a multi-objective optimization problem is solved through the employment of a genetic algorithm. Eight degrees of freedom are defined, namely start of injection, dwell time, energizing time of pilot and main pulses, EGR valve opening, throttle valve opening, swirl level, and turbine opening ratio. It is shown that non-negligible improvements can be gained, also depending on the importance given to the various objectives.

Simplified Calculation of Chemical Equilibrium and Thermodynamic Properties for Diesel Combustion

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Computation of combustion, in particular of emissions over crank angle, relies on chemical oriented models. In some cases, chemical equilibrium can be assumed, as chemical reaction time scales tend to be fast compared to the crank rotation, so the rather complex reaction kinetics can be neglected. For engine process calculation based on the measured cylinder pressure chemical equilibrium concentrations are needed for every crank angle or calculation time step. On the one hand the equilibrium concentrations are necessary for estimating the thermodynamic properties of the working gas (internal energy and specific gas constant) which are needed for deriving the energy release (burn rate) and on the other hand the obtained concentrations are inputs for crank angle based soot and nitric oxygen emission models which depends also on the engine process calculation results. For a common accurate 11 component equilibrium calculation a nonlinear equation system must be solved with an iterative method. To reduce calculation complexity a new explicit method is described in the paper which is especially designed for the typical range of a common Diesel. The main benefit is that it does not need initial values and iteration. Additionally new explicit descriptions for the thermodynamic properties are presented. The development process for both approaches was supported by data based identification methods. Several validation examples are shown to estimate the deviation of the new approaches for chemical equilibrium species and the gas properties compared to the more complicated standard methods in a practical use. In particular the importance of the achieved species accuracy on soot dynamics and nitric oxygen calculation based on published 1- and 2-zone models is presented in detail.

Study on the Effects of the In-Cylinder EGR Stratification on NOx and Soot Emissions in Diesel Engines

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Much research has been devoted to reducing NOx and soot emissions simultaneously in diesel engines. The low temperature combustion (LTC) concept has the potential to reduce these emissions at the same time, but it has limitations to its commercialization. In-cylinder EGR stratification is another combustion concept meant to reduce both types of emissions simultaneously using nonuniform in-cylinder EGR gas distribution. The EGR stratification concept uses a locally high EGR region of the in-cylinder so that the emissions can be reduced without increasing the overall EGR rate. In this study, the EGR stratification concept was improved with a CFD-based analysis. First, a two-step piston was developed to maximize the stratified EGR effect. Then, the feasibility of combustion and emission control by stratified EGR was evaluated under cases of artificially distributed EGR stratification and conventional diesel engine conditions.

Optimal Spectral Optical and Thermo Radiating Characteristics of Semitransparent Heat-Insulating Coatings for Low-Heat-Rejection Diesel Engines

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The main objective of this research is the analysis of influence of optical and thermo radiating characteristics on the transient (steady state) temperature distributions inside the heat-insulating semitransparent (SHIC) и opaque (HIC) coatings for thermal regulation and control of walls and elements of the combustion chamber (CC) of high speed diesel engines. Developed author's methodology of physical and mathematical simulation of parameters of the radiant and heat conductivity transfer was used to calculate optimal balance of optical and thermo radiating characteristics of coatings – as selectively absorbing and scattering materials with different transmittance, reflection and emittance depending on wavelength diapasons of irradiating or radiating heat fluxes. The paper presents a mathematical simulation of optimal balance of improved optical (transmittance, reflectance, absorption coefficients or absorption, scattering indexes) and thermo radiating (emittance coefficient) characteristics. It is considered the effect of the subsurface volumetric heating which at their display promotes decreasing of a surface overheating of coatings of the combustion chamber. It have been received by the numerical method temperature distributions for semitransparent heat-insulating coatings protecting metal substrate (CC wall) with different reflection of penetrating radiation by SHIC layer. It has been shown decreasing the surface temperature of SHIC in comparison with temperature of opaque HIC.

Detailed Kinetic Modeling of HCCI Combustion with Isopentanol

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Isopentanol is an advanced biofuel that can be produced by micro-organisms through genetically engineered metabolic pathways. Compared to the more frequently studied ethanol, isopentanol's molecular structure has a longer carbon chain and includes a methyl branch. Its volumetric energy density is over 30 % higher than ethanol, and it is less hygroscopic. Some fundamental combustion properties of isopentanol in an HCCI engine have been characterized in a recent study by Yang and Dec (SAE 2010-01-2164). They found that for typical HCCI operating conditions, isopentanol lacks two-stage ignition properties, yet it has a higher HCCI reactivity than gasoline. The amount of intermediate temperature heat release (ITHR) is an important fuel property, and having sufficient ITHR is critical for HCCI operation without knock at high loads using intake-pressure boosting. Isopentanol shows considerable ITHR, and the amount of ITHR increases with boost, similar to gasoline. However, the individual effect of pressure and temperature on ITHR for isopentanol is still unclear. Also, the chemistry leading to ITHR for isopentanol in an HCCI engine needs to be explained. To answer these key questions, a detailed chemical kinetic model for isopentanol has been developed and used to perform HCCI engine simulations. The isopentanol model consists of low- and high-temperature chemistry based on reaction models for butanol isomers and isooctane (an alkane which a branched molecular structure similar to isopentanol). The model includes a new reaction step for concerted elimination of HO2 from isopentanol, a process recently examined by da Silva and Bozzelli for ethanol (J. Phys. Chem. A, 113, 31, 2009). The isopentanol model was validated with rapid-compression-machine and shock-tube data over a wide range of temperatures, pressures and equivalence ratios (712 - 1205 K, 0.8 - 2.3 MPa, and 0.5 - 1.0, respectively). Excellent agreement between model predictions and experimental data was achieved. With regard to simulating HCCI combustion, the model reproduces the experimentally observed ITHR of isopentanol and its

enhancement when simultaneously increasing pressure and decreasing temperature for a set combustion phasing. As seen in the HCCI experiments, the model shows that increasing the temperature for a fixed intake pressure promotes hot ignition, with little effect on ITHR.

Experimental Validation of a Global Reaction Model for a Range of Gasolines and Kerosenes under HCCI Conditions

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Compact and computationally efficient reaction models capable of accurately predicting ignition delay and heat release rates are a prerequisite for the development of strategies to control and optimize HCCI engines. In particular for full boiling range fuels exhibiting two stage ignition a tremendous demand exists in the engine development community. To this end, in a previous investigation, a global reaction mechanism was developed and fitted to data from shock tube experiments for n-heptane and five full boiling range fuels. By means of a genetic algorithm, for each of these fuels, a set of reaction rate parameters (consisting of pre-exponential factors, activation energies and concentration exponents) has been defined, without any change to the model form. In the present paper, an extensive validation of the model using these existing and unaltered parameters from the shock tube optimization is presented, by comparing calculated pressures, heat release rates and ignition delays with data from HCCI engine experiments. The validation is performed for all fuels at a wide range of HCCI operating conditions: load was varied from 2 to 6 bar IMEP, intake temperatures from 40 to 80°C and exhaust gas recirculation rates (EGR) from 0 to 65 %. The results of the 3D-CFD simulations show a good overall agreement with the HCCI experiments for each of the fuels considered for the majority of the operating conditions investigated. The efficiency and good predictive capability of the model, even for the complex gasolines and kerosenes considered here, make the model particularly suited to study the impact of changing operating conditions on the ignition behavior and heat release in real HCCI applications. The promising results obtained furthermore indicate that the model could, in principle, be applied to any hydrocarbon fuel, providing suitable adjustments to the model parameters are carried out.

The HCCI Concept and Control, Performed with MultiAir Technology on Gasoline Engines

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The introduction of MultiAir technology [8] has had a strong impact on engine performance, fuel consumption, emissions and control. This technology, intended at first for gasoline engines and applied only on intake valves, is aiming at the reduction of engine breathing losses and, as a consequence, reduction of pollutant emissions and fuel consumption, together with an improvement of maximum intake efficiency. Further positive effects of MultiAir technology have been a significant improvement of Low End Torque, engine driveability ("fun-to-drive" index) and other operating conditions (e.g. idle control). Current development of MultiAir technology is focusing on a better management of hot EGR (Exhaust Gas Recirculation), still acting only on the intake side, although with specifically designed valve lift profiles. This application of MultiAir technology is pushing gasoline engines towards new levels of performance improvements. A further potential evolution of MultiAir technology is the controlled use of HCCI (Homogeneous Charge Compression Ignition, usually called CAI, Controlled Auto Ignition) concept and process, like in this paper we try to explain. Many different research teams, all over the world, have carried out important works about general, physical and chemical aspects of CAI (see, only e.g., [9], [10] and [11]). The focus here, instead, has been to only theoretically investigate - by way of reliable, coherent and global engine simulation - the opportunity of CAI introduction through valve control devices that today production has made available. In the first part of this paper, the authors present a quick review of a specific, complete, in-cylinder engine model, previously developed and accurately tuned for standard production MultiAir gasoline engines. The second part introduces the proposed evolution of MultiAir technology: acting on both intake and exhaust valves, a further degree of freedom becomes available, and the HCCI is achievable through NVO (Negative Valve Overlap). The NVO is a well-known way ([3], [5]) to trigger the combustion conditions from conventional to controlled autoignition, and it could be managed with production MultiAir components and control techniques. Simulated results are then presented.

Multi-Dimensional Modeling of Combustion in Compression Ignition Engines Operating with Variable Charge Premixing Levels

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Premixed combustion modes in compression ignition engines are studied as a promising solution to meet fuel economy and increasingly stringent emissions regulations. Nevertheless, PCCI combustion systems are not yet consolidated enough for practical applications. The high complexity of such combustion systems in terms of both air-fuel charge preparation and combustion process control requires the employment of robust and reliable numerical tools to provide adequate comprehension of the phenomena. Object of this work is the development and validation of suitable models to evaluate the effects of charge premixing levels in Diesel combustion. This activity was performed using the Lib-ICE code, which is a set of applications and libraries for IC engine simulations developed using the OpenFOAM® technology. In particular, a turbulence-chemistry interaction model, based on the simple Eddy Dissipation Approach, was introduced to account for the effects of turbulent mixing on chemical reaction rates. It is a tentative solution to represent the effects of sub-grid mixing on the chemical reaction rates when detailed reaction mechanisms are adopted. Chemical reaction rates were computed by a robust semi-implicit extrapolation method for integrating stiff Ordinary Differential Equations with monitoring of both local and global error to adjust step-size. To reduce the CPU time when detailed chemistry was used, both the ISAT (in-situ adaptive tabulation) and DAC (dynamic adaptive chemistry) techniques were adopted in combination. Simulations were performed by varying the charge premixing level from the typical diesel combustion mode towards an almost completely premixed/HCCI mode using n-heptane, whose injected mass was split between port-injection and direct-injection. This allowed a detailed investigation of the “mixed injection conditions”, that are typical of dual fuel configurations without employing fuels of different chemical nature, composition and ignition tendency. The choice of using a single fuel was motivated by the need to isolate the effects of different premixing levels and the resulting interaction between the charge and the fuel spray. Measurements for validation were collected by means

of specific experiments on a fully instrumented single cylinder research engine, having the injection and the combustion systems architecture typical of the current light duty diesel engine technology. To realize homogeneous air-fuel charge, the intake manifold is modified to provide the desired extent of fuel port-injection.

An Analysis on Time Scale Separation for Engine Simulations with Detailed Chemistry

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The simulation of combustion chemistry in internal combustion engines is challenging due to the need to include detailed reaction mechanisms to describe the engine physics. Computational times needed for coupling full chemistry to CFD simulations are still too computationally demanding, even when distributed computer systems are exploited. For these reasons the present paper proposes a time scale separation approach for the integration of the chemistry differential equations and applies it in an engine CFD code. The time scale separation is achieved through the estimation of a characteristic time for each of the species and the introduction of a sampling timestep, wherein the chemistry is subcycled during the overall integration. This allows explicit integration of the system to be carried out, and the step size is governed by tolerance requirements. During the subcycles each of the species is only integrated up to its own characteristic timescale, thus reducing the computational effort needed by the solver. The present ODE solver was first validated using constant pressure batch reactor simulations with two different reaction mechanisms. Then the solver was coupled with the KIVA-4 code, and validated using HCCI and DI diesel combustion cases. Performance is compared with the commonly used DVODE chemistry solver and the results show that significant reductions in the total computational time with comparable accuracy are obtained with the new solution methodology.

Aerodynamic Flow Simulation in an Internal Combustion Engine using the Smoothed Particle Hydrodynamics Method

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The numerical simulation of internal aerodynamic of automotive combustion chamber is characterised by complex displacements of moving elements (piston, intake/exhaust valves...) and by a strong variation of volume that cause some problems with classical numerical based mesh methods. With those methods (FEM, FVM) which use geometric polyhedral elements (hexaedron, tetrahedron, prismes...), it is necessary to change periodically the mesh to adapt the grid to the new geometry. This step of remeshing is very fastidious and costly in term of engineer time and may reduce the precision of calculation by numerical dissipation during the interpolation process of the variables from one mesh to another. Recently, the researcher community has renewed his interest for the development of a generation of numerical to circumvent the drawbacks of the classical methods. Among the large variety of innovating meshless methods, the so-called Smoothed Particle Hydrodynamics (SPH), appears to be suitable to describe the fluid dynamic equations which are generally the most studied. This paper presents the SPH formalism used in order to compute compressible flow with solid boundary conditions. The physical model used for compressible simulation is first described. In particular the treatment of compressible fluid is detailed with the use of a Riemann solver and its implementation in SPH formalism. The strategy chosen is to use only boundary particles to model walls and this specific solid boundary numerical treatment for compressible fluid is described. This original hybrid boundary treatment is based on a partial Riemann problem at walls. In order to test the accuracy of the solid boundary condition and of the SPH formalism in presence of moving wall and to handle a fluid with increase of density and pressure i.e a compression, relevant test cases are presented. Finally, a basic experimental engine is computed with the method presented in this paper and results are compared to experimental data (PIV).

Experimental and Numerical Investigation of the Idle Operating Engine Condition for a GDI Engine

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The paper investigates the idle operating condition of a current production turbocharged Gasoline Direct Injected (GDI) high performance engine both from an experimental and a numerical perspective. Due to the low engine speed, to the low injection pressure and to the null contribution of the turbocharger, the engine condition is far from the standard points of investigation. According to the low heat flux due to combustion, temperature levels are low and reduced fuel evaporation is expected. Consequently, fuel spray evolution within the combustion chamber and spray/wall interaction are key points for the understanding of the combustion process. In order to properly investigate and understand the many complex phenomena, a wide set of engine speeds was experimentally investigated and, as far as the understanding of the physics of spray/wall interaction is concerned, many different injection strategies are tested. Among the wide set of experiments, the present paper focuses on a restricted portion which is then numerically reproduced and further investigated. UV-visible imaging and spectral measurements are carried out in the engine to investigate the spray characteristics and flame propagation. Measurements are performed in the optically accessible combustion chamber realized by modifying the actual engine. The cylinder head is modified in order to allow the visualization of the fuel injection and the combustion process in the fourth cylinder using a high spatial and temporal resolution ICCD detector. The complete engine cycle is reproduced by means of 3D-CFD simulations using a commercial code; due to the many physical sub-models an ad hoc numerical methodology is validated and implemented. The CFD models are validated against experiments and particular care is devoted to the spray and wall film simulations. A lagrangian approach is implemented in order to simulate the GDI multihole spray. The experimental and numerical comparisons, in terms fuel mixing and flame front propagation, give a good understanding of the idle condition. CFD analyses prove to be a very useful tool to investigate and understand the effects generated by the direct injection into the combustion chamber and they integrate the information provided by the optical investigations.

Experimental Evaluation of Reduced Kinetic Models for the Simulation of Knock in SI Engines

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Downsizing by turbo charging is a current approach for the reduction of fuel consumption of Spark Ignition (SI) engines. For downsized engines compression ratio has to be set as high as possible to achieve substantial gains in thermodynamic efficiency. Unfortunately, the possibility to take full advantages offered by downsizing is limited by knock phenomenon, which imposes constraints both on supercharging and compression ratios. Quasi-dimensional and multidimensional simulation can play a role of increasing importance for the design and the optimization of future engine prototypes more and more based on advanced combustion concepts, provided that well proven tools for knock simulation may be available. In this regard, a number of detailed and semi-detailed kinetic schemes have been recently proposed to simulate the auto-ignition and combustion in wide ranges of temperature, pressure and air fuel ratio typical of different experimental approaches, such as: flow reactors, constant volume bombs, rapid compression machines, shock tubes, test engines. However, at moment, the use of large kinetic models is limited, particularly in multidimensional simulation, because of the enormous calculation effort required. On the other hand, different kinds of reduced models (skeletal, global, etc.) have been proposed, but they can be effectively used only on defined ranges of temperature, pressure and air fuel ratio. Thus, to set up reduced models, proper experiments are required for each field of interest. In this scenario, an experimental procedure to evaluate the auto-ignition behavior of different fuels in conditions similar to the ones of the end gas of SI engines is proposed in this paper. A CFR engine was used because of his flexibility and of his wide diffusion. For all tests, carried out using iso-octane as fuel, inlet temperature was controlled at 423 K, the engine speed set at 900 (rpm), and the relative air/fuel ratio varied in a wide range, from rich (0.74) to lean (1.51). For each test condition, the engine was motored and compression ratio was varied until auto-ignition was induced. The internal EGR and other not measurable parameters were estimated with the aid of a 1-D commercial code, whose user combustion module was customized with a FORTRAN routine developed by the authors. Numerical simulations were carried out using two reduced mechanisms due respectively to Tanaka [13] and to Golovitchev [16], and their capability of predicting autoignition was evaluated by comparison with experiments.

Multi-dimensional Modeling of Gas Exchange and Fuel-Air Mixing Process in a Direct-Injection, Gas Fueled Engine

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Direct-injection technology represents today a very interesting solution to the typical problems that are generally encountered in SI, gas fueled engines such as reduced volumetric efficiency, backfire and knock. However, development of suitable injection systems and combustion chamber geometry is necessary to optimize the fuel-air mixing and combustion processes. To this end, CFD models are widely applied even if the influence of the mesh structure, numerical and turbulence models on the computed results are still matter of investigation. In this work, a numerical methodology for the simulation of the gas exchange and injection processes in gas fueled engines was developed within the Lib-ICE framework, which is a set of libraries and applications for IC engine modeling developed using the OpenFOAM® technology. The gas exchange and fuel injection processes were simulated into a four-valve, pent-roof hydrogen-fueled engine with optical access. The availability of experimental optical data of charge motions within the cylinder and equivalence ratio distributions during injection allowed a detailed validation of the proposed approach. In particular the effects of different turbulence models and mesh structures were investigated.

Fuel Injection and Combustion Process _Modeling

Fuel Injection and Combustion Process _Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Lift-off Length and KL Extinction Measurements of Biodiesel and Fischer-Tropsch Fuels under Quasi-Steady Diesel Engine Conditions

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The relationship between ignition, lift-off length and soot formation was investigated for a collection of fuels in an optically accessible modified 2-stroke engine under a set of typical quasi-steady state Diesel DI conditions. Five fuels including biodiesel blends and Fischer-Tropsch fuels have been selected for their potential to substitute conventional diesel with no major modifications on the engine hardware, and were previously characterized under ambient pressure following ASTM standards. Fuels were injected into a large volume through a single-hole nozzle at three levels of injection pressure, by sweeping ambient temperatures at constant density, and ambient densities at constant temperature. The 8 ms single-shot injections were long enough to reach the stabilization of a free diffusion flame. The OH-chemiluminescence was imaged and lift-off length was measured via image post-processing. Simultaneously, flame opacity was measured along the flame axis using the laser extinction technique. The pressure trace analysis quantified the ignition delay. In a first step, the averaged lift-off length measurements are presented and contrasted with both ignition delay and previous liquid length measurements performed in similar thermodynamic conditions but with an inert spray configuration. Statistical analysis permitted assessment of the influence of engine parameters such as air density, air temperature and injection pressure independently of fuel origin. The strong effect of air temperature and the more moderate ones of both air density and injection pressure presented by other authors were confirmed. Then, fuel stoichiometric mixture fraction and ignition delay have been introduced in the analysis in order to investigate their implication in processes of lift-off stabilization. In a second analysis, values of both lift-off length and KL were compared with a cycle-to-cycle approach. Results showed that, at fixed engine operating conditions, the scattering of lift-off length measurements is directly linked to that of KL. This result was confirmed when using average values and when comparing different parameters that were tested in the study. Different sensitivities were observed from one fuel to another.

Experimental Study on Structure and Mixing of Low-pressure Gas Jet Using Tracer-based PLIF Technique

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Natural gas has been considered as one promising alternative fuel for internal combustion (IC) engines to meet strict engine emission regulations successfully applied into spark ignition (SI) engines in the past decade, natural gas direct injection compression ignition (DICI) engine with new injection system are being pursued to improve engine performance. Gas jet behaves significantly different from liquid fuels, so the better understanding of the effects of gas jet on fuel distribution and mixing process is essential for combustion and emission optimization. The present work is aimed to gain further insight into the characteristics of low pressure gas jet. An experimental gas jet investigation has been successfully conducted using tracer-based planar laser-induced fluorescence (PLIF) technique. For safety reason, nitrogen (N_2) was instead of CNG in this study. Vapor acetone was selected as a tracer. The fourth harmonic of a Nd:YAG laser (266nm) was used to excite the acetone, and the fluorescence signal was detected by a high-resolution charge coupled device (CCD) camera with an image intensifier. A series of instantaneous images captured in different delays after start of injection (ASOI) was used to study the time evolution and spatial distribution of fuel-air mixing processes and fuel concentration fields. The effects of gas injection pressure were investigated to characterize the mixture formation and the jet macroscopic structure. To further understand the gas jet characteristics, quasi-steady gas jets were studied under different injection pressure. Moreover, the different characteristics between transient jet and quasi-steady jet were compared and analyzed.

Injection of Fuel at High Pressure Conditions: LES Study

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This paper presents a large eddy simulation study of the liquid spray mixing with hot ambient gas in a constant volume vessel under engine-like conditions with the injection pressure of 1500 bar, ambient density 22.8kg/m^3, ambient temperature of 900 K and an injector nozzle of 0.09 mm. The simulation results are compared with the experiments carried out by Pickett et al. under similar conditions. Under modern direct injection Diesel engine conditions, it has been argued that the liquid core region is small and the droplets after atomization are fine so that the process of spray evaporation and mixing with the air is controlled by the heat and mass transfer between the ambient hot gas and central fuel flow. To examine this hypothesis a simple spray breakup model is tested in the present LES simulation. The simulations are performed using an open source compressible flow solver, in OpenFOAM. It is found that with the simple spray breakup model and almost unadjusted model parameters, the global quantities simulated from LES agree fairly well the experiments in terms of the vapor fuel penetration length and the vapor fuel mass fraction profiles along the axis of the injector and along radial direction at different axial positions downstream the injector nozzle. Sensitivity study is performed to examine the effect of the model parameters such as the number of injected parcels and the size of the injected parcels, as well as LES grid resolution on the numerical results. It is seen that the liquid penetration length, the flow velocity and vapor distribution in the near-nozzle region can be moderately sensitive to the model parameters. However, the vapor fuel penetration and distribution in the downstream region is rather insensitive to the model parameters. The good agreement between the numerical results and experiments is largely owing to the capability of the LES approach for capturing the shear layer instability and transition to turbulence. It implies the dominant effect of the large scale mixing of ambient air with the fuel on the spray injection and mixing process.

Experimental Study of Spray Characteristics between Hydrotreated Vegetable Oil (HVO) and Crude Oil Based EN 590 Diesel Fuel

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The aim of current study was to compare the global fuel spray characteristics between renewable hydrotreated vegetable oil (HVO) and crude oil based EN 590 diesel fuel. According to previous studies, the use of HVO enables reductions in carbon monoxide (CO), total hydrocarbon (THC), nitrogen oxide (NO_x) and particle matter (PM) emissions without any changes to the engine or its controls. Fuel injection strategies and global fuel spray characteristics affect on engine combustion and exhaust gas emissions. Due to different physical properties of two different fuels, fuel spray characteristics differ. Fuel spray studies were performed with backlight imaging using a pressurized test chamber imitating real engine conditions at the end of compression stroke. However, the measurements were made in non-evaporative conditions. Various injection parameters such as injection pressures and orifice diameter were tested. The global fuel spray characteristics such as spray tip penetration and spray angle were compared with various injection parameters and two different fuels. Velocities of spray tip penetrations were measured by double frame imaging method.

IR imaging of Premixed Combustion in a Transparent Euro5 Diesel Engine

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In the present paper, infrared (IR) measurements were performed in order to study the development of injection and combustion in a transparent Euro 5 diesel engine operating in premixed mode. An elongated single cylinder engine equipped with the multi-cylinder head of commercial passenger car and with common rail (CR) injection system, respectively, was used. A sapphire window was set in the bottom of the combustion chamber, and a sapphire ring was placed between the head and the top of the cylinder line. Measurements were carried out through both accesses by a new high-speed infrared (IR) digital imaging system obtaining information that was difficult to achieve by the conventional UV- visible camera. IR camera was able to detect the emitted light in the wavelength range 1.5 -5 mm that is relevant for the emission bands of CO_2 and H_2O. The evaporation phase of pre and main injection, and subsequent combustion evolution were analyzed. Moreover, IR imaging was carried out by means of “ad hoc” filter to evaluate the spatial distribution of CO_2 inside the cylinder. Images sequence during the whole engine cycle, starting from the intake and stopping to the exhaust phase, was observed from both optical windows. A comparison with visible imaging was carried out. IR measurements showed the ability to determine temporal and spatial distribution of fuel during evaporation phase and evaluate the combustion process evolution for longer time than visible imaging. Moreover, the IR camera was revealed very useful tool to detect the emitted light after a long operation time of the engine. The camera was able to acquire images of the reactions that happen in the combustion chamber and above the piston head even if the optical windows were obscured by the soot produced from the previous combustion cycles.

Experimental Analysis of Three-Dimensional Flow Structures in Two Four-Valve Combustion Engines

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The development of the flow field in the cylinder of a piston engine possesses a distinct influence on the fuel-air mixing and thus, on the combustion process. In particular, the flow structures that evolve during the intake and compression stroke are of major importance and at constant flow parameters, the intake port geometry influences these structures. To show this impact, the flow field of two engines with different intake port geometries is measured using particle-image velocimetry in the present study. The data are compared regarding the temporal and spatial development of the main flow phenomena and the turbulent kinetic energy. The study focuses on the impact of the two different formation mechanisms of tumble vortices due to the different intake port geometries on the flow structure. Engine A is an optical research engine optimized for high tumble ratios for combustion stability in combustion processes of tailor-made fuels. Engine B is a one-cylinder motorcycle engine optimized for high filling. For both engines, the flow is investigated in a set of eight vertical measurement planes and at thirteen crank angles using 2D/2C PIV. The main area of interest is in the center of the combustion chamber beneath the spark plug and injection nozzle. The in-plane velocity-components derived from the PIV measurements are used to visualize the main vortical structures, i.e., the ring vortices beneath the two inlet valves and the main tumble in the symmetry plane between the inlet and outlet valves revealing the typical spin-up towards the end of the compression stroke. The temporal development of the mean turbulent kinetic energy is calculated for crank angles from 80° to 300° after top dead center. The results show high turbulent kinetic energy during the intake stroke which dissipates at increasing crank angles and remains at an almost stable level during the compression stroke. The temporal analysis based on the ensemble and plane averaged mean and turbulent kinetic energies also show that the very well conserved tumble vortex dominates the flow structure in engine A during intake and compression. The influence of the tumble vortex in engine B is significantly smaller. The temporal analysis of the vorticity shows a comparatively small decay of the vorticity during the intake stroke in engine A, which is likely to be caused by the intake port transporting rotating flow structures into the combustion chamber and thereby equalizing the negative effect of volume growth. The vorticity of engine B, where the tumble is generated within the combustion chamber, decreases significantly due to the latter effect.

Optical Investigation of Premixed Low-Temperature Combustion of Lighter Fuel Blends in Compression Ignition Engines

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Optical imaging and UV-visible detection of in-cylinder combustion phenomena were made in a single cylinder optically accessed high swirl multi-jets compression ignition engine operating with two different fuels and two EGR levels. A commercial diesel fuel and a lighter fuel blend of diesel (80%) and gasoline (20%), named G20, were tested for two injection pressures (70 and 140 MPa) and injection timings in the range 11 CAD BTDC to 5 CAD ATDC. The blend G20 has a lower cetane number, is more volatile and more resistant to the auto-ignition than diesel yielding an effect on the ignition delay and on the combustion performance. Instantaneous fuel injection rate, in-cylinder combustion pressure, NOx and smoke engine out emissions were measured. Taking into account the particular configuration of the engine, the efficiency was estimated by determining the area under the working engine cycle. Moreover, it is also known that the diffusion flame lift-off length strongly influences the soot formation, which is affected by in-cylinder gas density, air swirl and jet to jet interaction. To understand the role played by these factors on lift-off length and soot formation, images of UV-VIS chemiluminescence were used to measure the diffusion flame lift-off length. The results demonstrate as the G20 fuel blend, at late injection timing and high EGR (50%), increases the ignition delay, allowing to operate, at late injection timing, in a partially premixed low temperature combustion (PPLTC) regime in which the fuel is completely injected before the start of combustion. In this regime, strong reduction of engine out emissions of smoke and NOx were obtained with a penalty on engine efficiency. This limitation was overcome operating at earlier injection timing (11 CAD BTDC) in which a mixing controlled low temperature combustion (MCC) LTC regime was realized. In this regime, a good compromise between low engine out emissions and efficiency was made possible. Finally, images of UV-VIS chemiluminescence were also used to measure the flame lift-off length, defined as the distance between the injector orifice and the most upstream location of flame chemiluminescence on the fuel jet. Flame lift-off data were plotted versus the visible emission intensity at 532 nm, representative of soot emission. It was observed that, for all engine test conditions an increase of lift-off length corresponded to a decrease of in-cylinder soot production.

Design for an Optically Accessible Multicylinder High Performance GDI Engine

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In this paper, the modifications realized to make optically accessible a commercial high performance spark ignition and direct injection (DI) 4-cylinder engine are reported. The engine has been designed trying to keep as much as possible its thermo-fluid dynamic configuration in order to maintain its performance and emissions. Two optical accesses have been realized in order to interfere as little as possible with the combustion chamber geometry. A first optical access has been achieved in the piston head and a second by inserting an endoscopic fiber probe in the head. Preliminary results demonstrated that this optical assessment responds to the design targets and allowed a characterization of a commercial GDI engine working with homogeneous and stratified charge mode.

Injection Effects in Low Load RCCI Dual-Fuel Combustion

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Dual-fuel reactivity controlled compression ignition (RCCI) engine experiments were conducted with port fuel injection of isooctane and direct injection of n-heptane. The experiments were conducted at a nominal load of 4.75 bar IMEPg, with low isooctane equivalence ratios. Two sets of experiments explored the effects of direct injection timing with single and double injections, and multi-dimensional CFD modeling was used to explore mixture preparation and timing effects. The findings were that if fuel-liner impingement is to be avoided, double injections provide a 40% reduction in CO and HC emissions, resulting in a 1% increase in thermal efficiency. The second engine experiment showed that there is a linear relationship between reactivity (PRF number) and intake temperature. It was also found that if the premixed fuel fraction is above a certain limit, the high-temperature heat release (HTHR) can be manipulated by changing the global PRF number of the in-cylinder fuel blend.

Effects of Premixed Low Temperature Combustion of Fuel Blends with high Resistance to Auto-ignition on Performances and Emissions in a High Speed Diesel Engine

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This paper reports results of an experimental investigation to demonstrate the potential to employ blends of fuels having low cetane numbers that can provide high resistance to auto-ignition to reduce simultaneously NOx and smoke. Because of the higher resistance to auto-ignition, blends of diesel and gasoline at different volume fraction may provide more time for the mixture preparation by increasing the ignition delay. The result produces the potential to operate under partially premixed low temperature combustion with lower levels of EGR without excessive penalties on fuel efficiency. In addition to the diesel fuel, the tested blends were mixed by the baseline diesel with 20% and 40% of commercial EURO IV 98 octane gasoline by volume, denoted G20 and G40. The experimental activity has been performed on a turbocharged, water cooled, DI diesel engine, equipped with a common rail injection system. The engine equipment includes an exhaust gas recirculation system controlled by an external driver, a piezo-quartz pressure transducer to detect the in-cylinder pressure signal and a current probe to acquire the energizing current to the injectors. Engine tests have been carried out at the engine speeds of 2500 rpm and a BMEP of 0.8 MPa exploring the effect of the start of injection, exhaust gas recirculation, injection pressure on combustion behavior and engine out emissions. The main results of the investigation have provided to realize a premixed low temperature combustion by the management of EGR rate, injection pressure and the longer ignition delay induced jointly by the higher resistance to auto ignition of fuel blends and their higher volatility. Results of smoke emissions have been cut down to zero for G20 and G40 blends at moderate level of injection pressure and oxygen concentration at the intake.

EGR and Intake Charge Temperature Effects on Dual-Fuel HCCI Combustion and Emissions Characteristics

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Homogeneous charge compression ignition (HCCI) combustion is a hybrid concept of compression and spark ignition combustions. It is a promised solution to environmental and fuel economy concerns for internal combustion engines. In this mode of combustion, a lean premixed charge combusts simultaneously from multiple sites. Utilizing very lean mixtures, and the lack of any obvious flame propagation, considerably reduces in-cylinder NO_x formation. In order to make the HCCI engine a feasible alternative to the SI and CI engines, several items must be elucidated. Control of the combustion timing is one of the most important of these items to be resolved. Combustion timing should be controlled in order that heat is released at the best time in the engine cycle. In this study, a Waukesha CFR single cylinder research engine with variable EGR was used to be operated in HCCI combustion mode fueled by natural gas and n-heptane. The main goal of the experiments was to make an attempt to control the combustion timing and duration by studying different approaches such as varying EGR rates, intake charge temperature and compression ratio. The main objective of the study is the investigation of how EGR rates and intake charge temperature can affect the HCCI combustion. In order to achieve this goal, a modified first law apparent heat release model, developed by the authors, was utilized. Utilizing this model, guarantee obtaining a well-behaved and accurate apparent heat release trend and magnitude in HCCI combustion engines. Also, the influence of EGR and intake charge temperature on emissions was discussed. Results indicate that applying EGR has profound effect on combustion phasing, leading to a retarded SOC and prolonged burn duration. It is favorable regarding fuel economy, too. The influence on emission characteristics is desirable with respect to NOx formation and unfavorable in the case of CO and HC emissions in a dual fueled HCCI combustion engine. Intake charge temperature has profound effects on in-cylinder charge pressure and temperature. It alters heat release rate magnitude and phasing. This parameter also affects indicated power and fuel consumption. Measured emissions have also shown changes due to variations of this initial condition.

An Experimental Study of Combustion Phasing Control in CAI Gasoline Engine with In-cylinder Fuel Reforming

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This paper presents an analysis of combustion phasing in a controlled auto-ignition (CAI) engine fuelled with gasoline. Auto-ignition was achieved using an exhaust gas trapping method via negative valve overlap (NVO). Under slightly lean mixture conditions variable intake and exhaust valves timings were applied in order to analyze influence of amount of retained exhaust on auto-ignition timing and combustion duration. Combustion on-set was independent of exhaust valve closing event, which was responsible for amount of trapped residuals. However, it was found that auto-ignition timing was determined by intake valve timing. Combustion duration was affected by both exhaust and intake valve timings. Direct injection allowed for application of different mixture formation strategies including in-cylinder fuel reforming during the NVO phase. When fuel was injected in the late stage of NVO increase of air-fuel ratio (AFR) caused a retard of auto-ignition and reduction of heat release rate. In contrast, opposite effect of AFR was observed if fuel was injected in the early stage of NVO, which resulted in its reforming. Increasing oxygen content during NVO influenced effects of reforming, thus determining combustion course. Split fuel injection, where the first injection timing was set constant in the NVO phase and the second fuel dose was injected during an intake process, allowed for improvement of engine thermal efficiency and exhaust emissions. Injection of the second fuel dose during a compression stroke resulted in advance of auto-ignition due to mixture stratification. However, at slightly lean mixture, stratification led to excessive emission of CO and drop of thermal efficiency.

Assessment of the Effect of Low Cetane Number Fuels on a Light Duty CI Engine: Preliminary Experimental Characterization in PCCI Operating Condition

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The goal of this paper is to acquire insight into the influence of cetane number (CN) and fuel oxygen on overall engine performance in the Premixed Charge Compression Ignition (PCCI) combustion mode. From literature, it is known that low reactive (i.e. low CN) fuels increase the ignition delay (ID) and therefore the degree of mixing prior to auto-ignition. With respect to fuel oxygen, it is known that this has a favorable impact on soot emissions by means of carbon sequestration. This makes the use of low CN oxygen fuels an interesting route to improve the applicability of PCCI combustion in diesel engines. In earlier studies, performed on a heavy-duty engine, cyclic oxygenates were found to consistently outperform their straight and branched counterparts with respect to curbing soot. This was attributed to a considerably lower CN. The oxygenate in question, cyclohexanone ($C_6H_{10}O$), has the advantage of being producible in a renewable way from lignin, a second generation biomass waste stream (e.g. paper pulp industry). To investigate the impact of cyclohexanone on diesel combustion and pollutant emissions in greater detail, a parametric test program was carried out in a joint project between Istituto Motori (Naples) and the University of Technology Eindhoven. To decouple the influence of a low cetane number and fuel oxygen content on the engine performance, diesel (commercial high quality diesel fuel), gasoline (commercial high quality gasoline) and cyclohexanone were blended into five mixtures, with varying cetane number or oxygen content. These blends were tested and compared on a modern single-cylinder light-duty (LD) direct injection (DI) research diesel engine. The results suggest that it is not possible to attribute favorable performance to either CN or fuel oxygen, but rather to the combination of both properties. In nearly all investigated work points, a decrease in CN led to a decrease in nitric oxides (NO_x) and particulate matter (PM), whilst slightly increasing carbon monoxide (CO) and unburned hydrocarbons (UHC). At an equal CN, the results suggest that fuel oxygen reduces soot emissions and also plays a role in suppressing UHC and CO emissions.

The Effect of Tumble Flow on Efficiency for a Direct Injected Turbocharged Downsized Gasoline Engine

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Direct gasoline injection combined with turbo charging and down sizing is a cost effective concept to meet future requirements for emission reduction as well as increased efficiency for passenger cars. It is well known that turbulence induced by in-cylinder air motion can influence efficiency. In this study, the intake-generated flow field was varied for a direct injected turbo charged concept, with the intent to evaluate if further increase in tumble potentially could lead to higher efficiency compared to the baseline. A single cylinder head with flow separating walls in the intake ports and different restriction plates was used to allow different levels of tumble to be experimentally evaluated in a single cylinder engine. The different levels of tumble were quantified by flow rig experiments. Two series of experiments were performed, one aiming to evaluate tumble in the region of low to medium load and engine speed, mainly focusing on efficiency, and one for the high load region to evaluate any negative consequences of increased tumble. The results indicate that tumble positively can influence the efficiency and emissions, however, the shape of the incoming flow dictate the level of impact significantly. Even for a relatively small change in tumble great differences in heat loss were seen. The efficiency increase seen originated mainly from lower heat loss through the exhaust gases. Additional gain came from lower in cylinder heat loss for the more favorable shape of the flow, where CFD indicates that the incoming air initially follows the cylinder head to a greater extent. Negative consequences are also associated with increased tumble. For instance, excessive pressure rise rates which can result in noise issues at higher loads. However, from a combustion perspective, the turbulence induced by the tumble positively effects the main parameters with reduced combustion duration, increased stability and increased exhaust gas recycling tolerance as well as increased combustion efficiency, features that are beneficial especially for a direct injected down sized turbo charged concept.

Effects of Ethanol Addition in RON 95 Gasoline on GDI Stratified Combustion

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The aim of this work is to study the effect of ethanol/gasoline blends on stratified operation in a single-cylinder GDI engine and to build up a large database that will be used to improve engine simulation codes. The effects of three different fuel blends are compared: a reference RON 95 fuel without oxygenates, E20 with 20% in volume of ethanol added to the RON 95 fuel, and E85 corresponding to 85% of ethanol added to the RON 95 fuel. The engine was equipped with a centrally-mounted piezoelectric injector. A wide range of engine speed and load operating conditions were studied: from 1000 to 4000 rpm and from 1.5 to 9 bar IMEP. Injection strategies were optimized using up to three injections per working cycle. It was shown that multi-injection is necessary to improve stratified combustion stability and to limit particulate emissions. Main effects of ethanol addition in gasoline are increasing laminar flame speed, lowering adiabatic flame temperature and elevating the latent heat value of the fuel. It was shown that ethanol addition leads to limited particulate emissions. It also has a positive effect on exhaust NOx emission reduction. For higher loads, exhaust CO emissions are reduced with ethanol addition. Ethanol addition in gasoline significantly improves combustion robustness to spark advance, start of injection timing and spark plug penetration in the combustion chamber. However, when decreasing load and engine speed, ethanol has a negative effect on the indicated efficiency. This is probably due to enhanced wall heat transfers with ethanol blends since a longer spray penetration may lead to combustion closer to the walls of the combustion chamber. The penalty on the lower heating value-corrected fuel specific consumption reached 19% with E85 vs. E0 at 1000 rpm / 2 bar IMEP. In the upper speed and load zone, at 3500 rpm / 8 bar IMEP, a 5% gain was observed.

Evaluating the Burning Velocity of Gaseous Fuels for Engine Applications: the DHARMA Project

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Characterization of combustion parameters of gaseous fuels is the main objective of a novel experimental laboratory, which recently became operational at Istituto Motori: the "Device for Hydrogen-Air Reaction Mode Analysis" (DHARMA in brief) project is meant to generate a systematic database on the burning properties of CH_4, H_2 and other species of interest, in conditions typical of i.c. engines. The experimental setup is based upon an optically accessible cylindrical bomb, where test are carried out on spherical expanding flames. High-speed shadowgraph is used to record the flame growth and to infer laminar burning parameters. Thorough details are given of the experimental apparatus and the data analysis. Experimental data are presented for the combustion in air of CH_4 and of CH_4/H_2 mixtures: the percentage of hydrogen was 20% and 30% (vol.). The tests have been performed under the same conditions: equivalence ratio was 1.0, initial pressure and temperature were 6.0 bar and 293 K, respectively. Data analysis yielded the laminar burning velocity and Markstein length: the variation of these parameters has been evidenced as a function of the hydrogen content. The obtained results have been compared to those available in literature, showing a good agreement.

Optical Investigation of the Effect on the Combustion Process of Butanol-Gasoline Blends in a PFI SI Boosted Engine

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The addition of alcohol to conventional hydrocarbon fuels for a spark-ignition engine can increase the fuel octane rating and the power for a given engine displacement and compression ratio. In this work, the influence of butanol addition to gasoline was investigated. The experiments were performed in an optical ported fuel injection single cylinder SI engine with an external boosting device. The engine was equipped with the head of a commercial SI turbocharged engine having the same geometrical specifications (bore, stroke and compression ratio). The effect of a blend of 20% of n-butanol and 80% of gasoline (BU20) on in-cylinder combustion process was investigated by cycle resolved visualization. The engine worked at low speed, medium boosting and wide open throttle. Changes in spark timing and fuel injection phasing were considered. Comparisons between the flame luminosity and the combustion pressure data were performed. The fuel was injected both at closed intake valve (CV) and open intake valve (OV). The spark timing was changed to identify the maximum brake torque and the knocking limit. Butanol blend allowed working in more advanced spark timing without occurrence of abnormal combustion. For the blend BU20, the duration of injection (DOI) was increased to obtain a stoichiometric mixture. For both fuels, at stoichiometric conditions, DOI in OV was maintained shorter than that in CV, due to the lower amount of fuel deposited on intake port and on piston surface. The combustion images showed a different combustion behavior injecting the fuel in CV and in OV conditions. In OV condition, several light spots were observed in the flame front region due to the condensed fuel attached on the optical piston wall. In CV condition, the light spots are bigger but less in number than in OV condition. For BU20 the previous phenomena were less evident due to the chemical composition of the blend that reduces the amount of fuel attached to the piston wall. For both fuels and at all engine conditions, a low variation of IMEP was observed (<5%). For BU20 injected at CV condition, the lowest IMEP value was measured for all spark timings.

Effect of the Multiple Injection on Stratified Combustion Characteristics in a Spray-Guided DISI Engine

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In this study, the single cylinder engine experiment was carried out to investigate the effect of multiple injections on stratified combustion characteristics in a spray guided direct injection spark ignition engine. The engine was operated at 1200 rpm. The total injection quantity applied was 11 mg/stroke to represent a low-load condition. Single injection and multiple injection were tested. Split ratio of each multiple strategies were 1:1 for double injection and 1:1:1 for the triple injection respectively. Dwell time between each injection was set to 200 μs. In the result of engine experiment with the single injection, indicated mean effective pressure was increased as injection timing was retarded to top dead center due to the increased effective work. However, the retardation of the injection timing was limited by the misfire occurrence resulted from the locally rich mixture generation under the high ambient pressure. Moreover, at the injection timing where the maximum indicated mean effective pressure was shown, hydrocarbon and smoke emissions were increased due to the locally rich area of the stratified mixture. The multiple injection strategy was applied to enhance the local homogeneity of the stratified mixture. In the result of engine experiment with the double injection, indicated mean effective pressure and combustion efficiency were increased. As an index of combustion instability, coefficient variation of indicated mean effective pressure was decreased significantly with the double injection. This result implies that the local homogeneity of the stratified mixture was enhanced by the double injection. Hydrocarbon and carbon monoxide emissions were decreased significantly with the double also. Nitrogen oxides emissions were increased due to the increased in-cylinder temperature resulted by more activated combustion. With the triple injection, the flammable injection timing window became narrower. Furthermore, indicated mean effective pressure and combustion efficiency were decreased. This is likely because the stratified mixture was formed on the upper position of the spark plug due to then shortened spray penetration.

Spectroscopic Measurements of Dual Fuel PCCI Engine

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In this work, optical diagnostics were applied in a transparent DI diesel engine equipped with the head of Euro5 commercial engine and the last generation CR injection system. In order to realize the PCCI combustion the injection of neat bio-ethanol was performed in the intake manifold and European commercial diesel fuel was injected into the cylinder. Different amounts of bio-ethanol were injected in order to create PCCI combustion with high levels of pre-combustion mixing, and to ensure low equivalence ratio and low flame temperatures too. UV-Visible imaging and spectroscopic measurements were performed in the engine in order to investigate the autoignition of the charge and the combustion process, respectively. In particular, the detection of the species involved in the combustion, like OH, HCO, and CH, was performed. The relevance of the radicals and species on PCCI were evaluated and compared with the data from thermodynamic analysis.

Effects of Low Pressure EGR on Transient Air System Performance and Emissions for Low Temperature Diesel Combustion

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Low pressure EGR offers greater effectiveness and flexibility for turbocharging and improved heat transfer compared to high pressure EGR systems. These characteristics have been shown to provide potential for further NO_x, soot, and fuel consumption reductions in modern diesel engines. One of the drawbacks is reduced transient response capability due to the long EGR path. This can be largely mitigated by combining low pressure and high pressure loops in a hybrid EGR system, but the changes in transient response must be considered in the design of an effective control strategy. The effect of low pressure EGR on transient emissions was evaluated using two different combustion strategies over a variety of transient events. Low pressure EGR was found to significantly lengthen the response time of intake oxygen concentration following a transient event, which can have a substantial effect on emissions formation. The difference in response time between the two EGR systems has important implications for prediction of transient emissions based on steady state mode points since the correlation between transient and steady state emissions may change substantially when low pressure EGR is implemented. NO emissions were found to be the most sensitive to intake oxygen concentration settling time, particularly for the kinetically controlled early injection combustion mode, resulting in large increases in transient emissions relative to steady state levels.

Measurement of Equivalence Ratio in a Light-Duty Low Temperature Combustion Diesel Engine by Planar Laser Induced Fluorescence of a Fuel Tracer

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The spatial distribution of the mixture equivalence ratio within the squish volume is quantified under non-combusting conditions by planar laser induced fluorescence (PLIF) of a fuel tracer (toluene). The measurements were made in a single-cylinder, direct-injection, light-duty diesel engine at conditions matched to an early-injection low temperature combustion mode. A fuel amount corresponding to a low load (3.0 bar indicated mean effective pressure) operating condition was introduced with a single injection. Data were acquired during the mixture preparation period from near the start of injection (-22.5° aTDC) until the crank angle where the start of high-temperature heat release normally occurs (-5° aTDC). Despite the opposing squish flow, the fuel jets penetrate through the squish region to the cylinder bore. Although rapid mixing is observed in the head of each jet, rich regions remain at the head at the start of high-temperature heat release. In contrast, the fuel mixture is generally lean in the clearance volume above the bowl, though near-stoichiometric pockets are observed near the bowl rim. Significant pockets of mixture in the central clearance volume, and between the jets in the squish volume, are sufficiently lean that complete oxidation is unlikely.

IFP Energies Nouvelles Approach for Dual-Fuel Diesel-Gasoline Engines

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Compared to Spark Ignition (SI) engines, Compression Ignition (CI) engines are more efficient because of the higher compression ratios and leaner operation. However, thanks to stoichiometric air fuel ratio, SI engines allow an efficient pollutants after treatment, particularly for NO_x emissions. In this context, IFP Energies nouvelles (IFPEN) has developed the concept of Diesel-Gasoline combustion in order to combine the advantages of both fuels and both combustion processes. Focusing on a passenger car application, experiments have been performed using a modified DI turbocharged small Diesel engine (the combustion chamber has been redesigned and port fuel injectors have been added). In-Cylinder Fuel Blending (ICFB) using port-fuel-injection of gasoline and optimized direct injection of Diesel was used to control combustion phasing and duration. This modified engine can still run on Diesel alone. ICFB mode is considered, either with a lean mixture, or at stoichiometric air fuel ratio to perform NO_x after treatment via a 3 way catalyst. The objective is to control the NO_x emissions over the whole operating range of the engine, while maintaining attractive fuel efficiency. In this paper, IFP Energies nouvelles describes the main results of Diesel-Gasoline Combustion, in order to understand what would be the best approach in terms of technological feasibility, fuel efficiency and pollutant emissions. The potential of the dual fuel concept has been investigated on several part load operating conditions, focused on a 2000 rpm engine speed. The operable range of load in ICFB combustion is extended from 7 to 16.5 bar IMEP. BSFC at part load is as low as that of a Diesel engine. At higher load, NOx emissions are very low (<0.5 g/kWh at 10 bar IMEP) and allow lean mixture operation until 14 bar IMEP. Outside of this ICFB operating range, the performance in full Diesel mode remains totally acceptable.

The Twin Swirl "MR-Process" Combustion Mechanism and Conversion of Diesel Engines to Operate with Gaseous Fuels

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Converting diesel engines to cheaper and cleaner fuels like LPG and CNG, with conventional methods needs a different combustion chamber, which has a lower compression ratio than a diesel engine (>16:1) due to risk of detonation. This alteration makes the conversion process more expensive and difficult. On the other hand, decreasing a compression ratio leads to lower performance and efficiency compared to those of the original engine. To overcome this disadvantage it is proposed a novel mechanism for mixture formation and combustion, named as "MR-Process". This mechanism is realized in a combustion chamber MR-2 with twin-swirl turbulent flow. This chamber is suitable for operation with diesel fuels as well as with LPG and NG. In this paper are presented theoretical and experimental investigations of engines operating with "MR-Process" combustion mechanism.

Experimental Heat Flux Analysis of an Automotive Diesel Engine in Steady-State Operation and During Warm-Up

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Advanced thermal management systems in passenger cars present a possibility to increase efficiency of current and future vehicles. However, a vehicle integrated thermal management of the combustion engine is essential to optimize the overall thermal system. This paper shows results of an experimental heat flux analysis of a state-of-the-art automotive diesel engine with common rail injection, map-controlled thermostat and split cooling system. Measurements on a climatic chamber engine test bench were performed to investigate heat fluxes and energy balance in steady-state operation and during engine warm-up from different engine start temperatures. The analysis includes the influence of the operating point and operating parameters like EGR rate, injection strategy and coolant temperature on the engine energy balance.

High-Resolution Transmission Electron Microscopy of Soot Directly Sampled at Different Axial Locations in a Diesel Spray Flame

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For better understanding of soot formation and oxidation processes in a diesel spray flame, morphology, microstructure and size of soot particles directly sampled at different locations in the spray flame (40mm to 90mm from injector nozzle tip) were investigated using a high-resolution transmission electron microscope (HRTEM). The diesel spray flame was achieved in a constant volume combustion chamber under diesel-like conditions (2.5MPa and 940K). The concentration, diameter of primary particles and the radius of gyration of soot aggregates increased in the upstream region (40 to 50mm), exhibited a peak around the mid-stream region (60 to 70mm), and then decreased in the downstream region (80 to 90mm) from the injector nozzle tip, which corresponds to formation, peak concentration and oxidation of soot particles in the spray flame, respectively. The fractal dimension of soot aggregates was also analyzed and is almost constant, with a value of approximately1.73over different axial locations in the spray flame.

Fuel Injection and Combustion Process _Modeling

Fuel Injection and Combustion Process _Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Electric Vehicle with Combustion Engine Assist (EV-CEA)

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Today, electric powered vehicles are in the focus of politics and the economy. They are very practicable and useful for limited ranges (about 100km) but for various reasons, such as battery aging, demand for heating, traffic jams etc., this already decreased driving range is not always attainable. In such cases, electrical energy can be generated with a more or less large combustion engine, a so called range extender. Such parallel and serial range extender systems are being tested at the moment. In the following paper, the advantages and disadvantages from small range extender systems ("coming home"-systems) and also concepts without restrictions (two electric motors; e.g. Toyota Prius, VW twin drive etc.) will be discussed and the CEA concept for a Mega City Electric Vehicle, developed by IVD, will be presented. This concept is based on a vehicle from the A-C segment with pure electric propulsion, which is supported by an internal combustion engine at higher speeds. This way, the vehicle remains a pure electric vehicle in urban areas and also reaches acceptable ranges overland. An essential aspect is that the CEA-system has just one electric motor for both driving and generating. Thus, the generator as a second electric motor incl. power control unit is not needed. Potentials and challenges caused by the direct implementation of the internal combustion engine in the electric propulsion will be presented.

Model-based Assessment of Hybrid Powertrain Solutions

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This paper shows the main results of a research activity carried out in order to investigate the impact of different hybridization concepts on vehicle fuel economy during standard homologation cycles (NEDC, FTP75, US Highway, Artemis). Comparative analysis between a standard passenger vehicle and three different hybrid solutions based on the same vehicle platform is presented. The following parallel hybrid powertrain solutions were investigated: Hybrid Electric Vehicle (HEV) solution (three different levels of hybridization are investigated with respect to different Electric Motor Generator size and battery storage/power capacity), High Speed Flywheel (HSF) system described as a fully integrated mechanical (kinetic) hybrid solution based on the quite innovative approach, and hydraulic hybrid system (HHV). In order to perform a fare analysis between different hybrid systems, analysis is also carried out for equal system storage capacities. All hybrid powertrain architectures include state-of-the-art hybrid components and are analyzed from the aspects of fuel economy related to the overall system efficiency, load point moving of the internal combustion engine due to energy flow control strategy operation, and regenerative braking (applying realistic drivability constraints). The simulations were performed within the IAV-VeLoDyn software environment. VeLoDyn (Vehicle Longitudinal Dynamics Simulation) is a modular and highly flexible Simulink-based software tool, which offers a straightforward simulation of longitudinal vehicle dynamics with special considerations on the driveline and model management functionality. In order to provide control and management of the hybrid powertrain system, a cycle-independent control strategy has been implemented into the supervisory hybrid control unit model, based on Equivalent Consumption Minimization Strategy (ECMS) approach. Due to the modular nature of the simulation tool, the control strategy was effectively implemented in all analyzed hybrid models with marginal modifications. In order to determine energy flows and validate hybrid powertrain behavior, a cycle-based energetic analysis was carried out, and the main results are presented in the paper.

Methodology Procedure for Hybrid Electric Vehicles Design

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Nowadays, fuel economy and pollutant emissions are keenly felt topics and hybrid electric vehicles (HEVs) represent the best opportunity to respond to this problem in the short term. Hybrid electric vehicles meet the high-efficiency of electric motors, with the high reliability of the internal combustion engines, granting optimal results both in terms of emissions and fuel economy. The vehicle and path features highly affect the architecture choice. A parallel architecture, having a more flexible layout and providing a higher drive power, is more suitable for long paths and higher speeds, while the series one better adapts to urban cycles, as can be switched to a pure electric mode. At the same time, a parallel-series architecture is in general a good choice. Another crucial point is the definition of a control strategy suitable for the mission the car is expected to accomplish, that must properly control both the load partitioning, between engine and motors, and the regenerative braking. According to all these considerations, with the present paper the Authors intend to lay the basis of a comprehensive methodology, which can allow to simply define an optimized powertrain layout, i.e. architecture and devices size, and an efficient control strategy. To this aim, our research group has developed an analytical code that simulates the power flows in HEV powertrain and allows to calculate the performances of a specific vehicle upon various and different missions. By knowing the energy required, the model allows to define a range of admissible states for each time step, resulting of the combination of the engine power and the corresponding motor power, considering regenerative braking and constraints imposed by the engine, the motors and the storage system. The best solution between all possible layouts is found with Dijkstra shortest path optimization algorithm electing the configuration allowing the minimum fuel consumption.

Design and Control of a Mobile Solar Roof for a Solar Vehicle

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The integration of photovoltaic (PV) panels on electric and hybrid vehicles is gaining interest, thanks to the increasing fleet electrification, the improvement in solar panel efficiency and the reduction in their costs. In order to maximize the solar contribution, the adoption of self-orienting solar roof when the vehicle is parked can be considered. In the paper, the authors present a study on the energy management of a moving solar roof, as a 3 d.o.f. parallel robot, in a solar assisted vehicle. A model based control is developed, based on combined use of measured solar power, image processing form a digital camera and data provided by a GPS module, and implemented over a small scale prototype. An optimal tracking strategy, considering the effects of different insolation and of mechanical losses, is also presented.

Optimal Use of HLA Systems

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In the recent years, a new interest on kinetic energy recovery (KER) of vehicles arose. In USA, car manufacturers (Ford, Sheep et al.) developed research programs on the use of hydraulic devices to realize KER system, also with economical support of government body (EPA). In 2002 Ford built a very interesting prototype (Ford Tonka) using such recovery device (named HLA, Hydraulic Launch Assist), achieving very interesting improvements of fuel economy and pollution, besides increasing of acceleration and making feasible downsizing of thermal engine. Nowadays, also D.I.M.E.G. of University of L'Aquila (Italy) is working about HLA systems and, in order to study its behaviour, a simulation model (named V&HLA-SC) particularly useful to evaluate its energetic efficiency and performance has developed. The studies here reported show that the system efficiency may be modified by different ways of driving a mission that is characterized by different braking and acceleration time, mantaining constant elapsed time and covered distance. In such a way, optimal driving strategies and/or control system laws may be suggested to optimize the cyclic process of recovering and reusing kinetic energy, i.e. to achieve the optimal use of HLA system, especially in urban areas.

One Dimensional Modeling and Experimental Validation of Single Cylinder Pneumatic Combustion Hybrid Engine

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The objective of this paper is to present and to validate a numerical model of a single-cylinder pneumatic-combustion hybrid engine. The model presented in this paper contains 0-D sub-models for non-spatially distributed components: Engine cylinder, Air tank, wall heat losses. 1-D sub-models for spatially distributed components are applied on the compressive gas flows in pipes (intake, exhaust and charging). Each pipe is discretized, using the Two-Steps Lax-Wendroff scheme (LW2) including Davis T.V.D. The boundaries conditions used at pipe ends are Method Of Characteristics (MOC) based. In the specific case of a valve, an original intermediate volume MOC based boundary condition is used. The numerical results provided by the engine model are compared with the experimental data obtained from a single cylinder prototype hybrid engine on a test bench operating in 4-stroke pneumatic pump and 4 stroke pneumatic motor modes. In each mode, the prediction of the mass flow rates, amplitude and timing of the charging pipe waves are satisfactory, without using any discharge coefficient. Indicated work and p-V diagrams are similar between simulation and measurements in the case of pneumatic pump mode. For the pneumatic motor mode the model underestimates cylinder pressure during the charging process.

Potential of Reduced Fuel Consumption of Diesel-electric APUs at Variable Speed in Mobile Applications

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Auxiliary power units (APUs) are used in mobile applications to provide electrical power until approx. 10 kW. It is state of the art that these generators are driven by a diesel engine at constant speed and are selected according to the expected maximal power needed. These systems have a low efficiency and consequently a high fuel consumption particularly when driven at small loads. The system can yield a higher efficiency for partial load conditions by reducing the rotary speed of the driving diesel engine. The optimum in rotary speed of the diesel engine for different loads is pre-programmed (engine mapping) in the diesel control unit. A frequency converter allows a constant frequency of the electricity output at variable speed of the generator. These higher costs for frequency converter and diesel controller demand especially for mobile applications a proof of efficiency, i.e. a proof of economics, which is shown in this paper. A diesel electric drive train has been mounted on the test rig consisting of a diesel engine, a permanent magnet synchronous generator, a frequency converter and an electric load. The components were analysed individually in a first step to determine the efficiency characteristics. With the individual efficiencies of the components, the total efficiency of the drive train can be calculated in respect to rotary speed and torque. Relevant load profiles where chosen which represent typical duty cycles in stationary and mobile applications. The consumption of the variable speed generator was tested and the control parameters for the diesel engine were optimized using a simulation model. The final control parameters were implemented into the diesel controller at the test rig. The recorded experimental results were compared to the simulation results. The test results proved the precise prediction of fuel consumption by the simulation model. Tests and simulations resulted in a reduction of fuel consumption of about 30% for all of the relevant load profiles compared to the state of the art power units operating at constant speed of revolution. Further fuel saving potential was achieved with a start/stop-function which stops the diesel engine after a determined time period when no power is needed in order to avoid idle operation periods. An economic analysis concludes this study. It was proved that the higher investment costs will be amortized within approx. one year.

Control Strategies for Light-Duty Diesel-Hybrid Powertrains

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Hybrid Electric Vehicles (HEVs) represent a powerful technology to save fuel and reduce CO_2 emissions, through the synergic use of a conventional internal combustion engine and one or more electric machines. However their performance strongly depends on the control strategy that shares the power demand among the engine and the electric motors at each time instant, with the objective of minimizing a pre-defined cost function over an entire driving cycle, and satisfying, at the same time, any additional constraints. The aim of this work is therefore the definition of a methodology to develop, through numerical simulation, a sub-optimal hybrid powertrain controller: starting from the problem definition, the ideal performance for a case study hybrid architecture was analyzed through a global optimization algorithm in order to point out information which can be used to define new control laws. Coupling these information with an approach based on the instantaneous minimization of a cost function, a sub-optimal energy management system was then developed trying to merge the strength of global optimization algorithm with the low computational requirements of heuristic strategies. Finally, the powertrain controller previously developed was implemented in a detailed vehicle model and tested through numerical simulations over different driving cycles in order to compare its performance with the upper bound set by the results achieved by the global optimization algorithm.

A Design Procedure for Alternative Energy Storage Systems for Hybrid Vehicles

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Although electrochemical batteries are the mainstream for hybrid vehicle energy storage, there is continuing interest in alternative storage technologies. Alternative energy storage systems (AESS), in the form of mechanical flywheels or hydraulic accumulators, offer the potential to reduce the vehicle costs, compared to the use of electrochemical batteries. In order to maximize the benefits of mechanical or hydraulic energy storage, the system design must maximize the energy recuperation through regenerative braking and the use of the energy stored with high roundtrip efficiency, while minimizing system volume, weight and cost. This paper presents a design procedure for alternative energy storage systems for mild-hybrid vehicles, considering parallel hybrid architecture. The procedure is applied with focus on the definition of design parameters and attributes for a hydraulic AESS with high pressure accumulator. The design methodology is based on a definition of targets and constraints for the AESS, obtained from a statistical analysis of the energy and power requirements of a variety of drive cycles. The design obtained was then implemented in an energy-based simulator over a selected variety of driving cycles. A comparison of performance (including power, energy and roundtrip efficiency) is conducted to evaluate the benefits provided by the hydraulic ESS for energy recuperation while comparing different design methods.

Energy-efficient Management of a Light-Duty Parallel-Hybrid Diesel Powertrain with Belt Alternator Starter

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The paper presents the main results of a study on the simulation of energy efficient management of on-board electric and thermal systems for a medium-size passenger vehicle featuring a parallel-hybrid diesel powertrain with a high-voltage belt alternator starter. A set of advanced technologies has been considered on the basis of very aggressive fuel economy targets: base-engine downsizing and friction reduction, combustion optimization, active thermal management, enhanced aftertreatment and down speeding. Mildhybridization has also been added with the goal of supporting the downsized/downspeeded engine performance, performing energy recuperation during coasting phases and enabling smooth stop/start and acceleration. The simulation has implemented a dynamic response to the required velocity and manual gear shift profiles in order to reproduce real driver behavior and has actuated an automatic power split between the Internal Combustion Engine (ICE) and the Electric Machine (EM). Typical parallel hybrid technology functions, such as Stop&Start, regenerative braking and power assistance from the EM have all been implemented in the GT-Drive model. After model calibration and validation versus the available experimental data, the energy management strategies of such a hybrid configuration were investigated. The results obtained for the New European Driving Cycle (NEDC) and a Real Life Driving Cycle (RLDC) have been discussed, in terms of fuel economy and performance.

Self-Learning Neural Controller for Hybrid Power Management using Neuro-Dynamic Programming

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A supervisory controller strategy for a hybrid vehicle coordinates the operation of the two power sources onboard of a vehicle to maximize objectives like fuel economy. In the past, various control strategies have been developed using heuristics as well as optimal control theory. The Stochastic Dynamic Programming (SDP) has been previously applied to determine implementable optimal control policies for discrete time dynamic systems whose states evolve according to given transition probabilities. However, the approach is constrained by the curse of dimensionality, i.e. an exponential increase in computational effort with increase in system state space, faced by dynamic programming based algorithms. This paper proposes a novel approach capable of overcoming the curse of dimensionality and solving policy optimization for a system with very large design state space. We propose developing a supervisory controller for hybrid vehicles based on the principles of reinforcement learning and neuro-dynamic programming, whereby the cost to-go function is approximated using a neural network. The controller learns and improves its performance over time. The simulation results obtained for a series hydraulic hybrid vehicle over a driving schedule demonstrate the effectiveness of the proposed technique.

0D-1D Coupling for an Integrated Fuel Economy Control Strategy for a Hybrid Electric Bus

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Hybrid electric vehicles (HEVs) are worldwide recognized as one of the best and most immediate opportunities to solve the problems of fuel consumption, pollutant emissions and fossil fuels depletion, thanks to the high reliability of engines and the high efficiencies of motors. Moreover, as transport policy is becoming day by day stricter all over the world, moving people or goods efficiently and cheaply is the goal that all the main automobile manufacturers are trying to reach. In this context, the municipalities are performing their own action plans for public transport and the efforts in realizing high efficiency hybrid electric buses, could be supported by the local policies. For these reasons, the authors intend to propose an efficient control strategy for a hybrid electric bus, with a series architecture for the power-train. To this aim, an integrated approach realized by coupling a zero-dimensional model of the vehicle with a mono-dimensional model of the thermal engine to evaluate fuel consumption and find the most suitable control strategy for the engine (totally decoupled to the mission). A kinematic approach has been implemented. The power required to the motor is defined by knowing the speed and altitude profiles related to the path, while the power request for the engine is calculated by means of a first order filter, which properly cuts the power load of the motor. A sensitivity analysis has been performed in order to define the optimal operating strategy for the engine, to minimize the fuel consumption. Moreover, a control on the state of charge (SOC) has been implemented to assure a correct use of batteries and avoid damages.

Wireless Transmission of Electric Energy

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This article focuses on the wireless transfer of energy. It describes the operation of a transformer without magnetic circuit associated with a resonant inverter to meet the constraints imposed by mobile sources (catenaries with magnetic induction to power electric vehicles). The receiving and transmitting units consist of an air-gap transformer and a generator who feeds the transformer. In this article, we show how to determine the transformer's parameters and configuration needed for this transfer to be efficient. The transformer is fed by a half-bridge converter for serial resonant load. The primary winding of the transformer is fixed on the ground. The secondary winding can move horizontally in a parallel plane of that of the primary. This application targets mainly the transfer of static electricity for the charging of batteries and super capacitors in electric cars and trams.

A Compact 10 kW Electric Power Range Extender Suitable for Full Electric and Plug-in Series Hybrid Vehicles

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The paper discusses the concept, specification and overall performance of a 10 kW electric power range extender suitable for electric plug-in and series hybrid vehicles, based on a single cylinder, high speed, four stroke internal combustion engine, tested and developed at Istituto Motori CNR of Italy. This unit has been conceived from the beginning as a compact on board recharging system for the mentioned kind of means, and especially for city cars and small commercial vehicles. The paper starts by defining some characteristics, advantages and drawbacks of an electric city car, followed by the criteria adopted to characterize the nominal power of the range extender. Then, the ratio which leaded to the adoption of a single cylinder internal combustion engine is discussed, followed by an explanation of the main design characteristics of the whole unit. The latter has been re-designed and constructed by means of mass produced elements only, in order to reduce cost coming from new design and manufacture. The use of liquid cooling for the engine and the electric generator permitted to make the whole unit very compact and completely packaged, allowing an easy application on the vehicle. After field test, a complete description of its running behavior has been reported; the unit has been tested with conventional unleaded gasoline, but it's ready to be converted to ethanol and methanol gasoline blends or LPG if required.

An Energetic Comparison for Hybrid Vehicles Ranging from Low to High Degree of Hybridization

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The efficiency achievable with effective energy management strategies represents a key issue for modern hybrid electric vehicles (HEVs). In this paper, by comparing different HEVs architectures with the same power to weight ratio, the dependence of energy consumption on different degrees of hybridization and powertrain architectures is analyzed. The fuel economy achievable by using dynamic programming based strategies is considered as the benchmark. The comparative study analyzes also the influence of driving cycles and the impact of plug-in concepts both on fuel economy and battery lifetime. Numerical results on realistic vehicles highlight the higher energy saving potentialities offered by parallel HEVs, while series HEVs remain of interest because of their simpler energy management and higher suitability for plug-in operations.

On-Board Plasma-Assisted Fuel Reforming

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It is well known that the addition of gaseous fuels to the intake manifold of diesel engines can have significant benefits in terms of both reducing emissions of hazardous gases and soot and improving fuel economy. Particularly, the addition of LPG has been investigated in numerous studies. Drawbacks, however, of such dual fuel strategies can be found in storage complexity and end-user inconvenience. It is for this reason that on-board refining of a single fuel (for example, diesel) could be an interesting alternative. A second-generation fuel reformer has been engineered and successfully tested. The reformer can work with both gaseous and liquid fuels and by means of partial oxidation of a rich fuel-air mix, converts these into syngas: a mixture of H_2 and CO. The process occurs as partial oxidation takes place in an adiabatic ceramic reaction chamber. High efficiency is ensured by the high temperature inside the chamber due to heat release. Thus, efficient thermal insulation is crucial to maintain said temperature. Heat recuperation from the reformer exhaust also improves the thermal efficiency. The prototype yields up to 20% of H_2 (80% of the theoretical maximum) and 22% of CO with all kinds of fuels tested, including automotive diesel fuel. Efficient thermal insulation allows to keep the dimensions below 40 cm in any direction for a full burning power of 10–30 kW while outer wall of the reformer is exposed to air at normal temperature.

2-Stroke High Speed Diesel Engines for Light Aircraft

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The paper describes a numerical study, supported by experiments, on light aircraft 2-Stroke Direct Injected Diesel engines, typically rated up to 110 kW (corresponding to about 150 imperial HP). The engines must be as light as possible and they are to be directly coupled to the propeller, without reduction drive. The ensuing main design constraints are: i) in-cylinder peak pressure as low as possible (typically, no more than 120 bar); ii) maximum rotational speed limited to 2600 rpm. As far as exhaust emissions are concerned, piston aircraft engines remain unregulated but lack of visible smoke is a customer requirement, so that a value of 1 is assumed as maximum Smoke number. For the reasons clarified in the paper, only three cylinder in line engines are investigated. Reference is made to two types of scavenging and combustion systems, designed by the authors with the assistance of state-of-the-art CFD tools and described in detail in a parallel paper. The former is a uniflow system, featuring two exhaust valves per cylinder in the engine head, piston controlled inlet ports and a combustion bowl in the piston; the latter is a loop scavenged design, with both inlet and exhaust ports controlled by the piston, and a non conventional combustion chamber in the engine head (no bowl in the piston). All the calculations presented in the paper are performed by using GT-Power models calibrated by means of CFD-3D calculations (by KIVA-3V) and experiments. The experimental support is provided by two engines: the former is a modern commercial aircraft 2- Stroke Diesel engine, indirect injected, uniflow scavenged; the latter is a research engine based on an old marine unit, featuring loop scavenging and direct injection. The calibration of the GT-Power models is reviewed in the paper.

Non-Equilibrium Plasma Ignition for Internal Combustion Engines

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Burning of highly diluted homogeneous mixtures, such as ultra-lean mixtures or mixtures involving heavy exhaust gas recirculation (EGR), can enable very efficient and low emission combustion. The challenge herein lies in overcoming the inherently slow flame propagation and ignition problems for these mixtures. One way of accomplishing this is to use stratified charge operation (e.g. fuel stratified injection), another by homogeneous charge compression ignition. Both combustion strategies, however, typically suffer from high unburned hydrocarbon emissions and difficulties in controlling the combustion timing and rates, notably during transient operating conditions. High-voltage nanosecond gas discharge has been shown to be an efficient way to ignite ultra-lean fuel air mixtures in a bulk volume, thanks to its ability to produce both high temperature and radical concentration in a large discharge zone. Recently, a feasibility study has been carried out to study plasma-assisted ignition under high-pressure high-temperature conditions similar to those inside an internal combustion engine. The experiments were carried out in a rapid compression machine with an option of installing custom-designed ignition devices into the cylinder cap. Propane-air mixtures of different stoichiometries were tested at various pressure-temperature conditions. Ignition delay times were measured during the tests, and were shown to be decreasing under high-voltage plasma excitation. The discharge allowed instant control of ignition, and specific electrode geometry designs enabled volumetric ignition even at high-pressure conditions. Measurements of ignition delay times were carried out in rapid compression machine (RCM) experiments with various discharge devices enabling high-voltage excitation of the fuel-air mixture. Various discharge modes were shown to be efficient in shortening and controlling the ignition delay times in conditions corresponding to different engine operation modes. Certain geometry designs have been shown to lead to volumetric ignition inside the combustion chamber.

Process Improvement within an Advanced Car Diesel Engine in Base on the Variability of a Concentric Cam System

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The process improvement within an advanced car diesel engine is strongly focused on the scavenging technique, on the mixture formation strategy using direct fuel injection as well as on the combustion control. The paper presents the potentials of process improvement by the variability of the scavenging timing combined with an adaptation of gas exchange, injection and mixture formation parameters. The scavenging timing is controlled by a new developed concentric cam system. The analysis is based on a combined 1D/3D simulation of the thermodynamic process stages within the engine with model calibration by numerous experimental results. The paper presents the effects of cam profile variation and camshaft phasing for two part load operating points of NEDC (New European Driving Cycle). Compared results are presented in terms of swirl rates, fuel distribution, combustion temperature, NO_x and soot curves.

Effects of Air-Hydrogen Induction on Performance and Combustion of a Diesel Engine

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The strategy of using hydrogen as an additive fuel for the diesel engine to improve exhaust emissions and combustion efficiency has been explored by many researchers in the last decade. The effects of pure hydrogen or the hydrogen-oxygen mixture generated by water electrolysis fueling car or heavy-duty diesel engines were studied, with notably different results. In the present work the supplementary fuel used was the gas produced by the water electrolysis process in a reactor with a special electrode design. Hydrogen-oxygen mixture or pure hydrogen was inducted with air in the engine intake manifold. Performance and emissions characteristics of a 3.6 liters tractor engine, naturally aspirated, were investigated for different operating conditions with gas substitution of diesel fuel up to 12% on energy basis. As expected, significant reductions of smoke, CO and CO_2 up to 25%, 11% and 4% respectively were obtained by increasing the aspiration of gas, while NO_x concentrations were higher up to 12%. A slight sacrifice in engine efficiency up to 2% when increasing the gas percentage was also found, which was correlated with the combustion characteristics. Alternative experiments conducted with pure hydrogen as complementary fuel did not result in significant differences in engine performance by comparison with hydrogen-oxygen mixture fuelling.

Mixture Formation in Direct Injection Hydrogen Engines: CFD and Optical Analysis of Single- and Multi-Hole Nozzles

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This paper describes the validation of a CFD code for mixture preparation in a direct injection hydrogen-fueled engine. The cylinder geometry is typical of passenger-car sized spark-ignited engines, with a centrally located injector. A single-hole and a 13-hole nozzle are used at about 100 bar and 25 bar injection pressure. Numerical results from the commercial code Fluent (v6.3.35) are compared to measurements in an optically accessible engine. Quantitative planar laser-induced fluorescence provides phase-locked images of the fuel mole-fraction, while single-cycle visualization of the early jet penetration is achieved by a high-speed schlieren technique. The characteristics of the computational grids are discussed, especially for the near-nozzle region, where the jets are under-expanded. Simulation of injection from the single-hole nozzle yields good agreement between numerical and optical results in terms of jet penetration and overall evolution. The 13-hole nozzle creates intense jet-to-jet interaction, with all jets merging into a single effective jet immediately downstream of the under-expanded region. This phenomenon (usually referred as Coanda Effect) is more challenging to the numerical simulation and requires higher level of detail in numerical simulation and grid resolution, with particular regard to the fields near the injector nozzle.

Influence of the Flow Field on the Flame Propagation in a Hydrogen-Fueled Internal Combustion Engine

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Flame propagation in an optically accessible hydrogen-fueled internal combustion engine was visualized by high-speed schlieren imaging. Two intake configurations were evaluated: low tumble with a tumble ratio of 0.22, corresponding to unmodified intake ports, and high tumble with a tumble ratio of 0.70, resulting from intake modification. For each intake configuration, fueling was either far upstream of the engine, with presumably no influence on the intake flow, or the fuel was injected directly early during the compression stroke from an angled single-hole injector, adding significant angular momentum to the in-cylinder flow. Crank-angle resolved schlieren imaging during combustion allowed deducing apparent flame location and propagation speed, which were then correlated with in-cylinder pressure measurements on a single-cycle basis. In a typical cycle, flame shape and convective displacement are strongly affected by the in-cylinder flow. For homogeneous fueling with low tumble, the flame is convected little, growing without significant wrinkling with a shape that is quite symmetric in the vertical plane. In contrast, in the other cases the flame is convected and stretched. Ensemble averaged results show that for fully homogeneous conditions the increase in tumble ratio from 0.22 to 0.70 results in increased flame growth and shorter combustion duration. For the stratified mixture, two regimes were observed: Early in the combustion, the flame grows faster for high intake-induced tumble, while during middle and late combustion low tumble yields a faster burn rate with an overall shortest combustion. On a single-cycle basis, early flame growth strongly correlates with the crank angle at which 5% of the fuel mass is burned. Convection is characterized by the displacement of the flame's projected area centroid, revealing that the multi-cycle centroid cloud spreads with time and that the cycles follow different paths corresponding to their flame speed: typically the slow cycles stay near the ignition point and at the top of the centroid cloud. For direct injection, the ensemble average centroid speeds are relatively high in the beginning and then slowly decrease. In contrast, with homogeneous fueling the centroids have nearly constant convective speed.

Experimental Activity on a Hydrogen Fuelled S.I. Engine with Two-Step D.I.

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An innovative hydrogen DI system was conceived, realized and tested that requires only 12 bar rail pressure, typical value of PFI systems, and does not need special injectors. The purpose is to combine the well known benefits of DI with the ones of PFI. The injection is accomplished in two steps: at first hydrogen, metered by an electroinjector (a conventional one for CNG application), enters a small intermediate chamber; then it is injected into the cylinder by means of a mechanically-actuated valve that allows very high flow rate (compared with the one of electroinjectors). In-cylinder injection starts at intake valve closing (an earlier injection start could lead to backfire) and stops early enough to allow proper charge homogeneity and, in any case, before cylinder pressure rise constrains hydrogen admission. The prototype engine was realised modifying a production single-cylinder 650 cm3 engine with three intake valves. The central one was modified and properly timed to inject hydrogen into the cylinder from the intermediate chamber. The experimental results satisfied the expectations. The prototype engine ran properly at full load, without pre-ignition, knocking or roughness even with stoichiometric or slightly rich mixtures, providing higher maximum power than with gasoline. Also at part load the engine proved to work correctly even with very lean mixtures (till $\lambda \sim 4$), reaching its maximum brake thermal efficiency with $\lambda \sim 2.4$.

Fuel Injection and Combustion Process _Modeling

Fuel Injection and Combustion Process _Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Nano-sized Additive Synthesis for Lubricant Oils and Compatibility Tests with After-treatment Catalysts

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Molybdenum sulfide nanoparticles have been successfully obtained, for lubricant applications, by means of a wet chemical synthesis in an aqueous solution employing ammonium molybdate, citric acid and ammonium sulfide as the reactants. Some molybdenumcitrate complexes were formed and they reacted with the ammonium sulfide to form MoS_2 nanoparticles. Mo:citrate molar ratio was identified as being the most relevant of the synthesis parameters that affected the phase and morphology of the final products. The optimized nanopowders were softly agglomerated and amorphous, with a mean size of the primary particles of about 30 nm. The compatibility between the thus obtained MoS_2 nanopowders and some commercial after-treatment catalysts for Diesel vehicle engines was tested. Diesel oxidation, soot combustion and ammonia-SCR de-NO_x catalysts were considered as were the possible effects on the catalytic activity and their possible reaction to the MoS_2 additive. In general, the presence of the MoS_2 nano-additive has been demonstrated to slightly decrease the catalytic performance of the commercial catalysts, especially for the Diesel oxidation and SCR ones. The chemical-physical analyses did not detect any interaction between the catalysts and nano-additives or any decrease in the specific surface areas of the catalysts.

Comparative Studies of Particles Deposited in Diesel Particulate Filters Operating with Biofuel, Diesel Fuel and Fuel Blends

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Macroscopic studies and scanning electron microscope (SEM), as well as transmission electron microscope (TEM) research were carried out to investigate the nature and properties of particulate matter (PM) deposited in three diesel particulate filters (DPFs) operating with different fuels: 100% rapeseed methyl ester (RME100), a blend of 20% RME and 80% diesel (RME20), as well as 100% diesel (RME0). The DPFs were catalytically coated with V_2O_5/TiO_2. The PM deposits were either extracted from sectioned DPFs or studied 'in situ', as deposited. In the RME100-DPF, the lowest soot and highest ash depositions are found. The higher amount of ash in RME100-DPF, as well as the higher participation of the element Ca in the ash from this filter, indicate that in addition to lubricating oil, the RME fuel contributes also to ash formation. Ash is found accumulating in the plugged inlet channels only in RME100 and as a few tens of mm-thick layer on the channel walls of all three filters. Most commonly, ash is mixed with fibres deriving from the gasket on the DPF inlet surface, fibres from the intumescing mat around the DPF and the diesel oxidation catalyst (DOC) upstream the DPF, as well as with newly formed V-O long-prismatic nanocrystals originating from the catalytic coating layer. SEM images reveal the presence of a 130-170 mm thick soot cake on the filter walls of RME20- and RME0-DPF. In RME100-DPF, the soot cake is thinner (ca. 100 mm) and is not any more attached on the channel walls but rather occurs as fragments within the filter channels. EDX analyses of the layer deposited on the channel walls underneath the soot reveal the following elements: Ca, P, Zn, Mg, S, Na (typical ash elements), V, Ti, W (deriving from the catalytic coating) and Fe, Cu from engine wear. The size distribution of individual soot particles in the soot aggregates (average diameter: 21 nm), together with the nanostructure of soot particles obtained by high resolution transmission electron microscopy (HRTEM) indicate that the RME100 soot is relatively more reactive compared to diesel soot.

Emission and Fuel Consumption Comparison of Three Light Duty Vehicles Fuelled with Diesel, Pure Plant Oil and a Biodiesel Mix

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Three Light Duty Vehicles were measured on-board for their fuel consumption and regulated emissions while driven on diesel, pure rapeseed plant oil (PPO) and a 5% biodiesel (B5) mix with diesel. They were driven along a realistic cycle covering urban, rural and motorway roads. The vehicles were an Opel Vivaro 1.9 DTI Van, a Citroën Berlingo 2.0 HDI car and a Nissan Patrol GR 3.0 diesel SUV. Each vehicle was retrofitted with an Econet PPO two tank kit. They started on diesel when cold and switched to PPO -heated over a heat exchanger- when warm. As PPO has a lower caloric value compared to diesel fuel, consumption on PPO was higher. On B5 no significant effect was noticed. PPO however has lower carbon content and CO_2 emissions were a few percent lower than on diesel except for the Nissan Patrol where they were 8% higher. Carbonmonoxide (CO) emissions were low on all fuels and showed no clear trend except for the Nissan Patrol that emitted three times more on PPO and for the Opel that emitted three times more on B5. The total hydrocarbon (THC) emissions were two to three times higher on PPO but at a very low absolute level. Nitrogen oxide (NO_x) emissions were higher on PPO, from 9 to 56%. On B5 there was no significant effect. As to the Particulate Matter (PM) emissions a drop of about 50 to 60% was found. On B5 there was a drop of less than 10%. The Nissan Patrol in this study showed high CO emissions at idling when running on PPO. The engine management system was not able to correct this and produced a fault code indicating that the fuel was out of specification. Overall this vehicle was having higher fuel consumption and emissions on PPO than the other two vehicles. This indicates that not every diesel fuelled vehicle can be easily converted to PPO with success.

Experimental Investigation of Rapeseed Oil Combustion in a Modern Common-Rail Diesel Engine

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Neat, non-esterified vegetable oils, alternative, locally produced, renewable fuels for diesel engines, have considerably higher viscosity than diesel fuel, even when heated. While mechanical injection pumps with volumetric fuel metering compensate for higher viscosity of the fuel by an increased injection pressure, and possibly longer ignition delay is on some engines compensated by an earlier injection due to higher density and bulk modulus of vegetable oils, newer common-rail type systems do not have such mechanism, and inject vegetable oils and diesel fuel at comparable timing and pressures. The complexity of the newer injection systems also raises the issue of the effects of varying fuel properties. This paper reports on laboratory experiments carried on a four cylinder,4.5-liter Cummins ISBe4 engine with a Bosch Common Rail injection system, fitted with an auxiliary heated secondary fueling system, and operated on fuel-grade rapeseed oil heated to 50-60 °C. The results show only a moderate (around 10%) decrease in maximum torque, a slight increase in NO_x emissions, and load-dependent effect on PM emissions, with no overall increase in PM over ESC and WHSC engine test cycles.

Determination of Oxidation Characteristics and Studies on the Feasibility of Metallic Nanoparticles Combustion under ICE-like conditions

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The present work relates to the investigation of the basic oxidation characteristics of iron and aluminium nanoparticles as well as the feasibility of their combustion under both Internal Combustion Engine (ICE)-like and real engine conditions. Based on a series of proof-of-concept experiments, combustion was found to be feasible taking place in a controllable way and bearing similarities to the respective case of conventional fuels. These studies were complimented by relevant in-situ and ex-situ/post-analysis, in order to elaborate the fundamental phenomena occurring during combustion as well as the extent and 'quality' of the process. The oxidation mechanisms of the two metallic fuels appear different and –as expected– the energy release during combustion of aluminium is significantly higher than that released in the case of iron. The peak gas temperatures recorded during combustion of iron under engine like and real engine conditions indicate that the NO_x formation threshold is not reached. Combustion of aluminium yields substantially higher peak combustion temperatures and thus it is likely that is accompanied by NO_x emissions. In addition, the experimental results provided indication that the approach of Exhaust Gas Recirculation (EGR) could be an efficient means of controlling the combustion process.

Performance of a Diesel Engine Fueled by Rapeseed Oil Heated to Different Temperatures

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Neat, non-esterified vegetable oils are often used as alternative, renewable, locally produced, low greenhouse gas emissions fuel for diesel engines, which are typically fitted with a heated secondary fuel system, and are started, warmed up, and shut down on diesel fuel. This paper addresses the question of the temperature to which the fuel should be, can be, and is heated. Experiments done on a tractor engine with a mechanical inline injection pump revealed that at sustained higher loads, the fuel can be heated by engine coolant nearly to the thermostat opening temperatures prior to the injection pump inlet, with additional heating taking place before the fuel reaches the injector inlet. While vegetable oil heating to at least about 40-50 °C was beneficial to prevent large power loss on a common-rail type engine tested, excessive heating decreased the maximum engine torque on the engine with an inline injection pump, and accelerated degradation of the fuel. At sustained idle, the coolant and fuel temperature decrease, with additional cooling of the fuel by the time it reaches the injector, and the delay of the onset of the combustion increases with decreasing fuel temperature. Recycling of the return fuel line back to the inlet is both beneficial, as it accelerates the heating of the fuel during engine warm up, prevents excessive heating of the fuel in the fuel tank, and prevents heated and possibly degraded fuel from returning to the tank, but also has drawbacks, as some heating of the fuel tank by the returned fuel is needed to ensure adequate fuel flow and filterability. Design of the secondary fueling system should therefore consider the engine type and the anticipated operating conditions.

A 1,5 KW Electric Power Microcogeneration Unit Suitable For Domestic Applications

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The paper discusses the concept, specification and overall performance of a small microcogeneration unit of about 1,5 kW of electric power and about 4,5 kW of thermal power, suitable for domestic applications, designed at Istituto Motori CNR of Italy. This unit has been conceived specifically as a energy conversion system for houses, having in durability, electric and thermal efficiency the most important goals to be achieved. The paper starts by defining the state of art of small power microcogeneration units and then the ratio which leaded to the adoption of a single cylinder internal combustion engine derived from a motorcycle unit, in order to produce the above mentioned electric and thermal power. This is followed by an explanation of the main design characteristics of the system, with a discussion over the modified elements, made to enhance electric efficiency, emissions and durability and reduce, at the same time, cost coming from new design and manufacture. The system has been separately analyzed in its two main elements, i.e. the electric generator and the internal combustion engine (the latter with the aim of a simulation program); then a complete running test of the whole equipment has been carried out, in order to evaluate the effective electric and thermal efficiency.

Effects of Rapeseed and Jatropha Methyl Ester on Performance and Emissions of a Euro 5 Small Displacement Automotive Diesel Engine

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The effects of using neat and blended (30% vol.) biodiesel, obtained from Rapeseed Methyl Ester (RME) and Jatropha Methyl Ester (JME), in a Euro 5 small displacement passenger car diesel engine have been evaluated in this paper. The impact of biodiesel usage on engine performance at full load was analyzed for a specifically adjusted ECU calibration: the same torque levels measured under Diesel operation could be obtained, with lower smoke levels, thus highlighting the potential for maintaining the same level of performance while achieving substantial emissions benefits. In addition, the effects of biodiesel blends on brake specific fuel consumption and on engine-out exhaust emissions (CO_2, CO, HC, NO_x and smoke) were also evaluated at 6 different part load operating conditions, representative of the New European Driving Cycle. Emissions were also measured at the DPF outlet, thus providing information about after-treatment devices efficiencies with biodiesel. The application of a specifically adjusted engine calibration showed a rise of fuel consumption, due to the lower energy content of biodiesel, at same fuel conversion efficiency and comparable CO_2 emissions. An appreciable increase of CO and HC emissions at low load could be noticed, along with a considerable smoke emission reduction. Finally, soot-NOx trade-off were also analyzed for three different engine operating points, in order to gather detailed information about further possible emissions benefits that could be achieved through a more extensive ECU recalibration.

CO_2 Reduction and Cost Effectivity of Natural Gas Hybrid Powertrains for Midsize Passenger Cars

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CO_2 reduction targets are a big challenge for the mobility sector because about 20% of all CO_2 emissions origin from road traffic. The problem is intensified by the expected traffic growth which will mainly take place in developing countries. Several powertrain and fuel technologies are competing regarding their CO_2 reduction potential compared to conventional gasoline and diesel vehicles. Hybrid electric vehicles with a certain energy saving potential as well as natural gas vehicles (NGVs) with their lower fuel carbon content are expected to gain on importance. But why not combining dedicated natural gas engine and hybrid powertrain technology to achieve very low CO_2 emissions even for mid size passenger cars? At a first glance, such a powertrain combination looks just like a combination of two expensive technologies without any market potential. A more detailed analysis shows, however, that NGV hybrids allow high CO_2 reductions without additional end-user costs over the vehicle's entire lifetime. The present study addresses both topics: it presents the CO_2 reduction potential of mid-size passenger cars driven with an average natural gas-hybrid powertrain and it addresses end-user costs compared with today's gasoline technology.

Biogasoline options – Possibilities for achieving high bio-share and compatibility with conventional cars

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In this study, vehicle exhaust emissions and performance were studied using various renewable components with the aim of achieving a high bio-share in gasoline and compatibility with conventional cars. Several biogasoline components were included in the fuel matrix: ethanol, ETBE, isobutanol, n-butanol and renewable hydrocarbon gasoline produced from hydrotreated oils and fats. The share of bioenergy in the test fuel blends varied from 7 to 28 Eeqv%, and the oxygen content from 0 to 11 m/m%. Fossil gasoline was used as the reference fuel for emissions performance, and E85 fuel as an example of a typical market fuel for FFV cars. Experimental work was carried out at -7 °C with two conventional gasoline cars and one FFV car. The measurements included regulated and unregulated exhaust emissions. The results show the possibility of increasing the bioenergy content of gasoline to up to 30% for use with conventional gasoline-fuelled cars, which are not necessarily compatible with a fuel oxygen content higher than approximately4 m/m%.

The Squish-Jet Combustion Chamber for Ultra-Lean Burn Natural Gas Engines

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Operators of natural gas engines, used for both mobile and stationary applications, are increasingly looking at running these engines under very lean air-fuel ratios in order to reduce exhaust emissions and increase thermal efficiency. Lean operation of homogeneous-charge spark-ignited engines reduces peak combustion temperatures, thereby reducing NO_x emissions. Lean operation is normally restricted, however, by the “lean-limit” of combustion, as measured by the air-fuel ratio above which ignition is impossible, or combustion is incomplete. Operation under lean conditions also reduces the mixture burning rate, which can lead to increased spark advance and lower thermal efficiency. In order to increase the burning rate under ultra-lean air-fuel ratios a new “Squish-Jet” combustion chamber concept has been developed. This technique incorporates a series of passages in the crown of a bowl-in-piston type of combustion chamber which generates increased levels of small-scale turbulence just before ignition and during the early phase of combustion. This increased burning rate enables the engine to operate with a smaller spark advance under lean conditions, thereby extending the lean-limit of operation and increasing the thermal efficiency. The additional small-scale turbulence levels generated with the squish-jet type of combustion chamber is also effective in improving the completeness of combustion, thereby reducing unburned hydrocarbon emissions. This paper presents the results of a series of tests of the squish-jet combustion chamber design in a single-cylinder Ricardo Hydra research engine. The engine was run at three different engine speeds and under both naturally aspirated conditions and a boost pressure of 1.75 bar manifold absolute pressure. Two different squish-jet piston geometries were tested, together with a conventional bowl-in-piston design for comparison. The squish-jet combustion chambers were found generally to reduce emissions under ultra-lean operating conditions.

GEM Ternary Blends: Removing the Biomass Limit by using Iso-Stoichiometric Mixtures of Gasoline, Ethanol and Methanol

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The paper presents the concept of ternary blends of gasoline, ethanol and methanol in which the stoichiometric air-fuel ratio (AFR) is controlled to be 9.7:1, the same as that of conventional 'E85' alcohol-based fuel. This makes them iso-stoichiometric. Such blends are termed 'GEM' after the first initial of the three components. Calculated data is presented showing how the volumetric energy density relationship between the three components in these blends changes as the stoichiometric AFR is held constant but ethanol content is varied. From this data it is contended that such GEM blends can be 'drop-in' alternatives to E85, because when an engine is operated on any of these blends the pulse widths of the fuel injectors would not change significantly, and so there will be no impact on the on-board diagnostics from the use of such blends in existing E85/gasoline flex-fuel vehicles. The resulting ability of such blends to extend the reach of a fixed amount of ethanol in the fuel pool is then demonstrated, together with the mechanism by which the addition of the methanol displaces additional gasoline. If the methanol used is of a renewable and energy-secure nature then, for a fixed volume of ethanol in the fuel pool, an increased level of renewability and energy security is achieved. This overall situation is made possible by the fact that there are more E85/flex-fuel vehicles in existence than can currently be serviced by the E85 fuel supply chain. Example price calculations are conducted to show the points of potential price competitiveness. Preliminary tests with such GEM blends in a production-specification E85/gasoline vehicle were conducted to show the validity of the approach, and the results are reported together with fuel characteristics such as RON, MON and sensitivity. Road mileage is also reported using one of the fuel blends. Together these findings show the attractiveness of the concept and that there is therefore a possibility to significantly extend the use of renewable alcohol

fuel in the market due to the miscibility of gasoline, ethanol and methanol. This is primarily because, when they are blended to a target stoichiometric AFR, any of the blends possible share essentially the same volumetric energy content, RON, MON, sensitivity and latent heat (to within 4%). In turn, this makes taxation and pricing of such fuels simple and straightforward, further removing roadblocks to introduction.

Influence of Fischer-Tropsch Incorporation on Engine Outputs and Performances of a Modern Diesel Engine with Standard and Optimized Settings

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In a context of a fossil reserve depletion and reduction of greenhouse gases (GHG) emissions, the search for new energyfor transport is fundamental. Among those new energies, alternative fuels and especially synthetic fuel from Fischer-Tropsch process (so-called XtL, "X-to-Liquid" fuels) seem to have an interesting potential in terms of availability and GHG emission reduction, according to the feedstock used. Due to the special properties of such products, especially high cetane number, several strategies of incorporation can be envisaged: as a blend in specific basestocks in order to obtain a conventional fuel or a premium fuel or as a pure component. In order to assess these strategies; a standard diesel fuel (B0), a blend with 40%vol of Fischer-Tropsch and a neat Fischer-Tropsch have been tested on a modern downsized high pressure direct injection single cylinder Diesel engine. The used Fischer-Tropsch fuel is a commercial GtL – Gas to Liquid, with a cetane number higher than 80. First, engine tests have been performed with the same engine settings than the B0 fuel in order to evaluate the impact of the fuel formulation on the combustion behavior and on the engine outputs. Then, the engine settings were optimized for each fuel in order to achieve the best engine outputs, and so, evaluate the intrinsic performance of the tested fuels. This study allows understanding the influence of high auto-ignition fuels with low aromatic content on pollutant emissions at low speed / low load conditions (1500rpm 3bar of IMEP) and also on performances at full load. Without a dedicated calibration, the Fischer-Tropsch based fuels induce a noticeable modification of the combustion process and engine outputs. The full potential of such fuels can only be achieved after a dedicated optimization of engine settings. This optimization thanks to a smoke emission decrease. Some of these tests have received funding from the European Community's FP7 under grant agreement n° 218890 "OPTFUEL".

Effect of Simulated Exhaust Gas Recirculation on a Spark Ignition Engine Fuelled by Biogas-Hydrogen Blends

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Efforts have been made to apply biogas to an IC engine for power generation as a way to cope with the energy crisis as well as to reduce greenhouse gas. However, due to its gas component variations by origin and low energy density, using biogas in the engine applications and achieving a steady power generation is not an easy task. One way to overcome these deficiencies is to add hydrogen in biogas. Because of the excellent combustion characteristics of hydrogen, use of hydrogen-biogas blend fuel can allow not only accomplishing stable in-cylinder combustion, but also reducing the harmful emissions such as THC and CO. Despite several advantages of this approach, there exists a major drawback-a significant increase in NO_x emission caused by high adiabatic combustion temperature of hydrogen. Therefore, in this study, use of exhaust gas recirculation (EGR) gas was employed to resolve this issue and performance and emission characteristics of an 8-liter spark ignition engine with both simulated EGR and biogas with varying hydrogen content were examined. From the results, optimum and practical operating conditions, EGR rates, and hydrogen blending ratio to realize maximum efficiency and minimum emission were suggested, and an effect of EGR introduction on NO_x emissions reduction was assessed.

Effect of Natural Gas/Hydrogen Blends on Spark Ignition Stoichiometric Engine Efficiency

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Hydrogen (H_2) added to natural gas (NG), improves the combustion process of the air-fuel mixture. This gives the potentiality to develop engines with better performance and lower environmental impact. In any case how hydrogen is produced represents a crucial aspect. In general, if H_2 is produced utilizing fossil fuels and not renewable or nuclear sources, the environmental benefit of CO_2 reduction could be reduced. In this paper two engines, a light duty (LD) and a heavy duty (HD), were tested in stoichiometric conditions. The engines were fuelled with NG and with two blends of NG with a 20% and a 40% by volume of H_2, respectively named NG/H_2 20% and NG/H_2 40%. The light duty engine was tested at different load and speed, with spark advance set by the electronic control unit (ECU). The ECU actuated a retarded ignition, especially at low load. With the heavy duty engine, the tests were carried out only at high load. Spark advance was tuned to obtain burning gravity centre at the same angular position with NG and the two NG/H_2 blends. Hydrogen positive effect on combustion development has been observed, even if global efficiency was only marginally affected for both the light and the heavy duty engine. Moreover, only with the heavy duty engine and NG/H_2 40% blend, knocking phenomena have been observed, requiring great attention in spark advance, boost pressure and EGR rate optimization. For best performance with high H_2 content, a specific combustion system design would be necessary to fully exploit H_2 characteristics.

Liquefied Natural Gas (LNG) as Fuel for Road Heavy Duty Vehicles Technologies and Standardization

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Natural Gas Vehicle (NGV) engine technology is mainly based on a well known and already established engine functioning principle, the Otto engine. The recent developments achieved and the OEMs push for this kind of technology clearly shows the confidence and reliability of this technology, especially when it comes to the use of compressed natural gas (CNG). For the above mentioned reasons, the number of applications involving NGVs have increased worldwide. Environmental and economic reasons, on the whole, have been the main drive for this diffusion. Natural Gas chemical properties are an irrefutable proof of the advanced behaviour, environmentally speaking, of a fuel that emits less CO_2 (due to its carbon-hydrogen balance when compared to other fuels) and less NOx and PM. In many countries, favourable taxation schemes have helped the development and entrance into the market of the NGV technology, especially for the light duty vehicles. Until now, practically no heavy duty vehicles or lorries have taken advantage of this fuel, because of payload restrictions, and due to the cylinders weight required for a suitable range, an issue requested by specific commercial mission profiles. Nevertheless, Liquefied Natural Gas (LNG) offers the possibility of using this fuel for heavy duty road transport applications due to its higher energy density. It should be taken into account that a temperature of -162 °C is required (at atmospheric pressure) to maintain the fuel in liquid state, therefore the main issue of this technology lies on the cryogenic tank installed on board with a thermal behaviour control system and the board vaporizer required to feed the internal combustion engine (ICE). This aspect (on board cryogenic vessels) and some others like the refuelling infrastructure still require some standardization work, aspect that is being developed at ISO level. In this context a new interesting opportunity arises with regards to the refuelling infrastructure, that is the L-CNG filling stations concept. This application could be used by all type of natural gas vehicles since it's able to deliver both LNG and CNG. The gas in compressed form in this case is obtained from a liquid cryogenic pump at 300 bar followed by a downstream vaporizer, which releases gas in compressed form at 200-250 bar. In this way, a

reduced amount of energy is required, when compared to the usual filling stations operated by compressors to build up the CNG from the piped gas.

Modeling and Analysis of a Turbocharged Diesel Engine with Variable Geometry Compressor System

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In order to increase the efficiency of automotive turbochargers at low speed without compromising the performance at maximum boost conditions, variable geometry compressor (VGC) systems, based on either variable inlet guide vanes or variable geometry diffusers, have been recently considered as a future design option for automotive turbochargers. This work presents a modeling, analysis and optimization study for a Diesel engine equipped with a variable geometry compressor that help understand the potentials of such technology and develop control algorithms for the VGC systems. A cycle-averaged engine system model, validated on experimental data, is used to predict the most important variables characterizing the intake and exhaust systems (i.e., mass flow rates, pressures, temperatures) and engine performance (i.e., torque, BMEP, volumetric efficiency), in steady-state and transient conditions. The model is used to explore the engine system sensitivity to the VGC control input; in particular, its effect on the engine performance and compressor stability is evaluated. A preliminary optimization for steady-state (open-loop) control of the VGC system is then proposed.

Map-Based and 1D Simulation of a Turbocharger Compressor in Surging Operation

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One-dimensional (1D) models are commonly employed to study the performances of turbocharged engine. Manufacturers' provided steady turbomachinery maps are usually utilized, although they operate in unsteady conditions as a consequence of pressure pulses propagating into the intake and exhaust systems. This may lead to some inaccuracies in the engine-turbocharger matching calculations, which may be solved through the introduction of proper time-delays (virtual pipe corrections). These drawbacks, however, became more relevant when engine operates under low speed and high load conditions, or during a transient maneuver, because of possibilities of compressor surging. This phenomenon can't be opportunely described employing classical manufacturers' maps: first of all, the flow through the compressor is strongly unsteady in these conditions; moreover, the information about both the unstable and reverse flow regions of compressor map is unavailable, and a somewhat arbitrary map's extrapolation technique must be utilized. In this paper two numerical procedures have been presented to predict automotive turbocharger compressor performance in surging operation. Firstly, a recently proposed approach is utilized to directly compute the stationary map of the compressor for direct and reverse flow conditions. The detailed 3D geometry of the compressor is reconstructed starting from a reduced set of geometrical data measured on the compressor wheel. Then, the 1D meanline evolution of blade angles, cross section and equivalent diameter are deduced from the 3D geometrical model. The steady 1D flow equations are finally solved along the meanline of stationary and rotating channels constituting the compressor device. Proper flow loss correlation holding for direct or reverse flow conditions are included in the model, which is applied to predict the extended steady maps of a turbocharger compressor. With reference to stable operating regions, the theoretically derived maps are compared to available manufacturer data and, after a limited loss coefficients tuning, a good agreement has been obtained. The steady procedure, however, can be utilized under unsteady flow conditions, too. Unsteady terms in flow equations are now accounted for, and mass and energy storages are allowed to occur within each stationary and rotating channel. In this way, compressor operation can be described with a quasi-steady method employing the extended map, or in a fully unsteady approach,

as well. In the quasi-steady case, a proper virtual pipe correction is introduced, too. The two methodologies are tested to analyze their potential in characterizing compressor operation under surging conditions. To this aim, a reference compressor is connected to a outlet duct and a plenum. Compressor speed and downstream circuit are managed in order to promote deep surging conditions. Results obtained through the applications of the two methods are discussed in terms of pressure and temperature waves, mass flow rate evolution at compressor inlet and outlet, and Surging loop frequency, as well.

Off-Road Diesel Engine Transient Response Improvement by Electrically Assisted Turbocharging

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Turbocharged diesel engines are widely used in off-road applications including construction and mining machinery, electric power generation systems, locomotives, marine, petroleum, industrial and agricultural equipment. Such applications contribute significantly to both local air pollution and CO_2 emissions and are subject to increasingly stringent legislation. To improve fuel economy while meeting emissions limits, manufacturers are exploring engine downsizing by increasing engine boost levels. This allows an increase in IMEP without significantly increasing mechanical losses, which results in a higher overall efficiency. However, this can lead to poorer transient engine response primarily due to turbo-lag, which is a major penalty for engines subjected to fast varying loads. To recover transient response, the turbocharger can be electrically assisted by means of a high speed motor/generator. When the engine load is increased, the electrical machine acts as a motor to accelerate the turbocharger so that the torque demand can be met rapidly. Conversely, when boost delivery exceeds demand the electrical machine can act as a generator to recover energy that would otherwise be wastegated. This paper presents a model for the transient response of the electrically-assisted turbocharged engine when subjected to a step increase of torque demand. The base model is representative of a 7-litre turbocharged intercooled diesel engine and has been implemented in Matlab-Simulink and calibrated against test bed data. The model is used for the analysis of the dynamic behaviour of the engine with different levels of electric assist to the turbocharger. The results show that while turbocharger response improves with electric assist, compressor surge can occur in generating mode and that limitations on electric assist power are present.

Durability Prediction of a Diesel Engine Piston-Rings-Cylinder Assembly on the Basis of Test Bench Results

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The wear of cylinder kit components of internal combustion engine leads to the increase in blowby and oil consumption and usually determines engine lifetime. Due to the reduced development time, efficient methods for predictive evaluation of engine life are necessary. The paper presents a method of engine lifetime prediction, which takes advantage of the results of test bench engine investigations as well as the results of simulations carried out with the use of the ring pack model of the engine. Ring pack simulations are used for the determination of the boundary wear at which the effectiveness of the pack drops to the permissible level. On the basis of the test bench investigations, the course of engine wear is established. Lifetime is estimated by extrapolating the wear course to the boundary value. The results of example calculations for automotive diesel engine are presented.

Validation of a CFD Methodology for the Analysis of Conjugate Heat Transfer in a High Performance SI Engine

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The paper presents a combined experimental and numerical activity carried out to improve the accuracy of conjugate heat transfer CFD simulations of a high-performance S.I. engine water cooling jacket. Due to the complexity of the computational domain, which covers both the coolant jacket and the surrounding metal cast (both head and block), particular care is required in order to find a tradeoff between the accuracy and the cost-effectiveness of the numerical procedure. In view of the presence of many complex physical phenomena, the contribution of some relevant CFD parameters and sub-models is separately evaluated and discussed. Among the formers, the extent of the computational domain, the choice of a proper set of boundary conditions and the detailed representation of the physical properties of the involved materials are separately considered. Among the latters, the choice between a simplified single-phase approach and a more complex two-phase approach taking into account the effects of phase transition within the engine coolant is discussed. The predictive capability of the CFD-CHT methodology is assessed by means of the comparison between CFD results and experimental measurements provided by the engine manufacturer for different engine operating conditions. At the end of the validation process, a methodology for the correct and cost-effective characterization of conjugate heat transfer is proposed, showing a reasonable trade-off between the predictive capability and the computational effort of the simulations.

Turbocharging a Small Two Cylinder DI Diesel Engine - Experiences in Improving the Power, Low End Torque and Specific Fuel Consumption

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Turbocharged common rail direct injection engines offer multiple benefits compared to their naturally aspirated counterparts by allowing for a significant increase in the power and torque output, while simultaneously improving the specific fuel consumption and smoke. They also make it possible for the engine to operate at a leaner air/fuel mixture ratio, thereby reducing particulate matter emission and permitting higher EGR flow rates. In the present work, a two cylinder, naturally aspirated common rail injected engine for use on a load carrier platform has been fitted with a turbocharger for improving the power and torque output, so that the engine can be used in a vehicle with a higher kerb weight. The basic architecture and hardware remain unchanged between the naturally aspirated and turbocharged versions. A fixed geometry, waste gated turbocharger with intercooling is used. With the help of an appropriately selected waste gate turbocharger, the naturally aspirated engine delivering 20 kW/lit peak specific power and 60.5 Nm/lit maximum specific torque is upgraded to deliver about 80% higher peak power and more than 75% higher peak torque with a wider peak torque band. Specific fuel consumption and smoke also show an improvement, while the peak firing pressure and turbine inlet temperature are kept within the system limits. It is shown that specific peak power can be increased by more than 80% and torque by close to 110% over the NA configuration by reducing the compression ratio. Peak power and torque are further raised by about 140% and more than 130% respectively over the NA engine with the help of a variable geometry turbocharger and reduced compression ratio. Benefits in fuel economy, emissions and noise are also obtained. Turbocharging, therefore, is an important step to increase power density and meet future emission norms in small single and two cylinder load and passenger carrying vehicles in developing countries, which are typically naturally aspirated, and usually incapable of achieving emission norms beyond Euro-III equivalent.

Application of Concentric Cam Shafts to a Passenger Car Diesel Engine to Significantly Improve the NO_x/ Soot Tradeoff

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Trying to improve the modern diesel engine's NOx / Soot tradeoff without giving up fuel economy continues to be a core target for the engine development community. One of the options not yet fully investigated for the diesel is applying variable valve events to the engine breathing process. Already used in some heavy duty applications, late intake valve closing has long been regarded as a possible strategy for small diesel engines. Single cylinder tests applying fully variable valve events have demonstrated potential but also raised doubts about VVA benefits on automotive size diesel engines. Full engine testing using realistic valve train technology is seen as key to judging its true performance because it covers not only combustion benefits but also influences like engine pumping on emissions and CO_2. Different to past publications, this paper focuses on testing a production feasible variable valve train technology on a fully instrumented modern Common Rail diesel engine. Applying a concentric intake cam in the described way to increase valve event duration allows running an over expanding combustion cycle (Miller Cycle). The benefits on the NO_x / Soot tradeoff as well as other effects are described.

Hybrid Oil Sump for CI Engine

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Recently fuel economy and stringent emission norms are the ever growing concern in automotive global scenario. So, automotive engineers are constantly seeking new cost effective methodologies and techniques to achieve considerable weight reduction and improved performance. Nowadays Automotive OEMs are using Aluminum Oil sump (which is a structured part of an engine and supports considerable amount of transmission housing weight) for better emission, reducing the engine height, engine weight and NVH levels. Our present work reveals the concept of 'Hybrid oil sump' which made by sheet metal and aluminum in such a way that weight and cost reduced by 20% and 30 % respectively, without compromising NVH and strength properties. Exactly it deals the iteration part of design to arrive the optimum model, various structural modifications since it carries considerable amount of weight of transmission. Also verification of the optimized design is done through CAE analysis as well as NVH simulation.

Turbocharging of Downsized Gasoline DI Engines with 2 and 3 Cylinders

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Turbocharged DISI engines with four cylinders have established in the market and provide a performance comparable to larger six-cylinder engines in the smaller compartment of a four cylinder engine. In the Japanese market, also turbo gasoline engines with 500 – 660 cm^3 displacement have a long tradition in Kei-Cars. However, those engines show a lower specific performance as would be required for propelling typical small or compact vehicles in Europe. Recently, two-cylinder turbo engines have come to market, that are found attractive with respect to sound, package, and also enable low vehicle fuel consumption in NEDC test. The paper presents a turbocharger layout study on 2- and 3-cylinder engines. It discusses the influence of cylinder displacement volume on the sizing of turbines and compressors, and how specific flow phenomena in the turbine can be captured in the simulation model.

Materials Evolution in the New Fiat Engines Design

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The automotive market is in continuous evolution and always more demanding. So in addition to the usual requirements of style, comfort, handling and powertrain, in the last years the car manufacturers had to take in consideration also new aspects such as safety, economy during usage and all the environmental issues. Specifically type and quantity of emissions plus oil consumption have become one of the most important aspects to fulfill. Type of emissions meant a decrease or elimination of the "bad particles" emitted by the vehicles; the target was achieved with the continuous evolutions of the engines through the new "Euro" versions developed during the last years. Quantity of emissions and oil consumption are directly linked with weight reduction of the vehicles. So, apart of the introduction of better materials in the Body in White (advanced high strength steels and aluminum), this means new developments in the powertrain area. The most important is the downsizing of the engines guaranteeing the same performances. This could be only possible with a new and more evolved engines design, that of course has to include also new and better materials usage. The parts initially involved in this materials' change are the engine block, the turbine housing and the turbo/exhaust manifolds. The engine block represents the simplest example of weight reduction for powertrain; passing from cast iron to aluminum means a weight reduction of approximately 50%. Of course also the costs aspects have to be taken in consideration. In order to guarantee the same performances, the downsizing brought to more powerful turbo charged solutions. So the gas temperatures are increased and consequently the materials of the turbine housing and the turbo/exhaust manifolds have to be changed.

Fault Detection for Common Rail Diesel Engines with Low and High Pressure Exhaust Gas Recirculation

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The complexity of the air path of modern common rail diesel engines is rapidly increasing and simultaneously, the demand on air and turbocharger control performances is becoming more challenging. To meet the upcoming emission regulations, the usage of a low pressure exhaust gas recirculation (EGR) circuit in addition to the standard high pressure EGR circuit is often considered. This kind of architecture usually requires a more sophisticated air control system in which a precise control of the EGR flow delivered by the two recirculation branches is required. Moreover, as an alternative or in addition to the low pressure EGR, the implementation of a NO_x reduction system e.g. a NO_x trap is possible. To proper maintain the correct efficiency of this kind of after-treatment system, special regeneration strategies are adopted where a rich combustion is used instead of the standard Diesel lean mode. During the rich phase the air control plays a key role since the air charge delivered to the cylinders is directly related to the torque. The above example shows that an air system monitoring function capable of detecting even small deviations from the nominal required control behaviour is becoming important. Additionally, due to an increasing number of components and a demand for a better service quality, particular attention is now required on the fault isolation capabilities of the diagnostic functions. In the above introductory section a representative scenario has been described recognizing the necessity to improve diagnostic functions for the air system monitoring. In this paper, diagnostic methods with enhanced fault detection and isolation capability for air systems with both low and high pressure EGR circuits are presented. For the detection of the faults, physical and semi-physical process and signal models for the components of the air path have been developed. Using these models a set of residuals is derived mainly by applying the parity equation approach. This set of model-based residuals is investigated using measurements from a real engine in fault-free and faulty condition. Typical faults like leakages, clogging, sensor or actuator errors are investigated. The fault detection system is verified over a wide operating range in closed loop operation (EGR and charge pressure control loops are working in parallel to the fault detection system). To evaluate the isolation capability of the residual sets the relationship between symptoms and faults is fully investigated. This paper presents results from a research corporation between the Institute of Automatic Control at TU Darmstadt and GM Powertrain Europe.

Improvement of a High-Performance CNG-Engine Based on an Innovative Virtual Development Process

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Methane as an alternative fuel in motorsports? Actually this solution is well known for the reduction of CO_2-emissions but apparently it does not really awake race feelings. At the 2009 edition of the 24-hour endurance race on the Nürburgring the Volkswagen Motorsport GmbH, in addition to vehicles powered by gasoline engines, introduced two vehicles powered by innovative turbo-charged CNG engines for the first time. The aim was to prove, that also an "environment-friendly" concept is able to provide the required efficiency, dynamic and reliability for a successful participation in motorsports. After the success in the 2009 edition the engagement has been continued also in 2010, this time exclusively with CNG-vehicles. Focusing on the CO_2-emission, reclusively the higher hydrogen content of methane which represents the main component of NG leads to a CO_2-reduction during the combustion of about 20% compared to gasoline. Thanks to the laminar burning speed of methane which is approximately maximal for a stoichiometric mixture, CNG engines do not require a mixture enrichment at WOT operating conditions, so that the fuel consumption decreases. In addition the very high knock-resistance of natural gas allows a further efficiency increasing by using a higher compression ratio. Conclusively the CO_2-reduction of the CNG-version ranges from ca. 30% using natural gas up to 80% for bio-gas. On the other hand gas injection in the intake manifold causes a loss of charge due to both the low mass density of natural gas and the absence of heat of vaporization. The latter also produces a temperature level of the exhaust gas at the turbine which is more critical. Another drawback of CNG-engines is the homogenization of the air-fuel mixture. This process is more critical because even high gas velocities at the injector nozzle cause a very low fuel penetration. Therefore, mixture homogenization or stratification depends much more on charge motion as usual for liquid fuels. For this reason the design of the intake system and the combustion chamber is a crucial step for the optimization of a CNG engine. In this paper the engine development process has been performed mainly in a virtual context. The implementation of an innovative 3D-CFD-tool (QuickSim) that has permitted full-engine simulations of this turbocharged CNG

race-engine has allowed, within short time (few months), to remarkably increase the engine performance. The virtual engine development process has started with the 3DCFD-analysis of the fluid motion of the basic engine. Based on this analysis many engine-design modifications have then been virtually tested, so that at the end only a few promising solutions have been “concretely” realized and tested at the test bench. Since the results at the test bench have finally confirmed the expectations from the simulation results, following this procedure it has been definitively possible to speed up the engine development process even by limiting the budget.

Virtual Set-up of a Racing Engine for the Optimization of Lap Performance through a Comprehensive Engine-Vehicle-Driver Model

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In Motorsports the understanding of the real engine performance within a complete circuit lap is a crucial topic. On the basis of the telemetry data the engineers are able to monitor this performance and try to adapt the engine to the vehicle´s and race track's characteristics and driver´s needs. However, quite often the telemetry is the sole analysis instrument for the Engine-Vehicle-Driver (EVD) system and it has no prediction capability. The engine optimization for best lap-time or best fuel economy is therefore a topic which is not trivial to solve, without the aid of suitable, reliable and predictive engineering tools. A complete EVD model was therefore built in a GT-SUITE™ environment for a Motorsport racing car (STCC-VW-Scirocco) equipped with a Compressed Natural Gas (CNG) turbocharged S.I. engine and calibrated on the basis of telemetry and test bench data. The driver is simulated by means of a "position based" control in order to determine the braking points at each corner by itself and regulate the braking/accelerating intensity. By means of simplified vehicle dynamics and a complete engine flow dynamic modeling the behavior of the overall system during the lap can be analyzed and different scenarios simulated. In particular the focus is concentrated on the real operating conditions of the powertrain unit, which can be eventually combined also with energy recovery systems (e.g. KERS and TERS). In the proposed EVD model each technical element (Engine, Vehicle) is distinct and can be interchangeable. For example the engine can be virtually optimized and the influence of different technical configurations or engine mapping on the global performance can be investigated. The aim is to create modeling solutions which are compatible with the short development time of motorsports and thus to maintain acceptable CPU-time. As results of the proposed simulations show, spark advance, fuel injection and direct control of the waste-gate (WG) are parameters which can influence the overall performance for the adopted racing vehicle.

Misfire and Partial Burn Detection based on Ion Current Measurement

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The paper presents the implementation of a combustion diagnosis system that integrates crankshaft speed oscillations analysis with ion current signal processing, for V8 and V12 high performance engines. Ion current sensing has been introduced in the last V8 and V12 Ferrari models in order to improve combustion control by implementing ion current based closed-loop spark-advance control systems, both under knocking and non-knocking conditions (respectively based on measured knocking level, and on ion current peak position control). Another area where ion current sensing can improve the engine controller performance is related to the ability of detecting and isolating missing and partial burn combustions. The typical approach to misfire detection (based on engine speed oscillation measurement) is in fact particularly critical for engines with a large number of cylinders, and ion current sensing provides additional information not only about presence (or absence) of combustion, but also about the causes that generated the fault. Moreover, the paper shows that real-time analysis of specific ion current signal features allows isolating incomplete and inefficient combustion events, thus providing extremely useful information to the engine control system, which can for example be used to activate multi-spark discharge ignition mode. The first part of the paper shows the main critical aspects of speed-measurement based misfire detection, and introduces the ion current signal main features during regular engine operation. Then, ion current signal is analyzed during abnormal combustion events: absence of combustion (both due to missing injections and missing ignitions) and partial burn cycles. It is shown how it is possible to isolate missing and incomplete combustions in a relatively straightforward way, and also how the causes that induced the fault may be isolated by integrating standard diagnostic functions with specific ion current signal processing algorithms. Finally, the performance of the diagnostic system that integrates engine speed oscillation analysis and information extracted from the ion signal has been evaluated during on-board tests, and the main results are presented at the end of the paper.

Combustion Modeling of a Direct Injection Diesel Engine Using Double Wiebe Functions: Application to HiL Real-Time Simulations

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This paper presents a DI Diesel engine combustion model based on double Wiebe equations approach. The aim of this work is to build a combustion model suitable for Hardware in the Loop (HiL) simulations, and thus to be able to run in Real-Time applications. First, an ignition model is presented and correlated function of engine operating conditions. Then the combustion model parameters have been calibrated with a curve fitting technique with test bench experimental results. The calibration and validation process have been realized first on Matlab. Then the combustion model was coded in S-functions Simulink blocks suitable for HiL implementation. Offline test results for single injection cases with high engine speed (>4000 rpm) are presented in this paper.

Control-oriented "Crank-angle" Based Modelling of Automotive Engines

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It is well known that in automotive applications problems related to control and management are nowadays of paramount importance to improve engine performance and to reduce fuel consumption and pollutant emissions. In the design of control and diagnostics systems the use of theoretical models proved to be very promising, also to reduce development time and costs, as widely documented in the open literature. From this point of view, the complexity of actual engines due both to the continuous enhancement of existing subsystems (e.g., turbochargers, exhaust gas recirculation systems, aftertreatment components, etc.) and to the introduction of specific devices (e.g., Variable Valve Actuation systems) give rise to challenging issues in modelling development and applications. The paper describes a theoretical model of an automotive engine built up starting from the original library developed in Simulink® by the authors for the simulation of last generation automotive engines. The tool was used in former works to build up Mean Value Models (MVMs) of automotive engines for "real-time" simulations, which were used in Hardware-in-the-Loop (HiL) applications. The model proposed in this work is an enhancement of the mentioned ones to allow for "crank-angle" simulations of engine thermodynamic processes. To this extent several blocks were built up for the simulation of intake and exhaust valves (with userdefined lift curves and variable actuation) and of in-cylinder processes. Combustion process has been described following a classic single-zone approach based on a proper Heat Release Rate (HRR). Other components of the intake and exhaust systems were modelled by using the original library blocks. Through a specific calibration procedure, the model was fitted on the typical layout of an automotive SI engine allowing for steady and transient simulations of the engine behaviour. Calculated results are compared in the paper with available experimental data, showing a good agreement.

Development and Validation of a Methodology for Real-Time Evaluation of Cylinder by Cylinder Torque Production Non-Uniformities

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Modern internal combustion engine control systems require on-board evaluation of a large number of quantities, in order to perform an efficient combustion control. The importance of optimal combustion control is mainly related to the requests for pollutant emissions reduction, but it is also crucial for noise, vibrations and harshness reduction. Engine system aging can cause significant differences between each cylinder combustion process and, consequently, an increase in vibrations and pollutant emissions. Another aspect worth mentioning is that newly developed low temperature combustion strategies (such as HCCI combustion) deliver the advantage of low engine-out NO_x emissions, however, they show a high cylinder-to-cylinder variation. For these reasons, non uniformity in torque produced by the cylinders in an internal combustion engine is a very important parameter to be evaluated on board. This work describes a methodology that allows determining the difference between torque delivered by each cylinder and the mean value. These differences can be caused by different reasons, such as different air breathing or deposits on the injectors that do not allow injecting the desired quantity. Once the differences in cylinder to cylinder torque production have been evaluated, the engine control system can adopt the interventions that are needed to re-establish the nominal behavior. The methodology presented in this paper requires no additional cost, because it is based on engine speed fluctuations measurement, that can be performed using the same phonic wheel already mounted on-board. This approach has been validated on an L4 Common Rail Multi-Jet Diesel engine mounted on-board a vehicle. In order to quantify the accuracy of torque non-uniformities estimation, specifically designed tests have been performed acquiring the instantaneous engine speed and the in-cylinder pressure signals (that allow evaluating indicated torque delivered by each cylinder) simultaneously. The presented approach has been applied to a Common Rail Diesel engine, nevertheless this methodology is general, and it is suitable for torque non-uniformities evaluation in spark ignited engines as well.

Tuning of the Engine Control Variables of an Automotive Turbocharged Diesel Engine via Model Based Optimization

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The paper deals with the steady-state optimal tuning of control variables for an automotive turbocharged Diesel engine. The optimization analysis is based on an engine simulation model, composed of a control oriented model of turbocharger integrated with a predictive multi-zone combustion model, which allows accounting for the impact of control variables on engine performance, NO_x and soot emissions and turbine outlet temperature. This latter strongly affects conversion efficiency of after treatment devices therefore its estimation is of great interest for both control and simulation of tailpipe emissions. The proposed modeling structure is aimed to support the engine control design for common-rail turbocharged Diesel engines with multiple injections, where the large number of control parameters requires a large experimental tuning effort. Nevertheless, the complex interaction of injection pattern on combustion process makes black box engine modeling not enough accurate and a more detailed physical model has to be included in the loop. An hybrid modeling approach, composed of black and grey box models is implemented to simulate compressor flow and efficiency maps. The grey box model is used at low engine speeds while the black box model, based on a moving least squares method, provides compressor data at medium- high speed. Both models appear to perform best in their respective area. On the other hand a classical grey box approach is implemented for the turbine, along its overall working range. Compressor and turbine models are implemented in a computational scheme for integration with a predictive multi-zone combustion model that simulates the fuel jet and its interaction with surrounding gases by dividing the jet core into many parcels in order to describe the thermal gradient and the chemical composition within the combustion chamber. The whole engine model allows simulating in-cylinder pressure and temperature, NO and soot emissions as well as turbine outlet temperature, depending on engine control variables (i.e. injection pattern, Exhaust Gas Recirculation - EGR, Variable Geometry Turbine - VGT). Model validation is carried out by comparing simulated in-cylinder pressure trace and exhaust temperature with a wide set of experimental data, measured at the test bench in steady-state conditions on a small automotive Diesel engine. In the paper the overall modeling approach is presented with a detailed description of in-cylinder, compressor and turbine models and the results of the experimental validation vs. measured data are shown. Furthermore, the optimization results over a set of operating points selected among those of interest for the ECE-EUDC test driving cycle are presented and discussed.

Model Based Fault Diagnosis of the Intake and Exhaust Path of Turbocharged Diesel Engines

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Faults in the intake and exhaust path of turbocharged common-rail Diesel engines can lead to an increase of emissions and performance losses. Standard fault detection strategies based on plausibility checks and trend checking of sensor data are not able to detect and isolate all faults appearing in the intake and exhaust path without employing additional sensors. By applying model based methods a limited sensor configuration can be used for fault detection. Therefore a model based fault diagnosis concept with parity equations is considered, [1]. In this contribution the fault diagnosis system, which comprises semi-physical thermodynamic turbocharger model, models of gas pressure in the intake and exhaust manifold, residual generation, residual to symptom transformation and fault diagnosis is presented. The residuals are calculated from the difference between the virtual sensors and the measured values and from the difference between the virtual sensors and outputs of reference models which represent the turbocharger quantities in the fault-free operation, [1], [2]. The created residuals are applied for the detection of leakages, restrictions and clogged actuators in the intake and exhaust path of the Diesel engine. The fault detection is based on deviations of the residuals if they transgress the operation point dependent thresholds. Further the engine operation area is divided into different regions with individual pattern of the residual deviations. The considered faults are isolated by combination of the residual deviations in different regions. Fault diagnosis system is implemented as a set of operation region dependent fuzzy systems suitability for onboard application due to the high level of interpretability and its manageable structure complexity. The model based fault diagnosis is verified on a dynamic engine testbench with 110kW Opel CR-Diesel engine with VGT turbocharger and HPEGR. Leakages and restrictions are implemented in the intake and exhaust path of the engine. Measurement data in faulty and fault-free operation is used for verification of the fault detection. Summing up it is shown with real measurements from the engine testbench that all considered faults can be isolated. The manageable complexity of the introduced models and the diagnosis system shows suitability for onboard application.

Real-Time Calculation of EGR Rate and Intake Charge Oxygen Concentration for Misfire Detection in Diesel Engines

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A new procedure for the real-time estimation of the EGR rate and charge oxygen concentration has been developed, assessed and applied to a low-compression ratio GMPT-E EURO V diesel engine. High EGR rates are usually employed in modern diesel engines to reduce combustion temperatures and NOx emissions, especially at medium-low load and speed conditions. The EGR rate is usually calibrated in steady-state conditions, but, under transient conditions, it can be responsible for misfire occurrence or non optimal combustion cycles, if not properly controlled. In other words, combustion instabilities can occur, especially during tip-in maneuvers, which imply transition from high EGR (low load) to low EGR (high load) rates. Misfire is determined by a temporary reduction in the intake charge oxygen concentration during the closure of the EGR valve. Therefore, a model-based approach for real-time estimation of the EGR rate and intake charge oxygen concentration is a powerful tool that could allow the engine ECU to prevent misfire occurrence. In this paper, a semi-empirical correlation has been developed to estimate the EGR rate under steady-state and transient operating conditions, on the basis of the measured pressure in the intake manifold, of the measured pressure and temperature upstream from the EGR valve, and of the duty cycle signal of the EGR valve. The intake charge oxygen concentration has been estimated on the basis of the measurements of the air mass-flow rate and injected fuel mass. The proposed technique has been applied to a modern EURO V diesel engine, in order to analyze two different engine transients: a severe tip-in maneuver with misfire occurrence and an acceleration ramp during the ECE cycle. The methodology has proved to be effective in the real-time monitoring of the EGR rate and intake charge oxygen concentration and to be simple enough to be implemented in the engine ECU in order to diagnose misfire occurrence in advance.

Modeling of Variable Valve Timing on High Performance Engine using Power-Oriented Graphs Method

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Engine efficiency is one of the key aspects to reduce CO_2 emissions. In order to improve the emission maintaining high performance capabilities several devices are introduced in the system; variable valve timing technology allows more flexibility for modern engines to meet peak performance, fuel economy and low emissions targets [7] while providing good driveability. This paper describes the Lamborghini continuouslyvariable cam phaser model using a graphical technique, called Power Oriented Graphs (POG), this uses an energetic approach for representing the physical systems. The generally accepted approach is to calibrate an engine on a dynamometer and to adjust the operation of the engine to meet performance targets. With the current build and test approach, these adjustments may not be made until well into the development program, and this calibration is a costly and time consuming step in the engine development process: the main purpose of this works is showing how was described the model in order to get more easy and fast the calibrating operations. Furthermore the usefulness to model the system consists of analyzing in simulation many more system configurations than those available for real experiments so it's important using a simple methodology that is able to analyze the whole system's dynamic in order to reach the performance expectations. The results obtained were validated demonstrating the effectiveness of the POG technique.

Cfd Diagnostic Methodology for the Assessment of Mixture Formation Quality in GDI Engines

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The fuel injection plays a crucial role in determining the mixture formation process in Gasoline Direct Injection (GDI) engines. Pollutant emissions, and soot emissions in particular, as well as phenomena affecting engine reliability, such as oil dilution and injector coking, are deeply influenced by the injection system features, such as injector geometric characteristics (such as injector type, injector position and targeting within the combustion chamber) and operating characteristics (such as injection pressure, injection phasing, etc.). In this paper, a new CFD methodology is presented, allowing a preliminary assessment of the mixture formation quality in terms of expected soot emissions, oil dilution and injector coking risks for different injection systems (such as for instance multihole or swirl injectors) and different injection strategies, from the early stages of a new engine design. The proposed methodology, after a number of validation steps with experimental data gathered from different injection systems, has then been applied to guide the choice of the injector type, injection targeting and injection pressure and phasing for a GDI engine.

Effect of Ports Configuration on Trapping Efficiency in a Two Stroke Engine – A CFD Analysis

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In this study, an attempt has been made to estimate trapping efficiency of a two-stroke engine by CFD analysis under cold flow conditions. A single-cylinder, loop-scavenged, spark-ignition, two-stroke engine extensively used for two-wheeler application in India is being considered for the analysis. Engine geometry is modelled using commercial PRO-E software. Simulation is carried out using commercial CFD code STAR-CD. The CFD predictions are validated by available experimental data. In the present study, the trapping efficiency is estimated at various engine speeds with change in configurations of ports. From the analysis of results, it is found that, increasing exhaust port area relative to total transfer port area and engine speeds increase the trapping efficiency significantly. In general, it is possible to increase the trapping efficiency by about 4% at the engine speeds considered.

A Methodology for Engine Performance Optimization

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Design and optimization of intake and exhaust systems and valve timing is crucial in development of a naturally aspirated engine. Nowadays numerical simulation is a fundamental tool for this area. Unfortunately to perform an optimization of engine performance by setting even only a few parameters needs great effort in terms of time and engineering resources even with simple architecture engines. To overcome this problem the authors have developed an optimization methodology: the use of a 1_D simulation code allows one to build a neural network (NN) that characterizes engine working conditions for several input data variations (such as intake/exhaust systems and valve timing). A genetic algorithm (GA) coupled with the neural network is used to carry-out the multi-parameter optimization of engine performance. As an initial application, this methodology has been used for a 1-cylinder four stroke engine for off-road motorcycle application: inlet and exhaust valve phase angles were the input parameters and the maximum shaft power was the fitness function of the optimization process. In this paper the optimization methodology is described and the results of the above-mentioned initial application presented.

Neural Network Based Models for Virtual NOx Sensing of Compression Ignition Engines

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The paper focuses on the experimental identification and validation of different neural networks for virtual sensing of NO_x emissions in combustion compression ignition engines (CI). A comparison of several neural network architectures (NN, TDNN and RNN) has been carried out in order to evaluate precision and generalization in dynamic prediction of NO_x formation. Furthermore the model complexity (number and types of inputs, neuron and layer number, etc.) has been considered to allow a future ECU implementation and on line training. Suited training procedures and experimental tests are proposed to improve the models. Several measurements of NO_x emissions have been performed through different devices applied to the outlet of an EURO 5 Common Rail Diesel engine with EGR. The accuracy of the developed models is assessed by comparing simulated and experimental trajectories for a wide range of operating conditions. The study highlights that history and proper inputs are significant for the output estimation, and good results can be achieved either through Recursive Neural Networks (RNN) and through Neural Networks (NN) with input history. A virtual NO_x sensor will offer significant opportunities for implementing on-board feed-forward and feedback control strategies in order to improve the performance and the diagnosis of the engine and of the after-treatment devices.

Idle Stalling Phenomena in High Performance Spark Ignition PFI Engines: an Experimental Analysis

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High performance Spark Ignition (SI) Port-Fuel Injected (PFI) internal combustion engines are usually optimized to deliver high power output at high speed in Wide Open Throttle (WOT) conditions. However, they also have to run consistently at idle, possibly with stoichiometric Air-Fuel Ratio (AFR), in order to limit tailpipe emissions. The two requirements are sometimes conflicting, as it is difficult to match high-speed volumetric efficiency with low-speed turbulence: the intake runner size and shape are often designed for performance, meaning that usually they do not guarantee a satisfying air-fuel mixing at idle. The consequence of poor mixture formation may be high cycle-to-cycle variation or misfiring, with obvious consequences on pollutant emissions and driveability. In the worst cases, however, the consequence could be even more serious: stalling phenomena have been observed on the test bench. While running at idle, the engine suddenly stops: the event is so quick that the idle controller is not able to react. The paper shows a detailed experimental analysis of stalling phenomena, based on engine speed, intake pressure, in-cylinder pressure, ion current information. Intake and in-cylinder pressure data show that stalling phenomena are related to anomalous combustions taking place during the compression stroke: the negative torque generated by such combustions is able to stop the engine. Further analysis show that these phenomena are triggered by defined conditions: a partial combustion releasing little heat and leading to a constant pressure exhaust stroke seems to be a necessary condition to ignite the undesired combustion. Ion current signals show that the combustion extends during the exhaust stroke, and continues throughout the following intake and compression strokes. The sensitivity of the phenomenon to changes in the injection layout suggests that its origin is related to the process of mixture formation. The presence of a large amount of liquid fuel in the cylinder could lead to diffusive combustions, maintained throughout the exhaust stroke and the subsequent intake stroke, thus resulting in a backfire. The Rate Of Heat Release (ROHR) analysis based on in-cylinder pressure confirms that the frequency of the phenomenon is higher in the cylinder where more liquid fuel is likely to be accumulated.

Architecture of a Detailed Three Dimensional Piston Ring Model

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Piston rings are faced with a broad range of demands like optimal sealing properties, wear properties and reliability. Even more challenging boundary conditions must be met when latest developments in the fields of direct injection as well as the application of bio fuels. This complex variety of piston ring design requirements leads to the need of a comprehensive simulation model in order to support the development in the early design phase prior to testing. The simulation model must be able to provide classical objectives like friction analysis, wear rate and blow-by. Furthermore, it must include an adequate oil consumption model. The objective of this work is to provide such a simulation model that is embedded in the commercial MBS software 'FEV Virtual Engine'. The MBS model consists of a cranktrain assembly with a rigid piston that contains flexible piston rings. The interaction of the piston rings with the liner surface is modelled via a hydrodynamic mixed friction approach for rough surfaces. From this contact model the wear of the individual rings as well as that of the liner surface is provided. The gas interactions are included by a so called gas labyrinth model. Finally, an oil film distribution model is included that allows the calculation of the oil consumption tendency. It even allows the modelling of oil dilution by fuels in case of DI engines. Parameter studies are made to show whether the specific models for ring pretension, HD-contact, friction and wear work properly. The paper closes with an assessment of the quality of the results and gives an outlook to further development steps.

Modelling and Experimental Study of Thermal Management System for HCCI

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This work presents a mass and enthalpy balance model for the air intake system of a multi-cylinder Homogenous Charge Compression Ignition (HCCI) gasoline engine. To achieve controlled auto-ignition across a wide range of engine conditions, a system for management of flow and temperature is installed at the air intake to enable the necessary regulation of temperatures and pressures at the inlet ports. In order to facilitate this control, a complete simulation model of the thermal system for a pressure-boosted multi-cylinder HCCI engine has been developed. The system includes a heat exchanger to heat the charge air, a supercharger to boost the charge air pressure, supercharger bypass and finally an intercooler, so that a wide range of combinations of pressures and temperatures can be achieved at the intake ports. The paper discusses the issues associated with control of the properties of charge air needed to extend the envelope of HCCI operation. This extension is one of the main objectives of the CHASE (Controlled Homogeneous Autoignition Supercharged Engine) project. General principles of the model are outlined and some nonstandard submodels for the individual components are presented in detail. Model calibration and validation are presented compared with measured data, experimental results for extensions of HCCI regime possible with the use of thermal management as predicted by the model is demonstrated and lastly the guidelines for control of the system are elaborated.

Reconstruction of In-Cylinder Pressure in a Diesel Engine from Vibration Signal Using a RBF Neural Network Model

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This study aims at building an efficient and robust radial basis function (RBF) artificial neural network (ANN), to reconstruct the incylinder pressure of a diesel engine 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. The RBF network is trained using measurements from different engine operating conditions. Training data are composed of time series from the accelerometer and corresponding measured in-cylinder pressure signals. The RBF network is then validated using data not included in training and the results show good correspondence between measured and reconstructed pressure signal. Various network parameters are used to optimize the network quality. The accuracy of the predicted pressure signals is analyzed in terms of mean square error and of a number of parameters, such as maximum pressure, peak location, and mass burned fraction (MBF). Robustness is sought with respect to changes in the engine parameters as well as with respect to changes in the nature of the fuel. The encouraging results indicate that the prediction model based on RBF neural network can be incorporated in the design of fuel-independent real-time control of diesel engines.

Effect of Traffic, Road and Weather Information on PHEV Energy Management

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Energy management plays a key role in achieving higher fuel economy for plug-in hybrid electric vehicle (PHEV) technology; the state of charge (SOC) profile of the battery during the entire driving trip determines the electric energy usage, thus determining the fuel consumed. The energy management algorithm should be designed to meet all driving scenarios while achieving the best possible fuel economy. The knowledge of the power requirement during a driving trip is necessary to achieve the best fuel economy results; performance of the energy management algorithm is closely related to the amount of information available in the form of road grade, velocity profiles, trip distance, weather characteristics and other exogenous factors. Intelligent transportation systems (ITS) allow vehicles to communicate with one another and the infrastructure to collect data about surrounding, and forecast the expected events, e.g., traffic condition, turns, road grade, and weather forecast. The ability to effectively interpret this traffic and weather data to estimate the power demand is important for the energy management and plays crucial role in the battery utilization. This paper presents an important step towards ITS integration with energy management of PHEVs: the goal of this research is to determine the correlation (or heuristic relationship) between different road events, weather conditions and PHEV energy management performance. The first step of this study utilizes real world data collected from a plug-in Toyota Prius (after-market conversion kit Hymotion L5) to determine the correlations between events and velocity profile characteristics. The second step finds the impact of power profile characteristics on the performance of equivalent consumption minimization Strategy (ECMS) for PHEV energy management using a high fidelity, validated PHEV simulator. The goal of this study is to identify the impact factors and define qualitative impact on the energy management algorithm and vehicle fuel economy.

On the Steady and Unsteady Turbulence Modeling in Ground Vehicle Aerodynamic Design and Optimization

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Computational Fluid Dynamics is nowadays largely employed as an effective optimization tool in the automotive industry, especially for what concerns aerodynamic design driven by critical factors such as the engine cooling system optimization and the reduction of drag forces, both limited by continuously changing stylistic constraints. The Ahmed reference model is a generic car-type bluff body with a slant back, which is frequently used as a benchmark test case by industrial as well as academic researchers, in order to investigate the performances of different turbulence modeling approaches. In spite of its relatively simple geometry, the Ahmed model possesses many of the typical aerodynamic features of a modern passenger car – a bluff body with separated boundary layers, recirculating flows and complex three-dimensional wake structures. Several experimental works have pointed out that the flow region which presents the major contribution to the overall aerodynamic drag is the wake flow behind the vehicle model: therefore, a more exact simulation of the wake and separation process seems to be essential for the accuracy of numerical drag predictions. As a consequence, a significant effort has been put in many computational studies carried out on the Ahmed model in the last two decades, in order to fix benefits and deficiencies of various turbulence modeling practices, from the steady-state RANS approach to the fully unsteady LES approach. Though now there are some generally accepted remarks, such as the difficulties encountered by some classical steady-state RANS models in giving accurate results for some critical flow regimes, it is authors' opinion that there are still some issues that need to be addressed, particularly for what concerns the differences and the possible improvements related to the passage from steady to unsteady approaches. In this paper a numerical investigation of turbulent flow around the Ahmed model, performed with the open-source CFD toolbox OpenFOAM®, is presented. Several URANS turbulence models, as well as different wall treatments, have been extensively tested on the notoriously critical 25° rear slant angle configuration of the Ahmed body. Simulations with the same models, but run in steady-state RANS mode, have been also provided in order to evaluate which kind of approach could be the best compromise as a sufficiently

accurate and time saving optimization tool for ground vehicle aerodynamic design. Drag predictions and other flow features, especially in terms of velocity profiles visualization in the rear region, have been critically compared with the experimental data available in the literature and with some prior numerical studies.

Thermo-structural Analysis of a New Engine Cylinder Head

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An engine head for microcar applications has been analysed and optimized by means of uncoupled CFD and FEM simulations in order to assess the strength of the component. This paper deals with a structural stress analysis of the cylinder head considering the thermal loads computed through an uncoupled CFD simulations of cylinder combustion and in cooling flow passages. The FE model includes the contact interaction between the main parts of the cylinder head assembly and it also considers the effects of bolts tightening and valve springs. Temperature dependent non-linear material properties are considered. The results, in term of temperature field, are validated by comparing with those obtained by means of experimental analyses; the engine has been instrumented with thermocouples on crank case and on cylinder head.

An Approach for the Objective Description of Vehicle Longitudinal Acceleration

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A trend in vehicle propulsion of converting from power sources such as a naturally aspirated internal combustion engine to turbocharged engines (Downsizing), multi-mode combustion systems (stratified charged combustion, HCCI) or multi-power source propulsion systems such as hybrid power-trains, can be observed. The subsequent switching between these different combustion modes or power sources, and, more importantly, the incorporation of turbochargers (turbo-lag) can affect the driveability, i.e. the smoothness of torque provision during transient driving manoeuvres. So far there is a lack of methodologies that can quantify and objectively describe vehicle transient acceleration events from a driver's point of perception. Thus an approach was developed while incorporating the acceleration transducers of men, the vestibular apparatus, into a longitudinal vehicle model with a transient engine / powertrain model. Finally the interaction between boost pressure generation, generated torque, vehicle acceleration and resulting stimulus of the driver is derived. In summary, this approach can support the development of well perceived longitudinal acceleration of vehicles.

Design of an Active Vehicle System for a Hybrid Race Car

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The aim of this work is to define the core of a stability control, called Active Vehicle System, for a hybrid Formula SAE car that will compete in the next season in the upcoming Alternative Energies (Class 1A) class. The vehicle on which the control system will act is equipped with two electric motors on the front axle and an internal combustion engine connected to the rear axle by the way of a semi-active differential. The layout of the car under consideration has been defined with the purpose of getting the most effectiveness by the Active Vehicle System, whose role is to define a yaw torque to be applied to the vehicle in order to correct its behavior during each maneuver. The results of the Upper Controller will be actuated by two Lower Controllers, one dedicated to the electric motors and one to the semi-active differential. On such controlled vehicle some testing maneuvers have been performed, in order to check its functionality. The analyses have been done with a mathematical model of the vehicle, in order to compare the behavior of the controlled car with respect to the uncontrolled and neutral ones. The results of these simulations have shown that the performance of the Class 1A equipped with the Active Vehicle System are closer to the reference model, effectively increasing the global performance and safety of the vehicle.

Use of Vibration Signal for Diagnosis and Control of a Four-Cylinder Diesel Engine

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In order to meet the stricter and stricter emission regulations, cleaner combustion concepts for Diesel engines are being progressively introduced. These new combustion approaches often requires closed loop control systems with real time information about combustion quality. The most important parameter for the evaluation of combustion quality in internal combustion engines is the in-cylinder pressure, but its direct measurement is very expensive and involves an intrusive approach to the cylinder. Previous researches demonstrated the direct relationship existing between in-cylinder pressure and engine block vibration signal and several authors tried to reconstruct the pressure cycle on the basis of information coming from accelerometers mounted on engine block. This paper proposes a method, based on the analysis of the engine vibration signal, for the diagnosis of combustion process in a Diesel engine. To this aim, the vibration signal was firstly pass-band filtered and then, using this signal, some global variables which characterize the combustion quality were estimated. Finally, a possible control system using the estimated combustion indicators was described. All the experimental tests were carried out on a four-cylinder Diesel engine running with operating conditions which ensured low temperature and premixed combustions.

Fuel Injection and Combustion Process _Modeling

Fuel Injection and Combustion Process _Experiments

Alternative and Advanced Power Systems

Fuels and Lubricants

Powertrain Technology

Exhaust Aftertreatment, Emissions and Noise

Particle Number Emissions: an Analysis by Varying Engine/Exhaust-System Design and Operating Parameters

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An increasing concern has been growing in the last years toward health effects due to Particulate Matter (PM) emissions. This triggered the widespread diffusion of Diesel Particulate Filters (DPFs), which equip almost every Diesel car and truck on the market, allowing to get large reduction (in the order of 95% and more) in terms of PM mass. However, PM health effects are believed to be more related to particle number rather than to particle mass. This gave rise in Europe to new regulations for passenger cars on total particle number, that will be introduced from EURO6 on. Engine/Exhaust-System assembly is therefore under investigation, to better understand the effectiveness of aftertreatment components toward particle number reduction, especially by varying engine and exhaust-system design/operating conditions, and to compare particle number emissions to particle mass emissions. Given the background, an experimental study on particle emissions of a FIAT 2.0l EURO5 passenger car Diesel engine coupled to a DOC-DPF system is proposed in this paper. Experimental data have been gathered at the engine test bench of the University of Rome Tor Vergata. Data have been acquired with regard to ECE-EUDC representative steady state engine operating points, to highlight correlations among specific engine operating conditions and upstream/downstream DPF particle number distribution and mass. Special attention has been devoted to the analysis of three different DPF materials and specifications toward particle emissions, both in terms of mass and number, during the transient loading and regeneration processes, as well as during steady state operating conditions after DPF pre-conditioning. Moreover, effects related to the variation of key engine operating parameters, such as EGR and pressure injection, have been analyzed.

Closed Loop Combustion Control – Enabler of Future Refined Engine Performance regarding Power, Efficiency, Emissions and NVH under Stringent Governmental Regulations

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Both, the continuous strengthening of the exhaust emission legislation and the striving for a substantial reduction of the carbon dioxide output in the traffic sector depict substantial requirements for the global automotive industry and especially for the engine manufacturers. From the multiplicity of possible approaches and strategies for clear compliance with these demands, engine internal measures offer a large and, eventually more important, very economical potential. For example, the achievements in fuel injection technology are a measure which in the last years has contributed significantly to a notable reduction of the emissions of the modern DI Diesel engines at favorable fuel efficiency. Besides the application of modern fuel injection technology, the linked combustion control (Closed Loop Combustion Control) opens possibilities for a further optimization of the combustion process. The availability of a highly-dynamic cylinder pressure signal makes it possible to analyze and affect the combustion characteristics based on new, advanced control algorithms even more exact than before. In order to control the temporal course of combustion, particularly a fast and precise high pressure fuel injection is qualified for dynamic adaptation by recording and evaluating the cylinder pressure signal and varying the injection accordingly. The highest degree of freedom is thereby obtained with a flexible rate shaping of the fuel introduction characteristic, which allows the realization of a pre-defined combustion pressure pattern or fuel burn rate. In this publication detailed results of experimental investigations identify the high potential of a direct fuel burn rate control, considering various possibilities with respect to the optimization of fuel consumption, the minimization of pollutant emissions and reduction of combustion noise. In the first section, the direct burn rate control is accomplished with a unique, experimental common-rail injector with specific rate shaping capabilities. In the second part of the paper an advanced control concept is presented which realizes the management of pre-defined combustion pressure traces and fuel conversion processes with a conventional, series production Piezoinjector by multiple injections. Thus control options result

in the possibility of a direct cost-attractive realization of pre-defined emission-, consumption- and noise-optimal fuel rates with proven injection technology. Particularly, this technology offers the possibility of compensating different fuel properties and qualities within a large range, thus showing a large potential for a future multi-fuel diesel combustion concept.

A Study on NO_x Reduction of Marine 4-Stroke Diesel Engine Using Charge Air Humidification

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This research has been carried out to verify the performance of a charge air moisturizer system which was developed to reduce NO_X emission from marine 4-stroke diesel engine, to comply with US EPA (Environmental Protection Agency) Tier II (Category 2) emission regulation. The charge air moisturizer system abates NO_X emission from a diesel engine through supplying high level of humid charge air into a combustion chamber. As a results, NO_X and THC (Total Hydro-Carbon) emissions met to the EPA Tier II regulations, and PM (Particulate Matter) emission also met the regulations on the condition of MGO (Marine Gas Oil) or low sulfur fuel oil usage. But, the SFOC (Specific Fuel Oil Consumption) increased slightly. Performance test using this system did not leave any trace of rust, corrosion, abnormal wear etc. on the inner parts of the engine. Thus, it can be concluded that the Charge Air Moisturizer system has little effect on the durability or reliability of engine components.

Fresh and Aged SCRT Systems Retrofitted on a MY 1998 Class-8 Tractor: Investigation on In-use Emissions

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In order to comply with stringent 2010 US-Environmental Protection Agency (EPA) on-road, Heavy-Duty Diesel (HDD) emissions regulations, the Selective Catalytic Reduction (SCR) aftertreatment system has been judged by a multitude of engine manufacturers as the primary technology for mitigating emissions of oxides of nitrogen (NO_x). As virtually stand-alone aftertreatment systems, SCR technology further represents a very flexible and efficient solution for retrofitting legacy Diesel engines as the most straightforward means of cost-effective compliance attainment. However, the addition of a reducing agent injection system as well as the inherent operation limitations of the SCR system due to required catalyst bed temperatures introduce new, unique problems, most notably that of ammonia (NH_3) slip. Even the most refined systems, while performing flawlessly during standardized certification tests, may encounter excursions during real-world operation, thereby leading to possible formation of secondary emissions and emit unacceptable high NO_x. The following study, funded by the South Coast Air Quality Measurement District (AQMD) and supported by Johnson Matthey, was initiated to provide a better understanding of the performance and especially durability of retrofit exhaust aftertreatment systems comprising of Diesel Particulate Filter (DPF) and SCR devices. Specifically, two SCRT® systems retrofitted to a Class-8 Heavy-Duty Diesel (HDD) truck, whereof one was new and another been in on-road operation for the duration of 15 months, were evaluated on a chassis dynamometer with regard to overall system performance, secondary emissions formation and NOx conversion efficiency deteriorations due to catalyst aging. SCR conversion efficiencies ranged between 67% to 71% and Particulate Matter (PM) filtration efficiencies above 90%, depending on vehicle test cycle. No statistical evidence for a reduction in SCRT® efficiency over the course of a 15 months on-road operation period could be found at the 5% significance level.

Exhaust Temperature Management for Diesel Engines – Assessment of Engine Concepts and Calibration Strategies with Regard to Fuel Penalty

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Both, the continuous strengthening of the exhaust emission legislation and the striving for a substantial reduction of carbon dioxide output in the traffic sector depict substantial requirements for the development of future diesel engines. These engines will comprise not only the mandatory Diesel oxidation catalyst (DOC) and particulate filter DPF but a NO_x aftertreatment system as well – at least for heavier vehicles. The oxidation catalysts as well as currently available NO_x aftertreatment technologies, i.e. LNT and SCR, rely on sufficient exhaust gas temperatures to achieve a proper conversion. This is getting more and more critical due to the fact that today's and future measures for CO_2 reduction will result in further decrease of engine-out temperatures. Additionally this development has to be considered in the light of further engine electrification and hybridization scenarios. To maintain the high NOx conversion level in the aftertreatment system adequate temperature management strategies will be beneficial. This includes not only conventional calibration measures such as throttling, split-main or post injection but also further evolution of the engine hardware such as cam phasing. Split-cooling and other thermal management measures have the potential to reduce CO_2 emissions and increase exhaust temperature during cold start at the same time. But also highly variable valve trains open up a wide spread of potential thermo management measures. In this paper different concepts for exhaust gas temperature management will be analysed and compared. The assessment will focus on the effectiveness regarding the exhaust temperature increase and the related fuel economy penalty. Further factors such as robustness, effects on operation strategy and required software functions and cost are discussed as well. The engine used in this study was an optimized in-line 4-cylinder research engine to achieve best combustion behaviour for lowest engine-out emissions and highest fuel efficiency. The investigations were carried out with pilot injection and simulated closed loop combustion control. The engine used in this study is capable to meet Euro

6 emissions limits. With all accomplished variations a significant increase in temperature downstream low pressure turbine can be achieved. The quantity of pilot and post injection plays an important role for emission formation under warm and under cold conditions. By using an exhaust cam-phaser CO-, HC- and NO_x emissions can be significantly reduced distinguishing exhaust cam-phasing from the other investigated strategies.

The Effect of Various Petrol-ethanol Blends on Exhaust Emissions and Fuel Consumption of an Unmodified Light-Duty SI Vehicle

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Due to limited fossil fuel resources and a need to reduce anthropogenic CO2 emissions, biofuel usage is increasing in multiple markets. Ethanol produced from the fermentation of biomass has been of interest as a potential partial replacement for petroleum for some time; for spark-ignition engines, bioethanol is the alternative fuel which is currently of greatest interest. At present, the international market for ethanol fuel consists of E85 fuel (with 85 percent ethanol content), as well as lower concentrations of ethanol in petrol for use in standard vehicles (E5, E10). The impact of different petrol-ethanol blends on exhaust emissions from unmodified vehicles remains under investigation. The potential for reduced exhaust emissions, improved security of fuel supply and more sustainable fuel production makes work on the production and usage of ethanol and its blends an increasingly important research topic. This paper evaluates the possibility of using petrol-ethanol blends in a modern Euro 4 vehicle without substantial engine modification. The influence of different quantities of ethanol in petrol blends (E5, E10, E25, E50 and E85) on the emission measurement of the gaseous pollutants carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and carbon dioxide (CO_2) for a passenger car were analysed over the New European Driving Cycle (NEDC) on a chassis dynamometer. The results obtained revealed that exhaust emissions are affected by the proportion of ethanol in the blend. Engine out emissions of HC, CO and NO_x were found to vary significantly with the blend used. Fuel injection time, engine-out and exhaust temperatures and the efficiency of the aftertreatment system were all also found to vary from blend to blend. Fuel consumption increased approximately in line with blend energetic content for all blends, apart from when running on E85. The experimental work presented in this paper was performed as part of a test program evaluating biofuels' influence on light-duty petrol engines for passenger cars and light commercial vehicles.

An Alternative Way to Reduce Fuel Consumption during Cold Start: The Electrically Heated Catalyst

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It is well known that the optimal management of cold start is crucial to fulfill present and future emission legislation. During past years the catalytic converter has left its original under floor position to get increasingly closer to the engine in order to exploit higher exhaust gas temperature. Simultaneously, the exhaust gas temperature is becoming significantly lower, both in gasoline engines due to the extensive use of turbo charging, and in diesel engines thanks to very high combustion efficiency and in some cases the use of two stage turbo charging. A well established way to reach the catalyst light-off temperature fast enough to fulfil emission limits consists of artificially increasing the exhaust gas temperature. This has the drawback of a higher fuel consumption which conflicts with the tight CO_2 targets now required of the OEMs. This paper describes an alternative way to warm up the catalytic converter in a fast and efficient manner using the electrical heated catalyst (EHC) with only minor increases of fuel consumption. Additionally, the application of the electrical heated catalyst is very effective in combination with a hybrid vehicle where the EHC itself can be activated via energy recuperation thus increasing the total energy efficiency.

Ceramic Foam Catalyst Substrates for Diesel Oxidation Catalysts: Pollutant Conversion and Operational Issues

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In the field of automotive exhaust catalysts, foam-type substrates have been proposed as alternatives to the well-established honeycomb substrates. The ceramic foams developed and manufactured in our laboratory are capable of redistributing the flow of exhaust gases, enhancing turbulence, mass transfer and species mixing, without increasing flow resistance and pressure drop to prohibitive levels. Based on the characteristics of turbulent mass and heat transfer, ceramic foam based catalysts have the potential for achieving similar pollutant conversion performances as state of art honeycomb catalysts with substantially lower precious metal requirements. In this paper we demonstrate this potential with a small Diesel powered Heavy Duty truck with a ceramic foam Diesel Oxidation Catalyst (DOC). Given the substantial differences in geometrical properties between foams and honeycombs a direct comparison with equal coating thickness, amount and precious metal amount is not feasible. We present however systematic comparisons with known precious metal amounts while pointing out important differences in the wash coating characteristics. As strongly affected, crucial operational characteristics we comment on, are the pressure drop and the homogenizing properties of the substrates on the temperature distribution. For the DOC applications we compared catalysts with an overall volume ratio of 1.4:1 (honeycomb:foam). The comparisons involved the serial production honeycomb to specifically coated foams. Here the wash coat amounts have been chosen in order to achieve almost equal layer thicknesses (wash-coat amount ratio of 6.5:1, honeycomb:foam). The entire precious metal load on the foam was approx. 2.8 times less than the corresponding one on the compared honeycomb. The conversion performances achieved with the foam catalyst were almost equal to those achieved by the honeycomb in respect to CO and THC oxidation, although honeycombs had 2.8 times more precious metals. In addition, the foams exhibited substantially better particle oxidizing behavior, as particle number measurements have shown. Nevertheless, NO oxidation light-off performance of the foams was worse. This may be attributed to different wash coat compositions, the wash coat composition of the serial production honeycomb was not fully known. The comparison of two differently coated foam DOCs have given insights in the conversion dependencies on the coating parameters and have shown further optimization directions.

Numerical and Experimental Analysis of the Flow Field within a Lean NOx Trap for Diesel Engines

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The present study aims at analyzing the flow field within a Lean NO_x Trap (LNT). To this purpose a twofold approach based on the synergic use of numerical and non-intrusive experimental techniques was adopted. The measurements were carried out at a steady flow rig in terms of global performances and local velocity measurements. In particular, mass flow rates and pressure drops were used to define the global fluid dynamic efficiency of the system, while the Laser Doppler Anemometry (LDA) technique was employed to determine the flow field within the aftertreatment apparatus. At the same time, a finite volume CFD code was adopted for the numerical analysis. The comparison between experimental and numerical data displayed a good agreement in terms of global and local quantities. Specifically, the numerical code well-reproduced the main structure within the emission control system. Furthermore, the analysis showed the influence of the trap on the flow field and the pressure drop distribution through the aftertreatment device.

Steady State Investigations of DPF Soot Burn Rates and DPF Modeling

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This work presents the experimental investigation of Diesel Particulate Filter (DPF) regeneration and a calibration procedure of a 1D DPF simulation model based on the commercial software AVL BOOST v. 5.1. Model constants and parameters are fitted on the basis of a number of steady state DPF experiments where the DPF is exposed to real engine exhaust gas in a test bed. The DPF is a silicon carbide filter of the wall flow type without a catalytic coating. A key task concerning the DPF model calibration is to perform accurate DPF experiments because measured gas concentrations, temperatures and soot mass concentrations are used as model boundary conditions. An in-house developed raw exhaust gas sampling technique is used to measure the soot concentration upstream the DPF which is also needed to find the DPF soot burn rate. The soot concentration is measured basically by filtering the soot mass of a sample gas continuously extracted from the engine exhaust pipe for 1-2 hours while also measuring the gas flow passed through the filter. A small silicon carbide wall flow DPF protected in a sealed stainless steel filter housing is used as sample filter. Measured DPF pressure drop characteristics are used to fit model constants of soot and filter properties. Measured DPF gas conversions and soot burn rates are used to fit model activation energies of four DPF regeneration reactions using O_2 and NO_2 as reactants. Modeled DPF pressure drops and soot burn rates are compared to the steady state DPF experiments in the temperature range between 260 and 480 °C. The model widely reproduces the experimental results. Especially the exponential soot burn rate versus temperature is accurately reproduced by the model.

Pulsed Regeneration for DPF Aftertreatment Devices

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DPF regenerations involve a trade-off between fuel economy and DPF durability. High temperature regenerations of DPFs have fewer fuel penalties but simultaneously tend to give higher substrate temperatures, which can reduce thermal reliability. In order to weaken the trade-off, the integrated system-level model [1-4] is used to conduct optimization studies and explore novel regeneration strategies for DPF aftertreatment devices. The integrated model developed in the Engine Research Center (ERC) includes sub-models for engines, emissions, aftertreatment devices and controllers. Based on the engine and regeneration fuel economy, multiple and single cycle regeneration tests are performed and analyzed. The optimal soot loadings to initiate and terminate regenerations are discussed. A pulsed regeneration strategy, which is characterized by injecting multiple pulses of fuel (upstream of a DOC) during regenerations, is investigated. It is found that pulsed regeneration has the potential to reduce regeneration fuel penalties without generating significantly high wall temperatures that can reduce DPF durability.

ExhAUST: DPF Model for Real-Time Applications

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Diesel Particulate Filters (DPFs) are well assessed exhaust aftertreatment devices currently equipping almost every modern diesel engine to comply with the most stringent emission standards. However, an accurate estimation of soot content (loading) is critical to managing the regeneration of DPFs in order to attain optimal behavior of the whole engine-after-treatment assembly, and minimize fuel consumption. Real-time models can be used to address challenges posed by advanced control systems, such as the integration of the DPF with the engine or other critical aftertreatment components or to develop model-based OBD sensors. One of the major hurdles in such applications is the accurate estimation of engine Particulate Matter (PM) emissions as a function of time. Such data would be required as input data for any kind of accurate models. The most accurate way consists of employing soot sensors to gather the real transient soot emissions signal, which will serve as an input to the model. Objective of this study is model a DPF in real-time by means of the 1-D code ExhAUST (Exhaust Aftertreatment Unified Simulation Tool). ExhAUST is characterized by a high degree of accuracy in capturing the essential phenomena, such as wall/cake collection and continuous/forced regeneration processes occurring inside the DPF. Moreover, it exhibits high computational efficiency due to its peculiar analytical formulation. In this paper, ExhAUST has been coupled to instruments, such as the micro-soot sensor and TSI-EEPS, which are capable of measuring transient PM emissions. Data acquired by the soot sensor have been used as continuous input in terms of PM flow rate entering the DPF, so that deposition and oxidation rates could be developed depending on those information. Numerical results are compared with experimental data gathered at the WVU engine laboratory using a Mack heavy-duty diesel engine coupled to a Johnson Matthey CCRT aftertreatment system tested on a transient FTP cycle. Results show that ExhAUST is capable of correctly capturing the evolution of back pressure during transient cycles, with minor model tuning during operation; thus, showing optimal pre-requisites for real-time vehicle applications.

New Concepts and Technologies for Integrated Diesel Exhaust Gas Aftertreatment Systems

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Automobile catalysts have been mandatory on new cars in the European Union since 1993 and approximately 70% of the 200 million car fleet in the EU today are nowadays equipped with them [1]. Because of increasingly stringent emission regulations and a growing number of vehicles in the EU, aftertreatment technologies for automobile emissions represent a rapidly growing market and Diesel engines are steadily expanding their market share. Current exhaust aftertreatment concepts for Diesel engines use extruded ceramic substrates with a honeycomb structure for the diesel oxidation catalyst (DOC) as well as the diesel particulate filter (DPF). The turbulent exhaust flow upstream the substrate is converted to laminar flow after entering the single channels of the DOC. The inlet velocity profile in the cross-section of the oxidation catalyst is strongly dependent on the upstream piping geometry and pressure distribution and is similar downstream in the exit cross section, due to the absence of any momentum and mass transfer among the monolith channels perpendicular to the main flow direction. In the concept evaluated in this paper, catalytic converters will not be implemented as laminar-flow honeycomb-type substrates, as in current systems, but as turbulent-flow ceramic foam substrates. Turbulent-flow foam structures homogenize the flow over its crosssection improving exhaust gas mixing, flow distribution and conversion efficiency by increasing the wall contact of the exhaust gas. Moreover, the ceramic foam based substrate has been functionalized with a specific catalytic coating based on DOC and LNT (lean NOx trap) technologies in order to implement in a single brick both the functionalities and comply with the forthcoming Euro 6 emission limits. The design and development process of the catalyzed foam based substrates is strongly influenced by the macroscopic properties of microscopically heterogeneous materials; therefore, the novel catalytic system has been experimentally evaluated from lab-scale up to vehicle level and, in parallel to the experimental work, a specific software tool has been developed in order to simulate all relevant physical phenomena occurring in porous structures thus satisfying both demands: i) detailed analysis of the exhaust gas flow and diesel particulate motion/deposition phenomena occurring inside the porous structure, ii) design and development of global devices/processes.

Active Regeneration Characteristics in Diesel Particulate Filters (DPFs)

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sParticulate matter (PM) captured in diesel particulate filters (DPF) consists of: (a) soot, the product of incomplete combustion of the fuel and (b) ash, produced by combustion of lubricating oil plus minor amounts of metal components in the fuel. Among the various types of DPFs, most efficient are the so-called wall flow filters, where the exhaust gas is forced to pass through porous walls of adjacent channels, which are plugged alternately at their opposite ends. Accumulation of PM in DPFs leads to increasing pressuredrop across the filter. Since increased PM load in the filter and thus increased pressure drop across the filter deteriorates the engine performance, the filter load of the DPF has to be periodically removed during a process referred to as regeneration. During the regeneration process, soot PM captured in the DPF is expected to be oxidized. The temperature needed for oxidation of PM is usually exceeding ca. 550°C. Since diesel exhaust temperatures seldom reach these levels, oxidation of soot is promoted by the so-called passive regeneration by means of different technologies: (1) the continuous regenerating trap (CRT) technology, which takes advantage of the NO_2 produced by oxidation of engine-out NO over a Pt catalyst preceding the DPF; (2) incorporation of a catalyst precursor in the fuel, so that PM and catalyst are built together and facilitate PM combustion in the presence of oxygen at lower temperatures. Both of these techniques are, however, only partly successful. Higher degrees of soot oxidation are achieved during the so-called active regeneration, whereby higher exhaust temperatures are enforced. In this study we have measured and computed the soot oxidation rates during active and passive regeneration in a small heavy duty truck. By means of the measured species mass flow balances over the diesel oxidation catalysts (DOC) and the DPF we are able to compute the soot burning rates and to compare them with the weight decrease of the DPF. In addition, we have examined in detail the emission characteristics of the entire after treatment system during defined active regenerations. Particulate emissions have been measured by particle number counting. Moreover, soot was measured optoacoustically. The emissions during active regenerations are deviate substantially from those in normal operation. Tailpipe CO and unburnt hydrocarbons, soot mass and particulate matter are significantly higher. Only NO_x is rather unaffected. The overall emission profile is not severely influenced given the rare occurrence of active regenerations. Based on the species balances over the DPF, the soot oxidation rate and the oxidized

soot mass during active regeneration were computed. The obtained remaining soot mass in the filter was in good agreement with the weight of the filter. Based on the soot oxidation rate and the temperature measurement characteristic kinetic parameters for soot oxidation have been computed. The activation energies have been in reasonable agreement with comparable values reported in the literature lying between 80 and 170kJ/kmol in the different regeneration phases. The computed pre-exponential factors are also in agreement with reported values, their high variations though renders interpretation more difficult. Targeted optimization in analytics and measurement techniques are expected to improve the accuracy of the kinetic parameters.

Model Based Design Procedure of After Treatment Systems for Off-Road Diesel Engines

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In 2011-2013, regulations will be tightened for non-road vehicles, via the application of Stage III-B standards in Europe. With state of the art technology (high pressure common rail, cooled EGR), non-road Diesel engines will require DPFs to control PM, as 90% reduction is requested with respect to STAGE III-A standards. Additional challenges may also foresee the obtainment of STAGE III-B standards with STAGE III-A engine technology, by means of retrofit systems for PM control. In that case, retrofit systems must furthermore guarantee simple control systems, and must be robust especially in terms of limited back pressure increase during normal operation. Moreover, retrofit systems must offer flexibility from the design point of view, in order to be correctly operated with several engines of same class, possibly characterized by totally different PM flow rates, temperature, NO_x and O_2 availability. The design process of such systems appears challenging itself, as experimental testing cannot be massively used to limit costs otherwise leading the product out of any feasibility. The design of OEM exhaust systems appears instead different, as the implementation of more effective regeneration strategies appears feasible, but time to market is limited and then efficient design procedures are required to save time and costs. In the provided background, a model-based design tool, specifically developed for non-road Diesel engines at the University of Rome Tor Vergata, is presented in this paper. This tool is partially based on the use of GT-Power, properly coupled to user-defined models to increase its flexibility as well as to improve computational efficiency. Moreover, an original clustering procedure has been specifically developed to understand the impact of key engine parameters (such as injection timing, EGR, etc) on exhaust operating conditions (in terms of mass flow rate, species concentration and temperature), and in turn on exhaust system behavior. Special care has been given to analyze the whole engine/exhaust-system performance on a transient basis, and properly estimate performance on the NRTC (Non-Road-Transient-Cycle). The design procedure was applied to characterize a DOC+DPF after treatment system, where the DOC/DPF volume and DOC noble metal loading have been assumed the main design parameters. Obtained results finally led to the selection of two layouts, respectively for after-market (retrofit) and OEM applications.

Advanced Modeling of Diesel Particulate Filters to Predict Soot Accumulation and Pressure Drop

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Diesel particulate filters (DPFs) are recognized as the most efficient technology for particulate matter (PM) reduction, with filtration efficiencies in excess of 90%. Design guidelines for DPFs typically are: high removal efficiency, low pressure drop, high durability and capacity to resist high temperature excursions during regeneration events. The collected mass inside the trap needs to be periodically oxidized to regenerate the DPF. Thus, an in-depth understanding of filtration and regeneration mechanisms, together with the ability of predicting actual DPF conditions, could play a key role in optimizing the duration and number of regeneration events in case of active DPFs. Thus, the correct estimation of soot loading during operation is imperative for effectively controlling the whole engine-DPF assembly and simultaneously avoidingany system failure due to a malfunctioning DPF. A viable way to solve this problem is to use DPF models. This paper presents a DPF model jointly developed by West Virginia University and University of Rome Tor Vergata. The fully analytical model is based on a single channel representation of the flow while the thermal and catalytic framework is based on a novel 2-layer approach Numerical results are compared with experimental data gathered at West Virginia University (WVU) engine laboratory using a Mack heavy-duty diesel engine coupled to a Johnson Matthey CCRT aftertreatment system. The engine test bench was equipped with a DPF weighing system to track soot loading over a customized engine operating procedure. The study shows that: a) Wall and washcoat layer present different regeneration and collection dynamics, whose behavior is important to capture back pressure and temporal evolution of the collected mass b) Advanced filtration and regeneration process treatment in the wall allow the use of constant wall and cake parameters; thus, the model can be used to track back pressure and mass history of DPFs under subsequent regeneration and loading processes, c) Filtration sub-model results are highly influenced by engine-out particle size distribution during deep bed filtration mechanism suggesting a possible implementation in conjunction with soot sensor devices, and d) Estimation of the mass trapped using the DPF sub-model affords the opportunity to define a possible control strategy for active regeneration and OBD diagnostics.

The Effect of De-greening and Pre-treatment on Automotive Catalyst Performance

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Computer simulation is now considered to be a crucial stage in the design of automotive catalysts due to the increasing complexity of modern aftertreatment systems. The resulting models almost invariably include surface reaction kinetics that are measured under controlled conditions similar to those found on a vehicle. Repeatability of the measurements used to infer surface reaction rates is fundamental to the accuracy of the resulting catalyst model. To achieve the required level of repeatability it is necessary to ensure that the catalyst sample in question is stable and that its activity does not change during the test phase. It is therefore essential that the catalyst has been lightly aged, or 'de-greened' before testing begins. It is also known that the state of the catalyst's surface prior to testing has an impact on its subsequent light-off performance and that test history can play an important role in catalyst activity. Suitably pre-treating the catalyst surface can ensure that a reference point is reached prior to a light-off test. The work summarised in this paper includes a study of both the de-greening phase and the state of the catalyst's surface on its activity, with the aim of developing a robust test protocol that provides repeatable kinetic data under realistic operating conditions. To establish a protocol for initial stabilisation of new catalyst samples a series of tests were conducted on catalysts that had been thermally aged at 600°C and 750°C respectively until the sample exhibited stability. The activity of the sample was assessed by repeating identical CO light-off tests following each period of time in the oven. A period of 8 hours at 750°C was found to sufficiently stabilise the sample. In the pre-treatment study an investigation into the effect of several pre-treatment protocols on CO light off was carried out on a three-way catalyst of commercial formulation in order to establish a robust protocol to ensure test repeatability. The investigation focused on pre-treating the catalyst sample in hydrogen, oxygen or nitrogen environments at specified conditions of flow and temperature. Following pre-treatment, identical CO light-off tests were performed in order to assess the respective influences of each pre-treatment. A trend of lower light off temperatures was observed for all pre-treatment strategies on the first of two consecutive light-off temperature ramps with a notable increase in light off temperature observed on the second ramp. As a result of this study a pre-treatment protocol was established. The protocol involves treating the catalyst sample in flowing nitrogen up to 600°C using a temperature ramp of 15°C/min.

Experimental Investigation of Measurement and Characteristics of Diesel Particulate Matter Size Distributions and Emissions

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Recent research has focused on engine combustion technology as well as application of after-treatment in order to comply with emission regulation. However, it is much more efficient way to control emissions from engine itself and furthermore research on engine control will provide the direction of after-treatment technology in future. Furthermore, emission standard regulation for passenger diesel vehicles has been stringent compared to others and nano-particles will be included in EURO6 regulation in Europe and similar emission standard will be introduced in Korea. A 3.0 liter high speed diesel engine equipped with by CRDI system of 160MPa injection pressure, and an intake/exhaust system of V type 6 cylinder turbo-intercooler was applied. The conditions of fuel spray and combustion were investigated by setting up an ETAS system which is a similar condition to the engine dynamometer test. The engine drives from an engine speed of 2000rpm to 3000rpm to provide 160MPa high pressure injection by using a piezo injector. The injection period and injection quantity, pilot injection types which are related to CRDI and air/fuel ratio control applied by EVGT were changed simultaneously. In order to select optimum injection timing, low engine load and injection quantity were fixed and this experiment were repeated by adjusting an injection timing driven at maximum high speeds. And then air excess ratio, cycle change, indicated pressure diagram, heat release rate and emissions were investigated after injection timing was selected by MBT. Standard experiment procedure constituted dilution apparatus and CPC system to collect nano-particles and this test results were compared with regulated materials of CO, HC, NO_x and investigated their relation and characteristics of nano-particles.

High Temperature Sampling System for Real Time Measurement of Solid and Volatile Fractions of Exhaust Particulate Matter

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This paper discusses the design and qualification of a High Temperature Sampling System (HTSS), capable of stripping the volatile fraction from a sample flow stream in order to provide for quantification of total, solid and volatile particulate matter (PM) on a near real-time basis. The sampling system, which incorporates a heated diesel oxidation catalyst, is designed for temperatures up to 450°C. The design accounts for molecular diffusion of volatile compounds, solid particles diffusion and reaction kinetics inside one channel of the oxidation catalyst. An overall solid particle loss study in the sampling was performed, and numerical results were compared with experimental data gathered at the West Virginia University Engine and Emissions Research Laboratory (EERL) and West Virginia University's Transportable Heavy-Duty Vehicle Emissions Testing Laboratory (THDVETL). Data indicated that "dry soot" aerosol streams, which were produced at a single engine operating mode on an engine test stand point using a dynamometer were largely unaffected by the sampling system. Important differences were identified in the nucleation mode between steady-state and transient tests - a smaller nucleation mode was observed in the transient operation. Depending upon the test cycle, the particle loss, on count basis, in the HTSS ranged from 10% to 26%. The HTSS was found to be very effective in scrubbing the volatile organic fraction (VOF) from the exhaust stream; hence, resulting in a 96% reduction in total PM count and 52% total PM mass under steady-state mode of engine operation. Under transient operation, the total PM count reduction was 55%, and the total PM mass reduction was 32%.The difference in the untreated sample stream and the treated sample was evident in the concentration and size distribution of nucleation mode particles. The sampling system represents a viable method for collecting nanoparticles and the larger accumulation mode particles and the opportunity to perform an extensive suite of chemical and morphological analyses.

Real-World Performance of a CNG Heavy Duty Articulated Truck

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In this study the performance of a monofuel compressed natural gas articulated truck was investigated under real-world conditions. To analyze the CNG vehicle due to fuel consumption and exhaust emissions a representative road-test route was conducted, including sections with significantly different driving conditions. Moreover, driving tests on freeway under higher load were carried out. As experimental equipment, a new ultra compact on-board system measured the in-car exhaust mass emissions in real time. Every second, a full dataset of CO_2, CO, HC and NO_x emission rates was provided. The real-world emission measurements are based on a modal analysis of the emission concentrations in the tailpipe of the vehicle. The exhaust gas mass flow is calculated from the air mass flow and the gas components with a real time reaction model. In combination with the vehicle speed, the emission rates in g/s are then calculated in gram per kilometer. Furthermore, the fuel consumption in g/s or kg/100 km is calculated with the carbon balance method according to the EU Commission directive 1999/100/EC. The gained distance related emissions and the derived mean values are based on the several thousand individual datasets measured at the drive tests. In order to link the measured exhaust emission data with geographical information of the road-test route a GPS tracking was implemented as well. Additionally, the application of new calculation and experimental methods in this investigation allowed developing characteristic maps of the CNG powertrain based on the real-world measurement data.

Performance Characterisation of a Range of Diesel Oxidation Catalysts: Effect of Pt:Pd Ratio on Light Off Behaviour and Nitrogen Species Formation

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Understanding the behavior of automotive catalysts formulations under the wide range of conditions characteristic of automotive applications is key to the design of present and future emissions control systems. Platinum based oxidation catalysts have been in use for some time to treat the exhaust of diesel powered vehicles and have, as part of an emissions control package, successfully enabled compliance with emissions legislation. However, progressively stringent legislated limits, coupled with the need to reduce vehicle manufacturing costs, is incessantly demanding the development of new and improved catalyst formulations for the removal of pollutants in the diesel exhaust. With the introduction of low sulphur diesel fuel, and the advantageous decline in Palladium prices with respect to Platinum, bimetallic Pt:Pd based catalysts have found an application in diesel after treatment. In this paper the findings of a study carried out on a range of lightly loaded (40g/ft^3) diesel oxidation catalysts with varying Pt:Pd ratios are presented. The catalysts' performance characterization was measured on a state of the art, commercially available, integral synthetic gas reactor and a range of exhaust analysers was used to speciate the exhaust gas on catalyst exit. The aim of the study was to determine the effect of the Pt:Pd ratio on catalyst performance. The evaluation of the impact of varying the formulation on catalyst light off and nitrogen species formation was of particular interest to support both catalyst modeling and exhaust system design. The study found that, at parity of exhaust flow conditions tested, the same nitrogen species are evolved in all of the catalysts, although in different concentrations. Higher Pt content distinctly favors higher conversion of NO to NO_2, which is beneficial if further treatment by LNT or SCR is implemented. Higher Pt content however, also promotes higher N_2O formation, which is undesirable. The effect on other nitrogen species of interest from an emissions control standpoint, namely NH_3 an N_2, is a more complex function of test conditions. Higher Pd content generally lowers the mixture CO catalyst light off temperature, driven by

higher metal activity towards CO conversion, which is highly desirable for the treatment of diesel exhaust gas. However, the performance of samples with higher Pd content appears to be affected by oxygen exposure. The effect on HC conversion is a more complex function of catalyst composition and reacting mixture, with CO concentration playing an important role on the overall catalyst performance

Study of Non-Regulated Exhaust Emissions using Biodiesels and Impact on a 4 Way Catalyst Efficiency

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This work focuses on analysis of fine particles and carbonyl compounds and the efficiency of a four way catalytic converter towards these pollutants using two different biodiesel fuels in 20% v/v with a reference petroleum diesel. The biodiesel tested are fatty acid methyl ester (FAME) of soybean oil and fatty acid ethyl ester (FAEE) produced from Waste Cooking Oil. The combustion of the reference petroleum diesel (B0) and biodiesel blends was carried out in the engine of a diesel power generator. Number size distributions of fine particles (<10μm diameter, named PM10) emitted were obtained using an Electrical Low Pressure Impactor (ELPI). It is shown that whatever the blend tested, particles are mainly composed of ultrafine particles with a diameter less than 0.4mm. The 4 way catalytic converter allows to reduce fine particle emission by at least 96.7%. Although the emission factor is dependent of the composition of the biodiesel blend, it was observed that introduction of FAME does not influence the number size distribution. The fraction PM0.1 represents then about 42% of the total number of particles. On the contrary, using FAEE blend leads to a shift of the number size distribution towards larger particles with a contribution of 70% of the fraction PM0.1-1. The use of FAEE blend leads to an increase of carbonyl compounds emission especially for acetaldehyde, acrolein, propanal and acetone production. However, it appears that the 4 way catalyst is not efficient towards carbonyl compounds conversion.

Measurement of Transient PM Emissions in Diesel Engines

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Transient emission peaks have become an important fraction of the total emissions during the standardized test cycles for passenger car Diesel engines. To this end this paper is concerned with the challenge of measuring emissions during transients. The importance of this topic is increasing due to strict regulation on pollutant emissions. Hence, suitably accurate and fast measurement devices for PM emission detection are required. Thus, we present a comparison between different measurement techniques for particulate matter (PM) emissions from a Diesel engine, in particular during transients. The compared equipments include AVL Micro soot sensor, AVL Opacimeter, Differential mobility spectrometer and Laser induced incandescence. The goal of this paper is to reveal the most accurate device in the sense of sensitivity and dynamics for fast measurements of PM from a Diesel engine. The main subject of the studies was to quantify the difference in transient performance of the devices at several measurement positions during standardized emission test cycles. The measurement devices were placed into various locations in the exhaust of a Euro 5 passenger car Diesel engine, namely in the upstream of the turbine, in the downstream of the turbine and in the tailpipe. The analyses present the benefits and disadvantages of measuring close to the actual combustion event. The obtained results will allow better understanding PM emissions and support dynamic emission modelling as well as control design.

Performance & Emissions of Diesel and Alternative Diesel Fuels in Modern Light-duty Diesel Vehicles

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Conventional diesel fuel has been in the market for decades and used successfully to run diesel engines of all sizes in many applications. In order to reduce emissions and to foster energy source diversity, new fuels such as alternative and renewable, as well as new fuel formulations have entered the market. These include biodiesel, gas-to-liquid, and alternative formulations by states such as California. Performance variations in fuel economy, emissions, and compatibility for these fuels have been evaluated and debated. In some cases contradictory views have surfaced. “Sustainable”, “Renewable”, and “Clean” designations have been interchanged. Adding to the confusion, results from one fuel in one type of engine such as an older heavy-duty engine, is at times compared to that of another fuel in another type such as a modern light-duty engine. This study was an attempt to compare the performance of several fuels in identical environments, using the same engine, for direct comparison. Results of a large-scale fleet test and emissions test to evaluate the performance of several diesel fuels in a modern heavy-duty diesel (HDD) engine were presented in an earlier technical paper. That study was followed by a more recent article describing the results of emissions and performance of the same fuels in an older heavy-duty industry-standard engine. This article is the third and the final in this series and includes three modern light-duty diesel vehicles (BMW 335d, Volkswagen Jetta TDI, and Chevrolet Silverado) to evaluate emissions and fuel economy with a number of diesel fuels that cover a range of products being used in the North American market. EPA, California, Texas LED diesel, biodiesel, biodiesel blends, and gas-to-liquid fuel were tested in this program. Federal Test Procedure (FTP), Highway Fuel Economy Test (HwFET) Procedure, US06 Test Procedure, and 0-to-60 mph wide-open-throttle (WOT) were utilized for emissions, fuel economy, and power effects evaluation. This document will provide a detailed description of this project along with statistical analysis of test results for eight diesel fuels.

Feasibility of Particulate Mass and Number Measurement with Portable Emission Measurement Systems (PEMS) for In-Use Testing

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Different particulate mass (PM) portable emission measurement systems (PEMS) were evaluated in the lab with three heavy duty diesel engines which cover a wide range of particle emission levels. For the two engines without Diesel Particulate Filters (DPF) the proportional partial flow dilution systems SPC-472, OBS-TRPM, and micro-PSS measured 15% lower PM than the full dilution tunnel (CVS). The micro soot sensor (MSS), which measures soot in real time, measured 35% lower. For the DPF equipped engine, where the emissions were in the order of 2 mg/kWh, the systems had differences from the CVS higher than 50%. For on board testing a real time sensor is necessary to convert the gravimetric (filter) based PM to second by second mass emissions. The detection limit of the sensor, the particle property it measures (e.g. number, surface area or mass, volatiles or non-volatiles) and its calibration affect the estimated real time mass emissions. Thus, the choice of the real time sensor might be critical if the emissions are close to the certification (or in-use) limit. Currently the emissions from DPF equipped engines are almost an order of magnitude below the laboratory PM certification limit. The particle number (PN) method (measurement of non-volatile particles >23 nm with a condensation particle counter) had lower detection limit than the emissions of the DPF engine and the differences between the CVS and the partial flow dilution system SPC were within ±15% for all engines. One advantage compared to other real time systems like DMM and MSS is that the number method is directly comparable to the certification results since PN limits will be introduced in the Euro VI heavy duty regulation.

A Calculation Procedure for the Evaluation of Cold Emissive Behaviour of High-Performance Motorcycles

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All the experimental investigations performed in the last years on newly sold motorcycles, equipped with a three-way catalyst and electronic mixture control, clearly indicate that CO and HC cold additional emissions, if compared with those exhausted in hot conditions, represent an important proportion of total emissions. Consequently, calculation programmes for estimating emissions from road transports for air quality modeling in dedicated local areas should take into consideration this effect. From this motivations, an experimental activity on motorcycles cold emissive behavior is being jointly conducted by Istituto Motori of the National Research Council (IM-CNR) and the Department of Mechanic and Energetic (DiME) of the University of Naples. The study explains a calculation procedure to model the cold start transient behavior of motorcycles; through this methodology it's possible to evaluate the cold transient duration, the emitted quantities during the cold phase and the relevant time-dependence function. This method also analyses the influence of kinematic parameters on motorcycles emission factors during the cold-start. The whole procedure was applied to analyze the exhaust cold extra emissions of the regulated pollutants (CO, HC and NO_X) for one high performance motorcycle of 1000 cm^3 swept volume, belonging to the Euro-3 legislative category, tested on a dynamometer bench. For this motorcycle, cold start extra emissions and transient durations depend on the pollutant and on specific driving cycles.

Toxic Impacts of Emissions from Small 50cc Engine Run Under EC47 Driving Cycle: a Comparison Between 2-stroke and 4-stroke Engines and Lube Oil Quality

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One 4-stroke scooter and two 2-stroke scooters (50 cc bore) were run on dynamic test benches according to the EC47 driving cycle. Emissions from these scooters were continuously monitored, sampled and hot- diluted prior being driven to continuous flow through chambers containing organotypic cultures of lung tissue under bi-phasic Air/liquid culture conditions for three hours. Lung tissue was evaluated for viability (ATP), anti-oxidant defenses (intracellular GSH, Catalase, superoxide-dismutases, glutathione-S-Transferase, glutathione peroxidase, glutathione-reductase activity levels) and inflammatory reaction through the measurement of TNFalpha secretion in the culture medium. 4-stroke engine emissions had a moderate impact on lung tissue viability but induced a marked GSH depletion concomitant of increased GPx activity. 2-strokes engine emissions had variable impacts according to after-treatment technology and lube oil quality. Lower oxidation catalysis and mineral lube oil were found to be the worse situation inducing a marked lung tissue viability loss and high intracellular glutathione depletion, a marked decrease in SOD activity both Mn and Cu/Zn iso-enzymes being affected and a decrease in TNFalpha secretion. On the other hand, thigh oxidation catalysis and semi-synthetic lube oil was found to be the best situation with only minor tissue viability loss, moderate glutathione depletion, moderate elevation of glutathione peroxidase, almost no impact on superoxide dismutase activities and a moderate increase in TNFalpha secretion. The measurement of regulated emissions (CO, NO, NO_2, HC, and particulate matter showed that under warm engine conditions, 2-stroke engine with high oxidation catalysis and semi-synthetic lube oil was the least emitting situation especially when CO, HC and particulate matter are considered. 4-stroke engine proved to have intermediate emissions levels especially for CO, HC and particulate matter. 2-stroke engine with low oxidation catalysis and mineral oil

was found to be the worse situation especially for HC and particulate matter. In conclusion : emissions from small scooters may have detrimental impacts on lung tissue which may be highly reduced by the use of an oxidation catalyst on the exhaust line and by using high quality grade oil like semi-synthetic oil compared to mineral oil. Suitable recently designed after-treatment strategies allow a very efficient reduction of 2-stroke engine emissions and toxic potential leading to an even lesser impact than for the 4stroke commercially available engine emissions.

Effect of Hydrogen in CNG on Small Engine Performance and Emissions

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Three-wheelers have a long history in Europe and Asia as extremely durable and reliable passenger and delivery vehicles. There are a number of reasons that have resulted into the proliferation of the 3-wheelers in developing countries especially in South Asian countries. 3-wheelers are quite economical in terms of manufacturing and maintenance. They have also earned huge popularity due to their easy maneuvering capabilities. The inherent engine design of 3-wheeler with conventional fuels have recognized for lower fuel economy and higher emissions. Concerns about energy security, air quality and need for sustainable economic growth are making it imperative that all nations, especially developing countries, begin making an accelerated transition from fossil fuels to clean energy alternatives. South Asian countries have already done a remarkable job of converting a large number of three-wheelers and buses to compressed natural gas (CNG), and in India there is an on-going effort to extend this transition to hydrogen blended CNG (HCNG). Hydrogen is being added in CNG as an additive for further improving its combustion efficiency. Optimized hydrogen enriched natural gas (HCNG) engine has potential in reducing of harmful emission and greenhouse gases. This paper highlights engine performance, regulated and non-regulated emissions using CNG and 18% HCNG blend (v/v) with different measures in a CNG three-wheeler was tested on chassis dynamometer for performance and emissions. Ignition timing of the engine was optimized for better performance. Results indicated that significant reduction in CO and HC with penalty in increase NOx emission with use of HCNG fuel. To control NOx emissions, simple mechanism of EGR system was introduced. Although hydrogen enriched fuel reduces harmful emissions significantly, non-regulated emissions were observed with HCNG fuel. Growing concern over non-regulated emissions, it is imperative to estimate non-regulated emission for assessing overall emission advantages of HCNG fuel. Non-regulated emission also measured and reported for overall emission benefits with use of HCNG fuel.

Influences of Different Exhaust Filter Configurations on Emissions of a 2-Stroke Scooter Peugeot TSDI

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Exhaust emissions measurements of a small 2-S Scooter Peugeot TSDI *), 50cc with different particle filters have been performer in this present work according to the measuring procedures, which were established in the previous research in the Swiss Scooter Network, [1-9]. The investigated particle filtration materials were supplied from different manufacturers as samples without specifications and they were applied by the research laboratory in a special muffler able to be taken apart. The investigated scooter represented a modern (2002) 2-stroke technology with direct injection, with oxidation catalyst and with injection of the lube oil to the intake air. Since there is a special concern about the particle emissions of the small engines, the particle mass and nanoparticle measurements were systematically carried out. The nanoparticulate emissions were measured by means of SMPS (CPC) and NanoMet *). The most important results are:

- for the 2-S aerosol, which consists mostly of lube oil droplets, the oxidation in the trap is more important than the filtration quality,
- with catalytic coated filters the reduction efficiency of total active aerosol surface (DC) is higher than the reduction of particle counts (CPC, SMPS), with uncatalysed filter inversely,
- the highest reduction rates were found: for DC 94% and for CPC 81%
- there is a little influence of different PF's on the maximum speed (speed limitation 45km/h), but a high influence on the full load power.

The present investigations did not concern the durability of the filtration materials, the continuous regeneration and the deposition of ashes during the real world operation.

Biodiesel Influence on Particulate Matter Behaviour During Active and Passive DPF Regeneration

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Merging the fuel efficiency of diesel combustion with the use of renewable bio-fuels presents an attractive way towards an environmentally sustainable road transportation. But the introduction of bio-fuels have an impact on emission parameters as well as on engine and emissions after-treatment components performance and durability. This paper relates to the evaluation of the bio-fuel influence on particulate matter characteristics produced by a diesel engine and on DPF behavior during active and passive regeneration phases. The study was based on an EN590 compatible diesel fuel commercially available (B7), an EN14214 FAME biodiesel (B100) and their blend (B20). A direct injection single cylinder diesel engine was adopted for the experimental activity. Active regeneration phase was carried out via fuel vaporizer upstream oxidation catalyst. Results showed the particulate production rate was inversely proportional to fuel biodiesel content. Lower temperatures and temperature gradients in filtering material were measured during active regeneration events in biodiesel based experiments, while passive regeneration behavior did not show appreciable differences among the investigated blends. Additionally thermal analysis confirmed an enhanced reactivity associated with biodiesel particulate in terms of combustion rate and the formation of an higher hydrocarbon fraction. Finally a growth of ashes content in particulate matter was detected with increased biodiesel percentage.

Gray Box Diesel Engine Soot Emission Modeling Based on Two-color Spectroscopy Measurements

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Modeling the soot emissions of a Diesel engine is a challenge. Although it was part of many works before, it is still not a solved issue and has a substantial potential for improvement. A major problem is the presence of two competing effects during combustion, soot formation and soot oxidation, whereas only the cumulative difference of these effects can be measured in the exhaust. There is a wide consensus that it is sensible to design crank angle resolved models for both effects. Indeed, many authors propose crank angle based soot models which are mostly based on detailed first principles based structures, e.g. spray models, engine process calculations etc. Although these models are appealing from a theoretical point of view, they are all lacking of the required measurement information to validate all the complex model parts. Finally, most parts of the model remain at their assumed values and only a few parameters are used for calibration. Against this background in the actual work a gray box approach is presented, where the basic ideas of a separation into formation and oxidation in the crank angle domain are followed, however the remaining structure is determined in a systematic way. To this end a two-color spectroscopy in cylinder soot measurement was applied and a sequential input selection method was combined with a generic nonlinear optimizer to predict the crank angle resolved soot emissions and in particular the tailpipe values. The proposed approach was compared against the well known model of Hiroyasu [1] on the basis of testbench measurements of a Euro 4 passenger car Diesel engine, whereas a considerable improvement of the predicted tailpipe soot emissions was achieved.

Cylinder- and Cycle Resolved Particle Formation Evaluation to Support GDI Engine Development for Euro 6 Targets

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Combustion of premixed stoichiometric charge is free of soot particle formation. Consequently, the development of direct injection (DI) spark ignition (SI) engines aims at providing premixed charge to avoid or minimize soot formation in order to meet particle emissions targets. Engine development methods not only need precise engine-out particle measurement instrumentation but also sensors and measurement techniques which enable identification of in-cylinder soot formation sources under all relevant engine test conditions. Such identification is made possible by recording flame radiation signals and with analysis of such signals for premixed and diffusion flame signatures. This paper presents measurement techniques and analysis methods under normal engine and vehicle test procedures to minimize sooting combustion modes in transient engine operation.

Accuracy of Particle Number Measurements from Partial Flow Dilution Systems

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The measurement of the particle number (PN) concentration of non-volatile particles >23 nm was introduced in the light duty vehicles regulation; the heavy duty regulation followed. Based on the findings of the Particle Measurement Programme (PMP) heavy duty inter-laboratory exercise, the PN concentration measurement can be conducted either from the full dilution tunnel with constant volume sampling (CVS) or from the partial flow dilution system (PFDS). However, there are no other studies that investigate whether the PN results from the two systems are equivalent. In addition, even the PMP study never investigated the uncertainty that is introduced at the final result from the extraction of a flow by a PN system from the PFDS. In this work we investigate the uncertainty for the three possible cases, i.e. considering a constant extracted flow from the PFDS, sending a signal with 1 Hz frequency to the PFDS, or feeding back the extracted flow to the PFDS. We also discuss what kind of tests could be conducted in order to ensure that the reported extracted flow is correct. The experimental results confirmed that if the extracted flow rate is accurately measured or fed back, then CVS and the PFDS give equivalent PN results with differences in the order of ±15% for PN emissions >1x10ˆ11 p/kWh. At lower levels, the PN backgrounds of the CVS and the PFDS become important.

Experimental Characterization of Nanoparticles Emissions in a Port Fuel Injection Spark Ignition Engine

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In the recent years, growing attention has been focused on internal combustion engines, considered as the main sources of Particulate Matter (PM) in urban air. Small particles are associated to fine dust formation in the atmosphere and to pulmonary diseases. The legislation proposes a stronger restriction in terms of particulate mass concentrations for both Diesel and gasoline engines and a limitation on number concentration. Unfortunately, the experimental evaluation of particles number and size is a hard task as they are strongly affected by the dilution conditions, due to condensation and nucleation phenomena, which may occur during the sampling. Even if a considerable amount of basic research on particulate matter emitted by engines has been carried out, the mechanisms governing particle formation are still not fully understood, neither for Diesel nor for gasoline engines. Furthermore, poor information is available on the effect of engine control parameters and of the emissions control technologies on particles size and number. The aim of the paper is the experimental characterization in terms of number and size of particles emitted from a gasoline engine in steady state operating conditions. The gasoline particles investigation was carried out at the exhaust of a 1.2 liters port fuel injection spark ignition engine. The engine test bench was equipped with a full-pass engine control system dSPACE MicroAutoBox and a Scanning Mobility Particle Sizer (SMPS) for particles counting and sizing, thus allowing accomplishing a detailed analysis on the effects of the engine control variables on particles emission.

Crankcase Sampling of PM from a Fired and Motored Compression Ignition Engine

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Crankcase emissions are a complex mixture of combustion products and aerosol generated from lubrication oil. The crankcase emissions contribute substantially to the total particulate matter (PM) emitted from an engine. Environment legislation demands that either the combustion and crankcase emissions are combined to give a total measurement, or the crankcase gases are re-circulated back into the engine. There is a lack of understanding regarding the physical processes that generate crankcase aerosols, with a paucity of information on the size/mass concentrations of particles present in the crankcase. In this study the particulate matter crankcase emissions were measured from a fired and motored 4 cylinder compression ignition engine at a range of speeds and crankcase locations. A sequence of sampling equipment was used to characterise the emissions in the size range 5nm - 19 µm; Cambustion DMS500 fast particulate spectrometer, TSI Scanning Mobility Particle Sizer (SMPS), TSITM Condensation Particle Counter (CPC) and, TSITM Aerodynamic Particle Sizer (APS). The combination of the two test engines and range of sampling equipment provided new information on the generation and behavior of aerodynamic particulate matter within an engine crankcase. Data is presented for the effect of controlled parameter changes on number distributions over the measured particle size range. A complex lognormal bimodal size distribution of sub micron accumulation mode particles was present in the crankcase of both engines at a low idle speed of 900rpm. At 1400rpm this complex distribution was not present. Increasing the engine load, on the fired engine, initially reduced the particle number concentration with a final significant increase in particle number concentration at 75% load. At 900 rpm 50% load there was a single strong peak at 32nm in the rocker cover however sampling from the push rod gallery and sump showed a strongly bimodal distribution with peaks at 32nm and 133nm. All other sampling data, from the fired engine, was consistent at each sampling location. The SMPS results, 15-665nm, on the motored engine showed location dependency, with the highest number concentration of particles present in the push rod gallery.

Analysis of Particle Mass and Size Emissions from a Catalyzed Diesel Particulate Filter During Regeneration by means of Actual Injection Strategies in Light Duty Engines

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The diesel particulate filters (DPF) are considered the most robust technologies for particle emission reduction both in terms of mass and number. On the other hand, the increase of the backpressure in the exhaust system due to the accumulation of the particles in the filter walls leads to an increase of the engine fuel consumption and engine power reduction. To limit the filter loading, and the backpressure, a periodical regeneration is needed. Because of the growing interest about particle emission both in terms of mass, number and size, it appears important to monitor the evolution of the particle mass and number concentrations and size distribution during the regeneration of the DPFs. For this matter, in the presented work the regeneration of a catalyzed filter was fully analyzed. Particular attention was dedicated to the dynamic evolution both of the thermodynamic parameters and particle emissions. The measurements were performed at the exhaust of a Euro 5 CR Diesel engine equipped with a Close Coupled DPF. The regeneration process was investigated in a point representative of an extraurban engine operating condition. The regeneration was managed by the electronic control unit (ECU). In particular, an injection calibration was implemented taking into account the engine and the filter features. The particle size distribution evolution during regeneration phase was measured in the size range 5-1000 nm using a differential mobility spectrometer. The particle mass concentration was monitored by means of a microsoot sensor. Particle mass and number concentrations strongly increase during the regeneration process. Moreover, a high concentration of the number of particles smaller than 30nm was observed in some critical phases of the re generation process.

Particle Size Distributions from a DI High Performance SI Engine Fuelled with Gasoline-ethanol Blended Fuels

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This paper reports the results of an experimental investigation on the combustion characteristics and exhaust particulate emissions of a GDI high performance engine, fuelled with blends of bio-ethanol and European gasoline fuel. The engine is a 4-cylinder, 4 stroke, 1750 cm^3 displacement, and turbocharged. The engine was operated at fixed speed and load, namely 1500 rpm and 110 Nm, and fuelled with gasoline (E0), ethanol (E100) and two blends 50% v/v (E50) and 85% v/v (E85) of ethanol in gasoline. Two fuel injection strategies were investigated: homogeneous charge and stratified charge combustion mode. The study mainly focuses on the effects of fuel injection strategy and ethanol upon the emissions of particulate matter (PM), in terms of mass, number concentration and size distribution. The particle size distribution was measured using a differential mobility spectrometer (Cambustion DMS500), which allows measuring the electrical mobility diameter of particles in the size range 5-1000 nm with high time resolution (10Hz). Smaller particles and lower total mass were emitted from the engine fuelled with pure ethanol with respect to gasoline. On the other hand, using the blends E50 and E85, a large increase of the number concentration of particles in the accumulation mode was observed. Furthermore, the PM mass increased largely under the stratified combustion mode with E50.

Emissions and Combustion Behavior of a Bi-Fuel Gasoline and Natural Gas Spark Ignition Engine

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In the last ten years, the number of natural gas vehicles worldwide has grown rapidly with the biggest contribution coming from the Asia-Pacific and Latin America regions. As natural gas is the cleanest fossil fuel, the exhaust emissions from natural gas spark ignition vehicles are lower than those of gasoline powered vehicles. Moreover, natural gas is less affected by price fluctuations and its resources are more evenly widespread over the globe than to oil. However, as natural gas vehicles are usually bi-fuel gasoline and natural gas, the excellent knock resistant characteristics of natural gas cannot be completely exploited. This paper shows the results of an experimental activity performed on a passenger car fuelled alternatively by gasoline and compressed natural gas (CNG). The vehicle has been tested on a chassis dynamometer over standard (NEDC) and real driving cycles (Artemis CADC), allowing to investigate a wide range of operating conditions. Cylinder pressure has been measured by means of a spark plug with an integrated pressure transducer. By processing the acquired signal, a combustion analysis has been performed allowing the evaluation of the burning rate affected by fuels properties. Furthermore, regulated and unregulated exhaust emissions have been measured and fuel consumption has been calculated by means of carbon balance method to evaluate engine average efficiency over driving cycles. CO and HC emissions were higher for CNG respect to gasoline over the type approval driving cycle, mainly because of cold start contribution. Over the much dynamic real-world driving cycles, gasoline showed always higher CO emissions due to the rich combustion operated by engine control during transients. NOx emissions were always higher with gasoline fuelled vehicle. Using the gaseous fuel, a consistent increase in engine efficiency was noticed, particularly evident over Artemis driving cycles. Particulate mass emissions were generally very low and close to background levels. Total particle number relative to gasoline is higher than that of natural gas, exceeding the Euro 5b standard limit currently prescribed only for diesel passenger cars. The slower combustion rate of natural gas respect to gasoline has not been compensated by appropriate ignition timing. A different ignition timing setup for the natural gas operation could give appreciable engine performance improvement.

Some Comparisons between Real and KEM Predicted Emission Values on a EURO 4 Panda Bi-fuel Vehicle

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The problem of emission evaluation control and modelling is nowadays an open question. In the framework of a Decision Support System (DSS), a new approach was developed for modeling and evaluating automotive pollutant emissions. An interesting point of this proposal was the integration of the micro simulated model to obtain driving cycle. In fact an important open issue is the very expensive costs of experimental campaigns needed to obtain driving cycle statistically representative of driving behaviour. So to overcome these high costs and to extend the real vehicle operating conditions framework, a possible solution is to integrate a microsimulation model in the general context of emission modeling. But the reliability of driving cycles coming from simulation models must be evaluated with respect to the possible influence on test bench measured emissions. In this paper, we would try to present some results related to two aspects of the problem. The first one is the possibility to emphasize the acceleration features as a key variable in the development of an emission model. The second aspect is the opportunity to show the effect of an aggressive driving style with respect to a smoothing one both qualitatively and partly quantitatively. This effect can be assessed through an evaluation of the kinematic variables that characterize the driving cycle and through their produced pollutant values. A Kinematic Emission model (KEM) is used to calculate predicted values, both on real than on microsimulated cycles. Experimental tests are performed on a chassis dynamometer for characterizing regulated emissions and fuel consumption on a Euro 4 Panda Bi-fuel vehicle, on which simulated trajectories are analyzed.

The 3Dcell Approach for the Acoustic Modeling of After-Treatment Devices

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In the last decades the continuously tightening limitations on pollutant emissions has led to an extensive adoption of aftertreatment devices on the exhaust systems of modern internal combustion engines. While these devices are primarily introduced for reducing and controlling the emissions, they also play an important role influencing the wave motion inside the exhaust system and so affecting the acoustics and the performances of the engine. In this paper a novel approach is proposed for the modeling of two after-treatment devices: the catalyst and the Diesel Particulate Filter. The models are based on a fast quasi-3D approach, named 3Dcell, originally developed by the authors for the acoustic modeling of silencers. This approach allows to model the wave motion by solving the momentum equation along the three directions. The capability of modeling complex shape devices, allowing the description of three-dimensional wave action, makes this tool an interesting solution for studying the acoustic behavior of today's mostly used after-treatment devices. In this work the 3Dcell approach has been extended to the modeling of the catalyst and DPF monolith, in order to combine the capability of predicting the flow distribution in the monolith channels with a lower computational demand than traditional 3D CFD approaches. The developed models have been applied to the simulation of the acoustic behavior of these components, comparing the results to measured data. For completeness sake the results have also been compared to traditional 1D models applied to the acoustic simulation of after-treatment devices.

Noise Prediction of a Multi-Cylinder Engine Prototype Using Multi-Body Dynamic Simulation

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In the paper a coupled Multi-Body and FEM-BEM methodology used to predict the noise radiated by a turbocharged 4-cylinder diesel engine prototype is described. A Multi-Body Dynamic Simulation (MBDS) of the engine has been carried out, simulating an engine speed sweep from 1500 to 4000 rpm, in order to determine the excitation force of the powertrain, and in particular to estimate the forces acting on the cylinder block. Thanks to the Multi-Body approach, the dynamics of the engine powertrain have been described taking into account both the effects of the burnt gas pressure during the combustion process and the inertia forces of the moving parts. Moreover to assess the real engine operating behaviour, both the crank and the block have been considered as flexible bodies. Afterwards, the cylinder block excitations, in terms of Modal Participation Factors, have been used to evaluate the engine radiated noise with the well-know MATV methodology, at a distance of one meter from the engine according to the ISO 3744 directives. The dynamics of the engine powertrain and its vibro-acoustic behaviour have been described using LMS Virtual.Lab tools.

Validation of 1D and 3D Analyses for Performance Prediction of an Automotive Silencer

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One dimensional (1D) and three dimensional (3D) simulations are widely used in technical acoustics to predict the behavior of duct system elements including fluid machines. In particular, referring to internal combustion engines, the numerical approaches can be used to estimate the Transmission Loss (TL) of mufflers, air boxes, catalytic converters, etc. TL is a parameter commonly used in almost any kind of acoustical filters, in order to assess the passive effects related to their sound attenuation. In this paper, a previous 1D-3D acoustical analysis of a commercial muffler, has been improved and experimentally validated. Features related to the manufacturing process, like the coupling of adjacent surfaces and the actual shape of components, have been noticed to heavily affect the muffler behavior. Hence, although numerical analyses are usually performed on ideal geometries (perfectly matched and shaped), schematizations utilized for acoustic simulations of real mufflers are being suggested to do not neglect these important aspects. On the other hand, for a given initial muffler design, the manufacturing process is assessed to be a critical aspect also for its remarkable effects on the acoustics. In this work, results have been carried out under different muffler operating conditions related to different mean flow velocities and presence or not of internal insulating material. 1D analyses have been performed by implementing a commercial software, solving the nonlinear flow equations which characterize the wave propagation phenomena. 1D approach has also been utilized to evaluate the fluid dynamic behavior of the studied muffler in terms of pressure drop when a mean flow is imposed. 3D results are obtained in absence of mean flow by using a commercial software based on Boundary Element approach and solving the three dimensional Helmholtz's equation. Finally, during the experimental tests, the muffler has been treated as an acoustic two-port element.

Aeroacoustics of Duct Branches-With Application to Silencers

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The inclusion of flow-acoustic interaction effects in linear acoustic multiport models has been studied. It is shown, using a T-junction as illustration example, that as long the acoustic system is linear the required information is included in a scattering matrix obtained by experimental or numerical studies. Assuming small Mach numbers and low frequencies—as in most automotive silencer applications—the scattering matrix for the T-junction can be approximated using quasi-steady models. Models are derived that holds for all possible configurations of grazing and bias flow in the T-junctions. The derived models are then used to predict the performance of a novel silencer concept, where a resonator is formed by acoustically short-circuiting the inlet and outlet ducts of a flow reversal chamber. The agreement between experiments and simulations is excellent, justifying the use of the quasi-steady modeling approach.

The Passive Acoustic Effect of Automotive Catalytic Converters

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For the last couple of decades, catalytic converters (CC) have become a standard part of the internal combustion engine exhaust systems. Besides reducing toxic components in exhaust gases, catalytic converters can have a certain effect on the acoustic performance of the exhaust system. In this paper the sound transmission and attenuation in the catalytic converters has been investigated. A catalytic converter is known to have two distinct acoustic effects: the reactive effect originating from the acoustic wave reflections caused by cross-sectional area changes within the unit and the resistive effect which results in the acoustic wave dissipation caused by visco-thermal losses. The flow resistance in the narrow tubes in the catalytic converter element results in frequency dependent dissipative effects on the transmitted sound. An experimental investigation on engine catalytic converters treated as acoustic two-ports is carried out. The acoustic behavior of the catalytic converters is investigated in detail by analyzing the scattering matrix elements.

Investigations of Automotive Turbocharger Acoustics

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In this paper an overview of recent experimental studies performed at KTH on the sound transmission and sound generation in turbochargers is presented. The compressor and turbine of the turbochargers are treated as acoustic active 2-ports and characterized using the unique experimental test facility established at KTH. The 2-port model is limited to the plane wave range so for higher frequencies the propagating acoustic power is estimated using an average based on pressure cross-spectra. A number of auto motive turbochargers have been studied for a variety of operating conditions systematically selected from the compressor and turbine charts. The paper discusses the experimental procedures including special techniques implemented to improve the quality of the data. Results from a number of experiments on various modern automotive turbochargers including a unit with variable turbine geometry (VTG) are presented.

Design Philosophy of Complete Traction Electric Equipment Sets for Hybrid Vehicles

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Traction electric drive is one of the basic units of the electric vehicles; its features define parameters of the total vehicle in many respects. Development of the traction electric drive takes place on base of extremely high technical and economical requirement. It can be claimed absolutely reasonably that nowadays in the traction electric drive there is realized a set of modern, advanced achievements in the field of electro mechanics, power and control electronics and control techniques. Electromechanical devices are relatively new in vehicle technology, their design principals concerning the specific of their application are not yet stable, and there is necessary reconsideration of many principal subjects. Transfer from the input data to the parameters of the specific devices now is based on the experience of development of these devices for other applications and appears to be more an art of designers. There are no standard and proven choosing procedures of the basic parameters of electromechanical devices for hybrid automotive machinery: reduction ratios, number of gears, rotation frequencies, electric machines power source frequencies, number of pole pairs, etc. The cases of correct comparison of the developed configurations are rare as there are no criteria of quality of their design work. All this largely constrains the development of the perspective samples of hybrid machinery, complicates mutual understanding of experts – designers of electric machines, electric drives, mechanical devices and transport experts. The article considers kinematical configurations of hybrid vehicles, specific requirements to traction drives and motor-generators, perspective types of electric machines and power converters, characteristic features of the systems “ICE-generator”, “buffer power storage”, “power converter – electric motor”, “reduction gear and gearbox”. Problems of synthesis of the control strategy for electric drive and the complete set of traction and power equipment are discussed.

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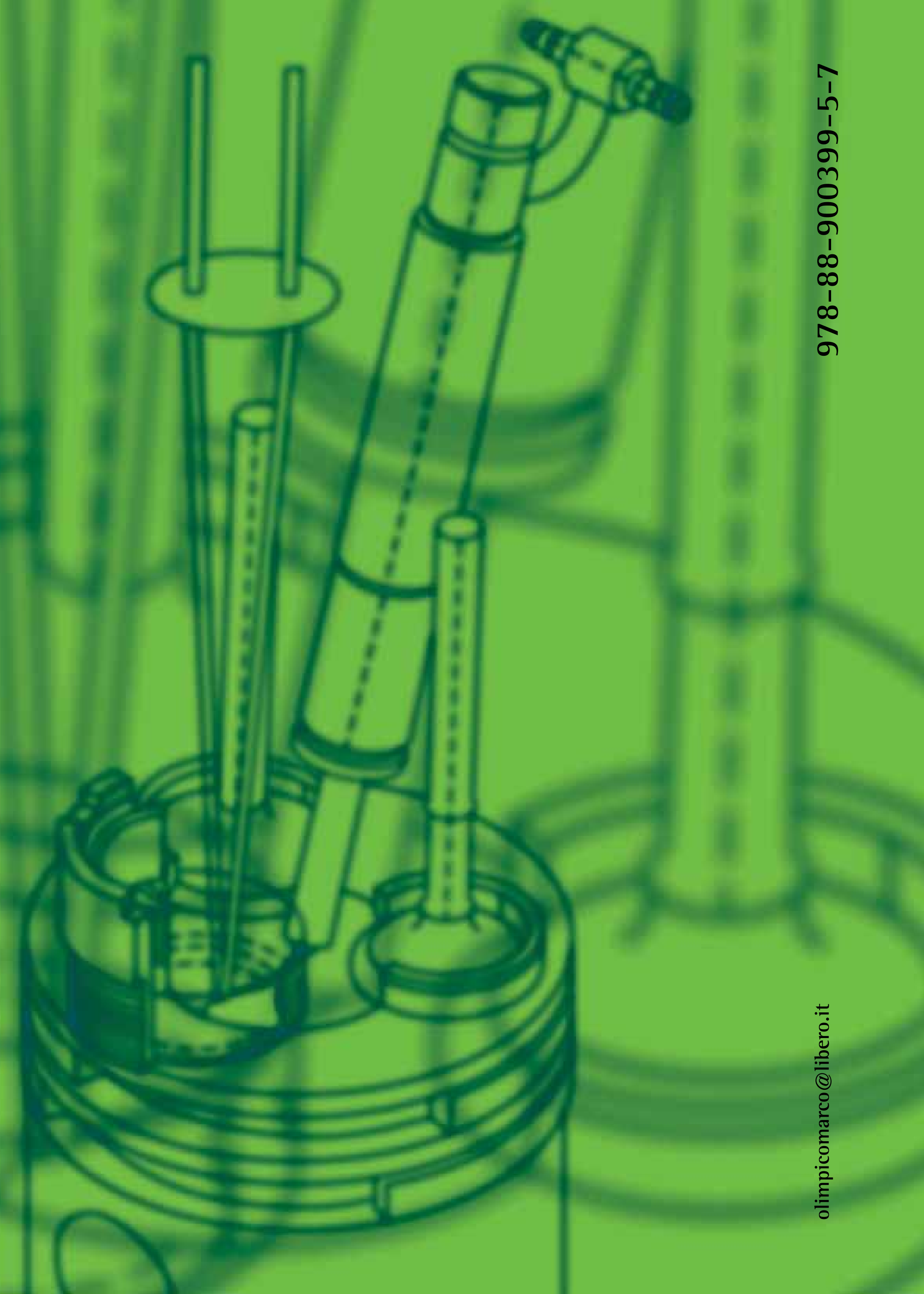

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