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ERC Newsletter

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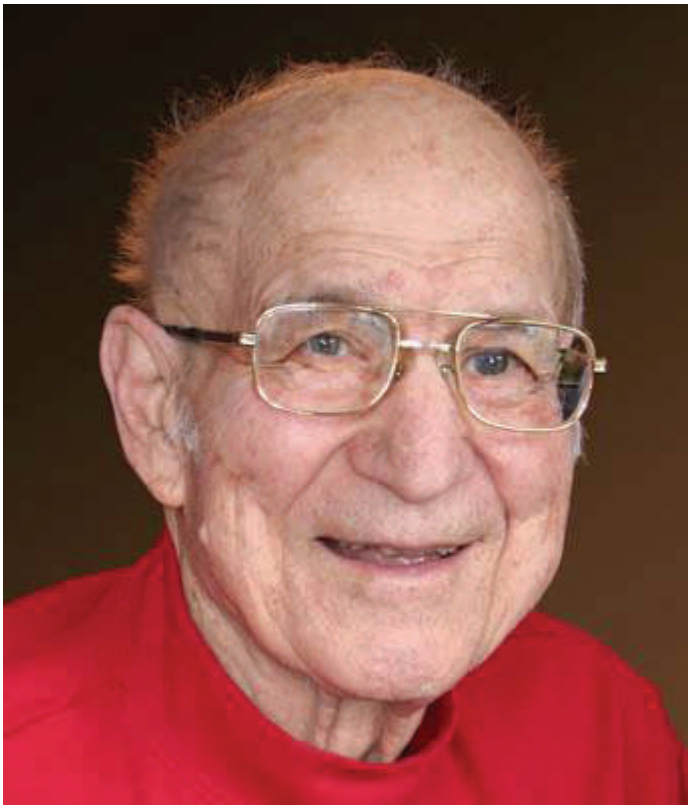
Phil Myers 1916-2006



One of the founders of the ERC, Phillip Samuel Myers passed away on October, 18 2006 at the age of 90. Phil Myers was, arguably, the most influential engine combustion researcher of his generation, and left a rich, unparalleled legacy of teaching, research and service. He was beloved by all that knew him and was for many people the heart and soul of the ERC.

Professor Myers was a world-renown expert in engine combustion. He pioneered techniques for in-cylinder temperature measurements, and made important contributions to understanding the diesel combustion process, droplet combustion, engine heat transfer, and engine modeling. His research excellence was recognized by a long and impressive list of citations from the Society of Automotive Engineers (SAE), including the Horning Memorial Award, the Ray Buckendale Award, and the Arch T. Colwell Award (twice). In 1977, Phil was named a Fellow of the SAE, and in 1987 he was the first recipient of the SAE Medal of Honor. In 1969 Prof. Myers served as the President of the SAE. Phil Myers was

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ERC Symposium

– *Fuels for Future Internal Combustion Engines*

Madison, WI June 6-7, 2007

The ERC is organizing a Symposium to explore the opportunities, issues, and potential impact of new fuel technologies for internal combustion engines. The Symposium will feature presentations by internationally recognized experts in fuels and engine research and senior executives from the major automotive/engine industries to provide their perspectives on fuels and future engines.

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T-25 Breakfast

We invite all ERC alumni and friends to the T-25 breakfast. The breakfast occurs at the traditional time, Wednesday morning during the week of the SAE International Congress. A continental breakfast will be available from 7:00 - 10:00 am on Wednesday April 18th. Remodeling is occurring at the location of the breakfast used in recent years. The location this year is in the same hotel, the Marriott Courtyard in downtown Detroit. But we will meet in Skyline Room on the 7th floor.

General Motors R&D Center continues to be a strong supporter of the ERC and is hosting the T-25 Breakfast for the 8th consecutive year.

Diesel Emissions Reduction Consortium Meeting

The next meeting of the Diesel Emissions Reduction Consortium will be held in Madison on June 5, 2007 in conjunction with the next biennial ERC Symposium.

The technical progress of four consortium-directed research projects will be reviewed including new directions. The meeting agenda and a social event will promote productive exchanges among representatives of member companies, ERC faculty, students, staff and 2007 ERC Symposium speakers.

International Multidimensional Engine Modeling Users Group Meeting

Cray Inc. is sponsoring the International Multidimensional Engine Modeling User's Group Meeting at the SAE Congress, organized in association with the Engine Research Center, in Detroit Downtown Courtyard by Marriot Hotel at 12:00 - 6:00pm on April 15, 2007. This time and place is chosen because it is expected that many engine modeling code users will be attending the Society of Automotive Engineers Congress and Exhibition to be held in Detroit, Michigan, on April 16-19, 2007.

The purpose of the conference is to encourage the exchange of information about engine modeling and to help promote the use of engine modeling by the engine industry. Presentations at the meeting will feature applications of CFD codes and the development of novel submodels for engine simulations. These will include presentations that use commercial engine CFD packages such as Star-CD, FIRE, Fluent, and Vectis. The agenda of the meeting will be available on the ERC website. The agenda and papers of previous meetings can be found at: http://www.erc.wisc.edu/modeling/modeling_index.htm#meeting

Phil Myers

(Continued from page 1)

also named a Fellow of the American Society of Mechanical Engineers (ASME) in 1971, and was award the Dugald Clerk Award from the Institute of Mechanical Engineers (England). In 1973 Professor Myers was elected to the National Academy of Engineering.

Professor Myers was one of the rare individuals whose research excellence was balanced by his strong commitment to teaching and service. He served the Mechanical Engineering Department in a wide range of capacities, culminating in his stewardship as its Chair from 1979-1983. In addition, Phil chaired and served on innumerable College and Campus committees

Professor Myers's teaching accomplishments were acknowledged with the Pi Tau Sigma Gold Medal Award, Tau Beta Pi Teaching Award, and the College of Engineering's Benjamin Smith Reynolds Award. His most significant teaching impact, however, was made one-on-one in the laboratory with his graduate students in conjunction with Prof. Uyehara.

Phil and Otto Uyehara began a life long friendship and collaboration while graduate students at UW-Madison. They both joined the faculty in Mechanical Engineering in 1947. Jointly, Phil and Otto founded what is now the Engine Research Center in a temporary building (T-25) on the engineering campus. Together, they mentored 48 PhD students and 80 MS students, many of whom went on to influential careers in the engine industry and academia. Phil's door was always open, and regardless of how busy his schedule was, he made time to answer student's questions.

Through all of his success, Phil never lost touch with his rural, Midwestern upbringing. He was a humble man who always made time to listen to all points of view, and was guided by an unwavering moral compass and a dogged pursuit of the truth. His compassion for others was as legendary as his water skiing prowess and his fondness for churning his own ice cream.

DERC Graduates 3 PhD Students

The ERC's Diesel Emission Reduction Consortium (DERC) was founded in 2004, and is now fully underway. The consortium aims to assist engine manufacturers and related industries to meet future diesel engine emissions regulations. The next meeting of DERC members will be held in Madison on June 5th, 2007. Details about DERC membership and its current research projects can be found at: http://2010.erc.wisc.edu

The consortium currently has 24 industrial members, including the major engine and automotive companies:

Caterpillar Inc.; CDadapco; Corning Incorporated.; Cummins Fleetguard Inc.; DaimlerChrysler AG; Delphi Corporation; Detroit Diesel Corporation; Donaldson Company, Inc.; FEV Engine Technology; Fluent Inc.; Ford Motor Company; GM R&D and Planning and Powertrain; Hyundai Motor Company; International Truck & Engine Corp.; John Deere Company; MotoTron; Nippon Soken Inc.; Oak Ridge National Laboratory; PACCAR; Renault; Thomas Magnete USA; Toyota Technical Center USA; Volvo Powertrain

Significant progress is being made on the four DERC consortium-directed research projects. Progress in 2006 included the completion of three PhD theses, and three new students have joined the program to build on and to continue the DERC projects. Several important milestones were reached including:

- The characteristics of stoichiometric diesel combustion have been evaluated experimentally and guidelines have been provided to improve fuel economy as well as exhaust emissions. The results are provided in the PhD thesis of Sangsuk Lee.
- The transient engine test cell for the new engine has been fully installed and upgraded with transient exhaust emissions measurement systems. Transient engine tests with the new engine have been performed, and are documented in the PhD thesis of Hyungsuk Kang.
- System level tools have been developed for describing HCCI and other low-temperature combustion regimes and used to study methods for combustion phase control and engine transient operation. This work is described in the PhD thesis of Kushal Narayanaswamy.
- The KIVA-CHEMKIN-GA multi-dimensional Computational Fluid Dynamics (CFD) code, featuring updated spray models and detailed chemistry, is being employed to optimize heavy-duty diesel engine operating parameters. This work will be described in the PhD thesis of Yong Sun to be completed later this year.

Finally, thanks are due to former Associate Researcher and Associate ERC Director, Manuel Gonzalez for his considerable contributions to DERC. Manuel has left the ERC to take up a position in the engine consulting industry.

ERC Symposium

(Continued from page 1)

This Symposium is the fifth biennial event organized and hosted by the ERC. The Symposiums focus on special topics that are current and relevant to people involved in the field. Presentations are given by a range of experts providing perspectives on technical, strategic planning, policy and regulatory issues. The meetings have traditionally been well attended with 100-150 people from engine, automotive, truck, and energy companies. Previous symposiums hosted by the ERC have been:

- 1999 The Next Fifty Years of Engine Research
- 2001 Exhaust Aftertreatment technologies
- 2003 Developing the Virtual Engine – Current Capabilities and Future Directions
- 2005 Low Emission Combustion Technologies for Future IC Engines

The 2007 ERC Symposium will be held June 6-7 in Madison, WI. The keynote speakers for each day are Norman Brinkman from General Motors and either John Robbins or Jeff Beck from ExxonMobil. The agenda will be placed on the ERC website as it becomes available. Additional information about registration and lodging will also be placed on the website: http://www.erc.wisc.edu/

New ERC Logo

The ERC recently updated their logo. The new logo is shown in the image to the right it maintains the same basic structure as the older logo. There is a schematic of an engine cylinder that has been simplified. The letters UW are carefully placed on the engine. The letter U is in the cylinder since it is commonly used in thermodynamics as the symbol for internal energy. The letter U is also used in multi-dimensional CFD as the symbol for velocity. The letter W is the thermodynamic symbol for work and is placed near the connecting rod. The font and wording around the logo have been simplified and the year in which Phil and Otto established the ERC appears.

ERC Students Form Committees

This past fall, a group of ERC grad students organized four student-led committees and gave those committees the task of taking care of certain non-research-related activities within the ERC. Participation in these committees is on a volunteer basis and the overall goal of these committees is to make life in the ERC easier and more enjoyable.

The four committees that were created are internal relations, external relations, computational resources, and experimental resources. The internal relations committee's aim is to organize fun and useful activities within the ERC, while the external relation committee's aim is to facilitate tasks related to interactions with people outside the ERC. The goal of computational and experimental resources committees is to provide resources that help with research activities for computationalists and experimentalists, respectively.

Highlights of the committee's activities include the ERC holiday party, a penny war which raised $400 for charity, and substantial contributions to the internal ERC wiki. Future planned activities include an update to the ERC display case, a series of practice presentation for those students presenting a SAE World Congress, and another computationalist vs. experimentalist competition.

Order an ERC Polo Shirt

One of the projects of the new ERC student committees was to design a polo shirt with the ERC logo. These are being made available to the students, staff, and faculty in the ERC.

We will have a limited number of shirts available for alumni and friends of the ERC. To cover our expenses, we are asking $24.50 per shirt plus shipping. To order a shirt, please email Chris Rutland (rutland@engr.wisc.edu).

SAE and Other Publications

A Computational Investigation into the Effects of Spray Targeting, Swirl Ratio and Bowl Geometry for Low-Temperature Combustion in a Heavy-Duty Diesel Engine

Genzale, C., Wickman, D., and Reitz, R.D.

SAE paper 2007-01-0119

A computational study was performed to evaluate the effects of spray targeting, swirl ratio and bowl geometry at highly diluted, low-temperature combustion condition in a heavy-duty diesel engine. This study is used to examine aspects of low-temperature combustion that are affected by mixing processes and offers insight into the effect these processes have on emissions formation and oxidation. The foundation for this exploratory study stems from a large data set which was generated using a genetic algorithm optimization methodology. The main results suggest that an optimal combination of spray targeting, swirl ratio and bowl geometry exist to simultaneously minimize emissions formation and offer improved soot and CO oxidation rates. Spray targeting was found to have a significant impact on the emissions and fuel consumption performance, and was found to be the most influential design parameter explored in this study. Specifically, variations in spray targeting were found to largely affect pre-combustion mixing processes and charge preparation, resulting in marked effects on soot formation levels. Swirl ratio was found to alter both pre-combustion mixture preparation and late-cycle oxidation processes, while bowl geometry was found to predominantly affect mixing processes through an interaction with swirl ratio levels. This study underscores the need to carefully consider mixing processes induced by bowl geometry and spray/bowl matching in the design of low-temperature diesel combustion systems.

Fuel Unmixedness Effects in a Gasoline HCCI Engine

Herold, R.E., Foster, D.E., Ghandhi, J.B., Iverson, R.J., Eng, J.A., and Najt, P.M.

To appear in *Int. Journal of Engine Research*, also to be presented as an oral-only paper at the 2007 SAE World Congress

Fuel stratification, independent of thermal and residual gas stratification, was studied in a gasoline HCCI engine. The unmixed charge was created by injecting fuel (iso-octane) into the intake port after being prevaporized and heated to the same temperature as the intake stream. Planar laser-induced fluorescence (PLIF) measurements showed that local equivalence ratios in the charge differed from the mean equivalence ratio by up to 50% for the latest possible injection timing. Experimental results showed little to no change in combustion performance between prevaporized port (unmixed) or premixed (homogeneous) fueling. Small increases in NOx and CO emissions were observed with the prevaporized port fueling and are believed to result from the regions richer or leaner than the mean equivalence ratio. These results indicate fuel stratification in the absence of thermal and residual stratification does not appear to be a viable method for HCCI combustion control.

(Abstracts continue on page 6)

ERC Participation in Upcoming Conferences

International Multidimensional Engine Modeling User's Group Meeting
April 15, 2007, Detroit, MI
https://www.cray.com/kiva/registration.html

SAE International Congress and Exposition
April 16-19, 2007, Detroit, MI
http://www.sae.org

CLEERS Aftertreatment Modeling Workshop
May 1-3, 2007, Dearborn, MI
http://www.cleers.org/

Institute of Liquid Atomization and Spray Systems 2007
May 15-18, 2007, Chicago, IL
http://www.ilass.org

Gordon Research Conference on Laser Diagnostics for Combustion
August 12-17, 2007, Oxford, UK
http://www.grc.org/programs.aspx?year=2007&program=lasdiag

13th Diesel Engine-Efficiency and Emissions Research (DEER) Conference
August 13-16, 2007, Detroit, Michigan
http://www1.eere.energy.gov/vehiclesandfuels/resources/index.html

ICE2007 8th Int. Conf. on Engines for Automobiles
September 16-20, Capri, Naples
http://www.sae.org/events/icea/

SAE Powertrain & Fluid Systems Conference
Oct. 29 - Nov. 1, 2007, Chicago, IL
http://www.sae.org

Modeling Knock in Spark-Ignition Engines Using a G-equation Combustion Model Incorporating Detailed Chemical Kinetics

Liang, L., Reitz, R.D., Iyer, C.O. and Yi, J.

SAE paper 2007-01-0165

In this paper, knock in a Ford single cylinder direct-injection spark-ignition (DISI) engine was modeled and investigated using the KIVA-3V code with a G-equation combustion model coupled with detailed chemical kinetics. The deflagrative turbulent flame propagation was described by the G-equation combustion model. A 22-species, 42-reaction iso-octane (iC8H18) mechanism was adopted to model the auto-ignition process of the gasoline/air/residual-gas mixture ahead of the flame front. The iso-octane mechanism was originally validated by ignition delay tests in a rapid compression machine. In this study, the mechanism was tested by comparing the simulated ignition delay time in a constant volume mesh with the values measured in a shock tube under different initial temperature, pressure and equivalence ratio conditions, and acceptable agreements were obtained. The mechanism was further validated by modeling a gasoline homogeneous charge compression ignition (HCCI) engine at both low and high engine speeds. The G-equation combustion model was validated on the Ford DISI engine with spark advance and intake manifold pressure sweeps. Based on the model validation, knocking combustion under boost and globally stoichiometric operating conditions was simulated. Finally, knock mitigation strategies using cooled EGR and/or "two-stage mixing" were assessed based on the numerical analysis.

PCCI Investigation Using Variable Intake Valve Closing in a Heavy Duty Diesel Engine

Nevin, R.M., Sun, Y., Gonzalez, M.A., and Reitz, R.D.

SAE paper 2007-01-0903

Parametric tests using various EGR amounts, boost intake pressures, fueling rates, intake valve closings (IVC), injection pressures, and start-of-injection timings were executed to explore the limitations and potential of an intake valve actuation system on a heavy-duty diesel engine. At high-speed, intermediate load (56%) operation, constant airflow and no EGR, the use of late intake valve closing enabled a 70% NOx reduction while maintaining PM levels. Through an investigation using low load operation, late IVC, and reduced intake pressure, 2010 not-to-exceed NOx and PM emissions (0.25 g/kW-hr NOx, 0.02 g/kW-hr PM) were achieved with 40% EGR. At medium load, constant air flow, and early SOI, it was found that the NOx, HC and BSFC levels at a late IVC with 30%EGR were comparable to those with the stock camshaft IVC timing of 143°BTDC with 40%EGR. In comparison, the CO and PM levels decreased by nearly 70% with the use of late IVC timing and less EGR. Through these parametric studies, it was concluded that the use of late IVC actuation is successful in controlling combustion phasing and emissions.

Multidimensional Simulation of PCCI Combustion Using Gasoline and Dual-fuel Direct Injection and Detailed Chemical Kinetics

Tamagna, D., Ra, Y., and Reitz, R.D.

SAE paper 2007-01-0190

Homogeneous or partially premixed charge compression ignition combustion is considered to be an attractive alternative to traditional internal combustion engine operation because of its extremely low levels of pollutant emissions. However, since it is difficult to control the start of combustion timing, direct injection of fuel into the combustion chamber is often used for combustion phasing control, as well as charge preparation. In this paper, numerical simulations of compression ignition processes using gasoline fuel directly injected using a low pressure, hollow cone injector are presented. The multi-dimensional CFD code, KIVA3V, that incorporates various advanced sub-models and is coupled with CHEMKIN for modeling detailed chemistry, was used for the study. Simulation results of the spray behavior at various injection conditions were validated with available experimental data. Then predictions of gasoline HCCI operation using detailed chemical kinetics were compared with experimental measurements for various charge equivalence ratios and injection timings. The results show good agreement with the experimental data in terms of pressure, apparent heat release profile and emissions. Further, the numerical code was modified to be able to simulate the combustion of gasoline pre-mixtures with ignition by diesel fuel direct injection and simulation results of the dual-fuel combustion are presented.

Effects of Engine Operating Parameters on Diesel Stoichiometric Combustion Characteristics

Lee, S., Gonzalez, M.D., and Reitz, R.D.

SAE paper 2007-01-0121

Stoichiometric combustion could enable a three-way catalyst to be used for treating NOx emissions of diesel engines, which is one of the most difficult species for diesel engines to meet future emission regulations. Previous study by Lee et al. [1] showed that diesel engines can operate with stoichiometric combustion successfully with only a minor impact on fuel consumption. Low NOx emission levels were another advantage of stoichiometric operation according to that study. In this study, the characteristics of stoichiometric diesel combustion were evaluated experimentally to improve fuel economy as well as exhaust emissions The effects of fuel injection pressure, boost pressure, swirl, intake air temperature, combustion regime (injection timing), and engine load (fuel mass injected) were assessed under stoichiometric conditions. The results showed that increased boost pressure and injection pressure improved the indicated specific fuel consumption (ISFC) and high swirl increases fuel consumption while intake air temperature, combustion regime, and engine load do not have significant effect on fuel consumption. The advantage of high injection pressure and boost pressure (air density) indicates that air entrainment is the most important process leading to an improved equivalence ratio distribution under stoichiometric operation, as well as for lean diesel operation.

Soot emissions under stoichiometric operation were significantly affected by the engine load and combustion regime, while the other operating parameters had only minor effects on the emissions. Boost pressure and engine load were the most dominant factors for NOx generation under stoichiometric operation and the intake air temperature and combustion regime had a relatively minor effect, while injection pressure and swirl did not have significant effects.

"Investigation of Mixing and Temperature Effects on HC/CO Emissions for Highly Dilute Low Temperature Combustion in a Light Duty Diesel Engine

Opat, R., Ra, Y., Gonzalez D., M.A., Krieger, R., Reitz, R.D., Foster, D.E., Siewert, R., and Durrett, R.

SAE paper 2007-01-0193

There is a significant global effort to study low temperature combustion (LTC) as a tool to achieve stringent emission standards with future light duty diesel engines. LTC utilizes high levels of dilution (i.e., EGR > 60% with <10%O2 in the intake charge) to reduce overall combustion temperatures and to lengthen ignition delay This increased ignition delay provides time for fuel evaporation and reduces inhomogeneities in the reactant mixture thus reducing NOx formation from local temperature spikes and soot formation from locally rich mixtures. However, as dilution is increased to the limits, HC and CO can significantly increase. Recent research suggests that CO emissions during LTC result from the incomplete combustion of under-mixed fuel and charge gas occurring after the premixed burn period [1, 2] . The objective of the present work was to increase understanding of the HC/CO emission mechanisms in LTC at part-load. To do this, fluid mechanics and chemical kinetics were decoupled by selectively varying in-cylinder mixing and charge temperature to influence not only the formation of CO and HC but also their oxidation during the latter stages of combustion and expansion. Controlled experiments in a single-cylinder light duty diesel engine and 3-D in-cylinder computations with a version of the KIVA-3V Chemkin CFD code recently tested at LTC conditions are used to describe the behavior of time and spatially resolved HC/CO emissions. The effect of such variables as rail pressure, swirl number and inlet temperature are explored using statistical experimental designs to first correlate with the kinetic behavior of HC and CO and second to help identify and understand the mechanisms of HC/CO formation and oxidation. The results were analyzed for major effects and CFD was used to understand the key phenomenon driving the increased HC/CO. A unique behavior was found in the HC/CO emissions while performing injection sweeps in these highly dilute environments. This behavior, termed a CO "sweet spot", was reproduced at higher loads with a production hardware set in order to confirm the results originally seen by Kook et al. [1, 2]. Use of a phenomenological engine spray model showed that increasing amounts of liquid fuel that miss the bowl for advanced timings coincide with increasing CO and that less than 100% of the fuel was vaporized prior to SOC at retarded timings where again CO increased from the minimum, thus resulting in the observed minimum "sweet spot". With use of CFD, this behavior was found to be the result of mixing related phenomenon. While reduced injection pressure increased the engine out HC/CO it also advanced the location of the CO minimum by reducing the amount of fuel that misses the bowl at a given timing. Varying swirl was found to dramatically change the behavior of the "sweet spot" due to changes in available O2 within the cylinder. Intake temperature was found to have only a small affect on the emissions; this was realized through the temperature dependence by kinetics.

Fuel Injection and mean swirl effects on combustion and soot formation in heavy duty diesel engines with EGR

Bergin, M., Reitz, R.D., Oh, S., Miles, P.C., Hildingsson, L. and Hultqvist, A.

SAE paper 2007-01-0912, 2007

High-speed video imaging in a swirl-supported (Rs = 1.7), direct-injection heavy-duty diesel engine operated with moderate-to-high EGR rates reveals a distinct correlation between the spatial distribution of luminous soot and mean flow vorticity in the horizontal plane. The temporal behavior of the experimental images, as well as the results of multi-dimensional numerical simulations, show that this soot-vorticity correlation is caused by the presence of a greater amount of soot on the windward side of the jet. The simulations indicate that while flow swirl can influence pre-ignition mixing processes as well as post-combustion soot oxidation processes, interactions between the swirl and the heat r.

Without swirl, combustion-generated gas flows influence mixing on both sides of the jet equally. In the presence of swirl, the heat release occurs on the leeward side of the fuel sprays. Asymmetric combustion-induced flows alter the vorticity on the leeward side of the jet and lead to better entrainment and fuel-air mixing during the period of peak heat release. This leads to lower elease can also influence mixing processeslocal equivalence ratio and lower soot production rates with swirl.

A Computational Analysis of Direct Fuel Injection during the Negative Valve Overlap Period in an Iso-Octane Fueled HCCI Engine

Tanet Aroonsrisopon, Dennis G. Nitz, John O. Waldman, and David E. Foster, ERC;
Minoru Iida, Yamaha Motor Company, Japan

SAE 2007-01-0227

This computational study compares predictions and experimental results for the use of direct injected iso-octane fuel during the negative valve overlap (NVO) period to achieve HCCI combustion. The total fuel injection was altered in two ways. First the pre-DI percent, (the ratio of direct injected fuel during the NVO period "pre-DI" to the secondary fuel supplied at the intake manifold "PI"), was varied at a fixed pre-DI injection timing, Secondly the timing of the pre-DI injection was varied while all of the fuel was supplied during the NVO period. A multi-zone, two-dimensional CFD simulation with chemistry was performed using KIVA-3V release 2 implemented with the CHEMKIN solver. The simulations were performed during the NVO period only.

Our simulated results show that when there is a very small change in the amount of heat released during the NVO period with a change in the pre-DI injection, it is the fuel reformation that produces the chemical effect which can alter the main combustion timing. This was observed when varying the pre-DI percent at a constant lean A/F of 17.0. The thermal effects produced by the energy release from the NVO fuel injection under this engine condition were not significant because the amount of heat release during the NVO period and its change with the percentage of pre-DI fuel injection were small. On the other hand, as the amount of heat release during the NVO period became greater, the thermal effect became more pronounced. This was observed in our experiments of varying the start of fuel injection timing during the NVO period. The combination of thermal and chemical effects showed a stronger impact on the main combustion than the chemical effect alone. The findings in this study indicate that the use of NVO fuel injection has the ability to expand the engine operating range and improve the HCCI combustion.

Measurement of Diesel Spray Impingement and Fuel Film Characteristics Using Refractive Index Matching Method

Yang, B. and Ghandhi, J.B.

SAE Paper 2007- 01- 0485

The fuel film thickness resulting from diesel fuel spray impingement was measured in a chamber at conditions representative of early injection timings used for low temperature diesel combustion. The adhered fuel volume and the radial distribution of the film thickness are presented. Fuel was injected normal to the impingement surface at ambient temperatures of 353 K, 426 K and 500 K, with densities of 10 kg/m3 and 25 kg/m3. Two injectors, with nozzle diameters of 100 μm and 120 μm, were investigated. The results show that the fuel film volume was strongly affected by the ambient temperature, but was minimally affected by the ambient density. The peak fuel film thickness and the film radius were found to increase with decreased temperature. The fuel film was found to be circular in shape, with an inner region of nearly constant thickness. The major difference observed with temperature was a decrease in the radial extent of the film. The injector nozzle diameter was not found to have a significant effect.

Assessment of Diesel Engine Size-Scaling Relationships

Stager, L.A., and Reitz, R.D.

SAE paper 2007-01-0127

Engine development is both time consuming and economically straining. Therefore, efforts are being made to optimize the research and development process for new engine technologies. The ability to apply information gained by studying an engine of one size/application to an engine of a completely different size/application would offer savings in both time and money in engine development. In this work, a computational study of diesel engine size-scaling relationships was performed to explore engine scaling parameters and the fundamental engine operating components that should be included in valid scaling arguments. Two scaling arguments were derived and tested: a simple, equal spray penetration scaling model and an extended, equal lift-off length scaling model. The simple scaling model is based on an equation for the conservation of mass and an equation for spray tip penetration developed by Hiroyasu et al. [1]. The extended scaling model includes the previous two equations as well as an equation for flame lift-off length developed by Pickett et al. [2]. The focus of the study was to apply these scaling hypotheses to new low emissions diesel engine operating regimes in order to determine the limits of the proposed scaling arguments and to assess the relative effects of chemical kinetics and turbulent mixing processes on combustion.

Experimental Investigation into the Effects of Direct Fuel Injection during the Negative Valve Overlap Period in an Gasoline Fueled HCCI Engine

John Waldman, Dennis Nitz, Tanet Aroonsrisopon, and David E. Foster, ERC; Minoru Iida, Yamaha Motor Company, Japan

SAE 2007-01-0219

A single cylinder Yamaha research engine was operated with gasoline HCCI combustion, using negative valve overlap (NVO). The injection strategy for this study involved using fuel injection directly into the cylinder during the NVO period (pre-DI) along with a secondary injection either in the intake port (PI) or directly into the cylinder (DI). The effects of timing of the pre-DI injection along with the percent of fuel injected during the pre-DI injection were studied in two sets of experiments using secondary PI and DI injections in separate experiments.

Results have shown that by varying the pre-DI timing and pre-DI percent the main HCCI combustion timing can be influenced as a result of varied degrees of reformation of the pre-DI injected fuel. In addition to varying the main combustion timing the ISFC, emissions and combustion stability are all influenced by changes in pre-DI timing and percent.

Experiments performed using secondary DI and secondary PI have shown similar trends in HCCI combustion timing influence of pre-DI timing and pre-DI percent are varied, but the effects of increased stratification of the air/fuel mixture when using secondary DI are observed with impacts on engine out emissions and ISFC benefits.

Combustion Modeling of Diesel Combustion with Partially Premixed Conditions

Hu, B., Jhavar, R., Singh, S., Reitz, R.D., and Rutland, C.J.

SAE paper 2007-01-0163

Two turbulent combustion modeling approaches, which were large eddy simulations in conjunction with detailed kinetics (LES-CHEMKIN) and Reynolds Averaged Navier Stokes with detailed kinetics (RANS-CHEMKIN), were used to model two partially premixed engine conditions. The results were compared with average pressure and heat release data, as well as images of in-cylinder ignition chemiluminescence and OH radical distributions. Both LES-CHEMKIN and RANS-CHEMKIN match well with experimental average data. However, LES-CHEMKIN has advantages over RANS-CHEMKIN in predicting the details of location of ignition sites, temperature as well as OH radical distributions. Therefore, LES offers more realistic representations of the combustion process. As a further improvement aiming at saving computational cost and accounting for turbulence-chemistry interactions, a flamelet time scale (FTS) combustion model is coupled with CHEMKIN to predict the entire combustion process. In this new approach (i.e. LES-CHEMKIN-FTS), CHEMKIN was responsible for the low-temperature phase to provide sufficient chemical kinetic information whereas the FTS model played its role in the high-temperature phase to account for subgrid mixing-chemistry effects and save CPU time. We showed that LES-CHEMKIN-FTS performed better than LES-CHEMKIN under conventional diesel-type combustion.

Development and Validation of a hybrid, auto-ignition/flame-propagation model against engine experiments and flame lift off

Singh, S., Wickman, D., Stanton, D., Tan, Z., and Reitz, R.D.

SAE paper 2007-01-0171, 2007

In previous publications, Singh et al. [1,2] have shown that direct integration of CFD with a detailed chemistry auto-ignition model (KIVA-CHEMKIN) performs reasonably well for predicting combustion, emissions, and flame structure for stratified diesel engine operation. In this publication, it is shown that the same model fails to predict combustion for partially premixed dual-fuel engines. In general, models that account for chemistry alone, greatly under-predict cylinder pressure. This is shown to be due to the inability of such models to simulate a propagating flame, which is the major source of heat release in partially premixed dual-fuel engines, under certain operating conditions. To extend the range of the existing model, a level-set-based, hybrid, auto-ignition/flame-propagation (KIVA-CHEMKIN-G) model is proposed, validated and applied for both stratified diesel engine and partially premixed dual-fuel engine operation. The newly proposed model gives good predictions of trends in cylinder pressure and exhaust NOx emissions for both the engines. Finally, both the KIVA-CHEMKIN and the KIVA-CHEMKIN-G models are validated using available measurements of diesel flame liftoff lengths. The models give good qualitative predictions of trends in liftoff; however, the predicted liftoff is shorter than the experimental measurements.

Detailed Diesel Exhaust Particulate Characterization and Real-Time DPF Filtration Efficiency Measurements during PM Filling Process

Ekathai Wirojsakunchai, Eric Schroeder, Chris Kolodziej, David E. Foster, Niklas Schmidt, Thatcher Root, UW, Terunao Kawai, National Traffic Safety and Environmental Laboratory, Toshiyuki Suga, Honda R&D, Inc., Tim Nevius, Takeshi Kusaka, Horiba Instrument, Inc.

SAE World Congress

An experimental study was performed to investigate diesel particulate filter (DPF) performance during filtration with the use of real-time measurement equipment. Three operating conditions of a single-cylinder 2.3-liter D.I. heavy-duty diesel engine were selected to generate distinct types of diesel particulate matter (PM) in terms of chemical composition and size distribution. Cordierite and Silicon-Carbide (SiC) DPFs with different washcoat formulations were studied to observe the effects of DPF variation on filtration characteristics. Real-time filtration performance indicators such as pressure drop and filtration efficiency were investigated using real-time PM size distribution and mass analyzer. Types of filtration efficiency included: mass-based, number-based, and fractional (based on particle diameter). In addition, time integrated measurements were taken with a Rupprecht & Patashnick Tapered Element Oscillating Microbalance (TEOM), Quartz filters and Teflon filters.

Results show that different engine operating conditions resolve in distinct PM concentration, chemical composition, size distribution, and filtration velocity. Differences in the particulate composition and filtration characteristics strongly influenced DPF pressure drop and filtration performance. Depending on the dominating filtration mechanism, convective or diffusive, the mass of particulate in the filter required to build a cake layer was shifted. Although the coating of the substrate contributes to higher pressure drop, it does not influence the onset of the different stages of filling. Comparing substrates with different geometry and physical properties, a shift in the most penetrating particle range (Greenfield Gap) was observed.

Detailed Diesel Exhaust Particulate Characterization and DPF Regeneration Behavior Measurements for Two Different Regeneration Systems

Niklas Schmidt, Thatcher Root, Ekathai Wirojsakunchai, Eric Schroeder, Christopher Kolodziej, David E. Foster, UW, Toshiyuki Suga, Honda R&D Corp., Japan, Terunao Kawai, NTSEL, Japan

SAE World Congress

Three distinct types of diesel particulate matter (PM) are generated in selected engine operating conditions of a single-cylinder heavy-duty diesel engine. The three types of PM are trapped using typical Cordierite diesel particulate filters (DPF) with different washcoat formulation and a commercial Silicon-Carbide DPF. Two systems, an external electric furnace and an in-situ burner, were used for regeneration. Furnace regeneration experiments allow the collected PM to be classified into two categories depending on oxidation mechanism: PM that is affected by the catalyst and PM that is oxidized by a purely thermal mechanism. The two PM categories prove to contribute differently to pressure drop and transient filtration efficiency during in-situ regeneration.

19-color H2O absorption spectrometer applied for real-time in-cylinder gas thermometry in an HCCI engine

Chun Lan, Andrew W. Caswell, Laura A. Kranendonk, Scott T. Sanders, Yasuhira Urata, Yasuhira Okura

SAE paper 2007-01-0188

An all fiber-optic sensor has been developed to measure H_2O mole fraction and gas temperature in an HCCI engine. This absorption-spectroscopy-based sensor utilizes a broad wavelength (1320 to 1380 nm) source (supercontinua generated by a microchip laser) and a series of fiber Bragg gratings (19 gratings centered on unique water absorption peaks) to track the formation and temperature of combustion water vapor. The spectral coverage of the system promises improved measurement accuracy over two-line diode-laser based systems. Meanwhile, the simplicity of the fiber Bragg grating chromatic dispersion approach significantly reduces the data reduction time and cost relative to previous supercontinuum-based sensors. The data provided by the system is expected to enhance studies of the chemical kinetics which govern HCCI ignition andHCCI modeling efforts.

Integrated Engine, Emissions, and Exhaust Aftertreatment System Level Models to Simulate DPF Regeneration

England, S.B., C.J. Rutland, and D.E. Foster, Yongsheng He,

SAE Powertrain and Fluid Systems Conference (submitted), October 2007

Experimental tests were conducted to determine the sensitivity of Diesel particulate matter (PM) at a given engine operating condition using a single cylinder research engine at the UAn integrated system model containing sub-models for diesel engine, emissions, and aftertreatment devices has been developed. The emissions sub-models used are for NOx and PM (particulate matter) prediction. The aftertreatment sub-models used include a diesel oxidation catalyst (DOC) and a diesel particulate filter (DPF). Controllers have also been developed to allow for transient simulations, active DPF regeneration, and prevention/control of runaway DPF regenerations. The sub-models have been developed separately and come from a variety of different sources. The engine model is in WAVE, the emissions models are in Matlab, the DPF model is in Fortran, and the DOC model is in Simulink. Matlab Simulink is used to integrate the existing sub-models into an overall system model. The model has been developed to allow for easy modification. Thus, additional aftertreatment sub-models can be added and/or rearranged allowing for studies of different aftertreatment configurations. The developed Integrated Model has been used to simulate DPF regeneration via exhaust fuel injection ahead of the DOC. In addition, the controller model can use intake throttling to assist in active DPF regeneration if needed. Regeneration studies have been done for both steady engine load and with load transients. High to low engine load transients are of particular interest because they can lead to runaway DPF regeneration. Therefore, the Integrated Model has been used to simulate methods to prevent and control runaway regenerations. The simulation results are consistent with experimental observations, thus confirming the utility of the developed Integrated Model.

Study on Characteristics of Gasoline Fueled HCCI Using Negative Valve Overlap

Takeru Ibara, Minoru Iida, Yamaha Motor Co., Ltd., David E. Foster,

Small Engine Technology Conference, San Diego, CA, November 2006, *SAE Transactions*

Gasoline fueled Homogeneous Charge Compression Ignition (HCCI) combustion with internal exhaust gas recirculation using Negative Valve Overlap (NOL) was investigated by means of calculation and experiment in order to apply this technology to practical use with sufficient operating range and with acceptable emission and fuel consumption. In this paper we discuss the basic characteristics of NOL-HCCI with emphasis on the influence of intake valve timing on load range, residual gas fraction and induction air flow rate. Emission and fuel consumption under various operation conditions are also discussed.

Gaseous Fuel Injection Modeling using a Gaseous Sphere Injection Methodology

Randy P. Hessel, Neerav Abani, Salvador M. Aceves and Daniel L. Flowers

SAE paper 2006-01-3265

To facilitate the growing interest in hydrogen combustion for internal combustion engines, computer models are being developed to simulate gaseous fuel injection, air entrainment and the ensuing combustion. This paper introduces a new method for modeling the injection and air entrainment processes for gaseous fuels. Modeling combustion is not covered in this paper. The injection model uses a gaseous sphere injection methodology, similar to liquid droplet injection techniques used for liquid fuel injection. In this paper, the model concept is introduced and model results are compared with correctly- and under-expanded experimental data.

Comprehensive Characterization of Particulate Emissions from Advanced Diesel Combustion

Christopher Kolodziej, Ekathai Wirojsakunchai, David E. Foster, Niklas Schmidt. UW, Takeyuki Kamimoto, Tokai University, Terunao Kawai, National Traffic Safety and Environmental Laboratory, Mike Akard, Horiba Instruments, Inc.

Submitted to JSAE/SAE, Kyoto Japan, July 2007

The applicability of several popular diesel particulate matter (PM) measurement techniques to low temperature combustion is examined. The instruments' performance in measuring low levels of PM from advanced combustion is evaluated. Preliminary emissions optimization of a high-speed light-duty diesel engine was performed for two conventional and two advanced low temperature combustion engine cases. A low PM (<0.2 g/kg_fuel) and NOx (<0.07 g/kg_fuel) advanced low temperature combustion (LTC) condition with high levels of exhaust gas recirculation (EGR) and early injection timing was chosen as a baseline. The three other cases were selected by varying engine load, injection timing, injection pressure, and EGR mass fraction. All engine conditions were run with ultra-low sulfur diesel fuel.

An extensive characterization of PM from these engine operating conditions is presented. Real-time mass concentration, filter based mass, filter chemical speciation, and particle size distribution analyses were performed. Advanced LTC PM proved to differ significantly from conventional diesel combustion PM by having smaller average particle size and higher organic content. Particulate from conventional diesel combustion matched published trends in particle sizes and chemical content. Between conventional diesel cases, increased load caused higher mass concentration, larger mean particle diameter, and decreased organic content. Increased injection pressure between LTC cases resulted in lower mass concentrations, smaller particle diameters, and higher organic content.

Simulation of the Effect of Spatial Fuel Distribution Using a Linear-Eddy Model

Richard Steeper, Vaidya Sankaran, Randy Hessel

SAE Powertrain and Fluid Systems Conference (submitted), October 2007

Prior HCCI optical engine experiments utilizing laser-induced fluorescence (LIF) measurements of stratified fuel-air mixtures have demonstrated the utility of probability density function (PDF) statistics in correlating mixture preparation with combustion. But PDF statistics neglect all spatial details of in-cylinder fuel distribution, and the question arises whether such spatial details are important to the design of injection strategies. The current work addresses this question through an innovative application of two computational models. A KIVA/Multi-Zone model of our automotive HCCI engine provides Reynolds-averaged estimates of large-scale turbulent kinetic energy and turbulent dissipation as a function of crank angle. The second model, a 1D linear-eddy model (LEM), uses the KIVA data as boundary values while simulating turbulence as a stochastic sequence of stirring (eddy) events. A simple n-heptane chemical kinetics mechanism tuned to match experimental heat release data is integrated in the LEM to compute chemical reactions. By imposing hypothetical initial fuel distributions at the start of the LEM computations, spatial details of the distribution could be varied (from very coarse to very fine) while holding PDF statistics constant. The LEM steps through time from 30 crank-angle degrees (CAD) before top center of combustion to 30 CAD after, solving diffusion, reaction, and turbulent advection equations.

Results predict that the spatial distribution of the fuel affects combustion for cases where the length scale of the initial fuel distribution matches the integral length scale of the turbulence. For finer fuel distributions, molecular diffusion alone is sufficient to homogenize the fuel/air mixture prior to the start of heat release. For coarser distributions, turbulence and diffusion together are insufficient to mix out the coarse fuel zones. For the matching-length-scales results, cycle-to-cycle variation in average heat-release rates is observed due to the LEM's capture of the stochastic nature of turbulence.

Comparisons of Diesel PCCI Combustion Simulations Using a Representative Interactive Flamelet Model and Direct Integration of CFD With Detailed Chemistry

Kong, S.C., Kim, H., Reitz, R.D., and Kim, Y.

ASME Journal of Engineering for Gas Turbines and Power, Vol. 129, pp. 252-260, 2007.

Diesel engine simulation results using two different combustion models are presented in this study, namely the representative interactive flamelet (RIF) model and the direct integration of computational fluid dynamics and CHEMKIN. Both models have been implemented into an improved version of the KIVA code. The KIVA/RIF model uses a single flamelet approach and also considers the effects of vaporization on turbulencechemistry interactions. The KIVA/CHEMKIN model uses a direct integration approach that solves for the chemical reactions in each computational cell. The above two models are applied to simulate combustion and emissions in diesel engines with comparable results. Detailed comparisons of predicted heat release data and in-cylinder flows also indicate that both models predict very similar combustion characteristics. This is likely due to the fact that after ignition, combustion rates are mixing controlled rather than chemistry controlled under the diesel conditions studied.

Near-wall formaldehyde planar laser-induced fluorescence measurements during HCCI combustion

Schrewe, M.R. and Ghandhi, J.B.

Proceedings of the Combustion Institute, 31 pp. 2871–2878, 2007.

The role of thermal boundary layers on homogeneous charge compression ignited engine combustion was directly evaluated by measuring the spatial profile of the formaldehyde concentration near the combustion chamber wall. Formaldehyde forms naturally as an intermediate species of the combustion process. A through-the-wall imaging scheme, in which the laser propagated at an angle through a window and the fluorescence signal was collected through the same window, was employed to avoid the effect of optical vignetting. Intensity profiles acquired in the wall-normal direction from the mean image show that during the first stage of combustion (cool flame) there is a substantial region of lower intensity, and presumably lower formaldehyde concentration, near the wall. This region extends more than 5 mm. After the completion of the first stage of combustion, the formaldehyde is found adjacent to the wall within the measurement limits of the system. During the second stage of combustion, the intensity near the wall and the intensity gradient in the normal direction remain constant, but the intensity is found to decrease preferentially away from the wall at a distance comparable to that observed in the first-stage combustion. Both of these findings are consistent with a thermally affected region near the wall that delays combustion. Individual cycle images, however, show that the true spatial gradients in the flow field are much steeper than in the mean data, and that regions of high temperature fluid can be found in close proximity to the wall. No appreciable thickening of the thermally affected region was seen at low equivalence ratios where there was incomplete combustion.

Wavelength-Agile H_2O Absorption Spectrometer for Thermometry of General Combustion Gases

Laura A. Kranendonk, Scott T. Sanders, Robert Huber and James G. Fujimoto

Proceedings of the Combustion Institute 31, 783-790, 2007

Using a novel Fourier-Domain Mode-Locking (FDML) laser scanning 1330-1380 nm, we have developed a gas thermometer based on absorption spectroscopy that is appropriate for combustion gases at essentially arbitrary conditions. The path-integrated measurements are particularly useful in homogeneous environments, and here we present measurements in a controlled piston engine and a shock tube. Engine measurements demonstrate a RMS temperature precision of ±3% at 1500 K and 200 kHz bandwidth; the precision is improved dramatically by averaging. Initial shock tube measurements place the absolute accuracy of the thermometer within ~ 2% to 1000 K. The sensor performs best when significant H_2O vapor is present, but requires only $X_{H2O}L$ > 0.07 cm at 300K, $X_{H2O}L$ > 0.25 cm at 1000 K, or $X_{H2O}L$ > 1.25 cm at 3000K for 2% accurate thermometry, assuming a 4 kHz measurement bandwidth (200 kHz scans with 50 averages). The sensor also provides H_2O mole fraction and shows potential for monitoring gas pressure based on the broadening of spectral features. To aid in designing other sensors based on high-temperature, high-pressure H_2O absorption spectroscopy, a database of measured spectra is included.

Modeling Diesel Spray Flame Lift-Off, Sooting Tendency and NOx Emissions Using Detailed Chemistry with Phenomenological Soot Model

Kong, S.-C., Sun, Y., and Reitz, R.D.

ASME Journal of Engineering for Gas Turbines and Power, Vol. 129, pp. 245-251, 2007.

A detailed chemistry-based CFD model was developed to simulate the diesel spray combustion and emission process. A reaction mechanism of n-heptane is coupled with a reduced NOx mechanism to simulate diesel fuel oxidation and NOx formation. The soot emission process is simulated by a phenomenological soot model that uses a competing formation and oxidation rate formulation. The model is applied to predict the diesel spray lift-off length and its sooting tendency under high temperature and pressure conditions with good agreement with experiments of Sandia. Various nozzle diameters and chamber conditions were investigated. The model successfully predicts that the sooting tendency is reduced as the nozzle diameter is reduced and/or the initial chamber gas temperature is decreased, as observed by the experiments. The model is also applied to simulate diesel engine combustion under premixed charge compression ignition (PCCI) conditions. Trends of heat release rate, NOx, and soot emissions with respect to EGR levels and start-of-injection timings are also well predicted. Both experiments and models reveal that soot emissions peak when the start of injection (SOI) occurs close to TDC. The model indicates that low soot emission at early SOI is due to better oxidation while low soot emission at late SOI is due to less formation. Since NOx emissions decrease monotonically with injection retardation, a late injection scheme can be utilized for simultaneous soot and NOx reduction for the engine conditions investigated in this study.

Development of a Semi-Implicit Solver for Detailed Chemistry in I.C. Engine Simulations

Liang, L., Jung, C., Kong. S.-C., and Reitz, R.D.,

ASME Journal of Engineering for Gas Turbines and Power, Vol. 129, pp. 2271-278, 2007.

An efficient semi-implicit numerical method is developed for solving the detailed chemical kinetic source terms in I.C. engine simulations. The detailed chemistry system forms a group of coupled stiff O.D.E.s, which presents a very stringent timestep limitation when solved by standard explicit methods, and is computationally expensive when solved by iterative implicit methods. The present numerical solver uses a stiffly-stable non-iterative semi-implicit method. The formulation of numerical integration exploits the physical requirement that the species density and specific internal energy in the computational cells must be nonnegative, so that the Lipschitz timestep constraint is not present [1,2], and the computation timestep can be orders of magnitude larger than that possible in standard explicit methods. The solver exploits the characteristics of the stiffness of the O.D.E.s by using a sequential sort algorithm that ranks an approximation to the dominant eigenvalues of the system to achieve maximum accuracy. Subcycling within the chemistry solver routine is applied for each computational cell in engine simulations, where the subcycle timestep is dynamically determined by monitoring the rate of change of concentration of key species which have short characteristic time scales and are also important to the chemical heat release. The chemistry solver is applied in the KIVA-3V code to diesel engine simulations. Results are compared with those using the CHEMKIN package which uses the VODE implicit solver. Good agreement was achieved for a wide range of engine operating conditions, and 40~70% CPU time savings were achieved by the present solver compared to the CHEMKIN.

An Experimental Investigation on the Effect of Post Injection Strategies on Combustion and Emissions in the Low-Temperature Diesel Combustion Regime

Yun, H., and Reitz, R.D.

ASME Journal of Engineering for Gas Turbines and Power, Vol. 129, pp. 279-286, 2007.

In order to meet future emissions regulations, new combustion concepts are being developed. Among them, the development of low-temperature diesel combustion systems has received considerable attention. Low NOx emissions are achieved through minimization of peak temperatures during the combustion process. Concurrently, soot formation is inhibited due to a combination of low combustion temperatures and extensive fuel-air pre-mixing. In this study, the effect of late-cycle mixing enhancement by post injection strategies on combustion and engine out emissions in the low-temperature (low soot and NOx emissions) combustion regime was experimentally investigated. The baseline operating condition considered for low-temperature combustion was 1500 rev/min, 3bar IMEP with 50% EGR rate, and extension to high loads was considered by means of post injection. Post injection strategies gave very favorable emission results in the low temperature combustion regime at all loads tested in this study. Since post injection leads to late-cycle mixing improvement, further reductions in soot emissions were achieved without deteriorating the NOx emissions. With smaller fuel injected amounts for the second pulse, better soot emissions were found. However, the determination of the dwell between the injections was found to be very important for the emissions.

Direct numerical simulation of ignition in turbulent n-heptane liquid fuel spray jets

Wang, Y. and C. J. Rutland

Combustion and Flame (accepted—to appear)

Direct numerical simulation was used to investigate the ignition process of turbulent n-heptane liquid fuel spray jets. A chemistry mechanism with 33 species and 64 reactions was used to describe the chemical reactions. The Eulerian method is employed to solve the carrier gas flow field, while the Lagrangian method is used to track the liquid fuel droplets. Two-way coupling interaction is considered through the exchange of mass, momentum and energy between the carrier gas fluid and the liquid fuel spray. In the calculation of the spatial derivatives in the transport equations, an 8th-order explicit finite difference scheme is used, and the transport equations for both phases are integrated in time by a fourth-order explicit Runge-Kutta scheme. The initial carrier gas temperature was 1500 K. In total six cases were simulated with different droplet radii (from 10 microns to 30 microns) and two initial velocities (100 m/s and 150 m/s). From the simulations, it was found that evaporative cooling and turbulence mixing plays important roles in the ignition process of liquid fuel spray jets. Ignition first occurs at the edges of the jets where the fuel mixture is lean, and the scalar dissipation rate and the vorticity magnitude are very low. For smaller droplets, ignition occurs later than larger droplets due to increased evaporative cooling. Higher initial droplet velocity enhances turbulence mixing and evaporative cooling. For smaller droplets, higher initial droplet velocity causes the ignition to occur earlier, whereas for larger droplets, higher initial droplet velocity delays ignition time.

Turbulent liquid spray mixing and combustion – fundamental simulations

Rutland, C.J. and Y. Wang,

J. of Physics: Conference Series (SciDAC), Vol. 40, pp. 28-37

Fundamental simulations are used to investigate the ignition process of turbulent n-heptane liquid fuel spray jets. A DNS quality Eulerian method is used to solve the carrier gas flow field, while a Lagrangian method is used to track the liquid fuel droplets. Two-way coupling between the phases is included through the exchange of mass, momentum and energy. A detailed mechanism with 33 species and 64 reactions is used to describe the chemical reactions. The simulation approach allows studies of larger scale interaction of sprays and turbulence, including evaporation, mixing, and detailed chemical reaction. Both time developing and spatially developing liquid spray jets are studied. The initial carrier gas temperature was 1500 K. Several cases were simulated with different droplet radii (from 10 microns to 30 microns) and two initial velocities (100 m/s and 150 m/s). In the time developing case it was found that evaporative cooling and turbulence mixing play important roles in the ignition process of liquid fuel spray jets. Ignition first occurs at the edges of the jets where the fuel mixture is lean, and the scalar dissipation rate and vorticity magnitude are low. In the spatially developing liquid jets, ignition and flame lift-off characteristics similar to diesel sprays are observed. Near the injector, combustion development progresses very rapidly along the stoichiometric surface. In the downstream region of the spray, combustion develops with steep temperature fronts in a flamelet mode.

A-priori tests of one-equation LES modeling of rotating turbulence

Lu, Hao, C. J. Rutland, and Leslie M. Smith

Journal of Turbulence (under review)

A-priori tests of subgrid-scale (SGS) models are performed using results of direct numerical simulations for forced isotropic (Re = 100) and rotating turbulence (0.1 < Ro < 0.4). A range of SGS models are tested varying from algebraic, gradient, and scale similarity, to one-equation viscosity and nonviscosity dynamic structure models. Anisotropy and Material Frame Invariance (MFI) requirements for SGS models in rotating systems are reviewed and used to help construct new models based on the dynamic structure approach. The models are evaluated primarily using correlation and regression coefficients of individual components of the SGS tensor, components of the divergence of the SGS stresses, and the kinetic energy transfer term between large and small scales. For all measures examined, the MFI dynamic structure models perform significantly better, especially for rotating turbulence.

Direct numerical simulation of turbulent flow with evaporating droplets at high temperature

Wang, Y., and C.J. Rutland

Heat and Mass Transfer, 2006, Vol. 42, No. 12, pp. 1103-1110

Direct numerical simulation is used to investigate turbulent flows with evaporating fuel droplets. For the solution of the carrier gas fluid, the Eulerian method is employed, while for fuel droplets, the Lagrangian method is used. The two-way coupling interactions between the carrier fluid and the fuel droplets are described by the mass, momentum and energy transfers. Direct numerical simulation is performed by a compressible code, named S3D. In this paper, the effects of evaporating and non-evaporating droplets on isotropic turbulent flows are investigated. From the simulations it is found that for the case without evaporation, the inclusion of small droplets suppresses the turbulence, while evaporation usually enhances turbulence at later times for higher mass-loading ratios.

Large eddy simulation of homogeneous shear flows with several subgrid-scale models

Wang, Y., F.G. Jacobitz, C.J. Rutland

Int. Journal for Numerical Methods in Fluids, 2006, vol. 50, pp. 863-883

In this article, large eddy simulation is used to simulate homogeneous shear flows. The spatial discretization is accomplished by the spectral collocation method and a third-order Runge–Kutta method is used to integrate the time-dependent terms. For the estimation of the subgrid-scale stress tensor, the Smagorinsky model, the dynamic model, the scale-similarity model and the mixed model are used. Their predicting performance for homogeneous shear flow is compared accordingly. The initial Reynolds number varies from 33 to 99 and the initial shear number is 2. Evolution of the turbulent kinetic energy, the growth rate, the anisotropy component and the subgrid-scale dissipation rate is presented. In addition, the performance of several filters is examined.

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From the Director...Transitions

At the ERC there are always many people coming and going. Most of these are students – new students arriving to pursue their educational goals and advance their careers, and students graduating slightly older and much wiser ready to embark on the next phase of their lives.

More recently we have had several staff and faculty make significant changes in their careers. Professor Pat Farrell became Provost of the Madison campus. This is the second in command position at the University of Wisconsin's flagship campus. Pat started his faculty career here 25 years ago and has been a part of the ERC essentially that whole time. This included a period as ERC Director. As Pat takes on significant challenges in his new position we will miss his contributions to the ERC, but we are very grateful that his enlightened leadership is part of our larger institution.

Song-Charng Kong moved from his Senior Scientist position at the ERC to a faculty position as an Assistant Professor at Iowa State University. Song-Charng received his PhD degree at the ERC with Rolf Reitz in 1994. He worked for four years as a professor in Taiwan and then returned to the ERC as a Research Scientist. Song-Charng has made many significant contributions to multi-dimensional CFD modeling in IC engines. He continues his modeling work at Iowa State in addition to setting up new experimental facilities for IC engines.

Very recently Manuel Gonzalez moved from an Assistant Scientist position at the ERC to a Senior Project Engineer position with FEV in Auburn Hills, MI. Manuel was also an ERC graduate, receiving his MS degree in 1990. He worked for many years in his home country of Venezuela. In 2004 he returned to the ERC taking on a wide variety of duties including overseeing laboratory work in the GM CRL, coordinating many of the DERC consortium activities, and being an Associate Director of the ERC.