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ERC NEWSLETTER

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GARY BORMAN—*HIS SPIRIT LIVES ON*

Gary Lee Borman, Emeritus Professor of Mechanical Engineering, passed away on January 17, 2005 after a courageous battle with cancer. He was born in Wauwatosa, WI on March 15, 1932. He was the only child of Meta Singer and Louis Borman. He graduated from West Allis High School and continued his education at UW-Madison in mathematics (BS, 1954; MS, 1956) and mechanical engineering (MS, 1957) where his thesis was on droplet vaporization. In 1971 he married Marlene Mehls in Chippewa Falls. He is survived by Marlene and cousins in the Milwaukee area.

After graduating from UW-Madison and a semester teaching math at UW-Milwaukee, Borman joined General Electric Co. in Cincinnati, OH. His work involved rocket heat transfer and electric propulsion research for space applications. Although having gained the title "senior engineer" after three years at GE, when Professor Phil Myers contacted Gary about becoming an instructor in Mechanical Engineering to teach engineering analysis and pursue a PhD he chose to return to academia. Borman's 1964 PhD thesis was titled, "Mathematical Simulation of IC Engine Processes and Performance".

Professor Borman's research concentrations included engine combustion, lubrication, spray vaporization and cycle analysis. His keen intellect, coupled with this strong analytical background, gave him insight into the processes occurring within the engine that propelled him to the pinnacle of his field. He received acclaim for activities in engine modeling as well as fundamental experiments. His pioneering work in thermodynamic analysis of engines lead to an analysis technique known as heat release analysis. This analysis

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ERC Symposium

– Low Emission Combustion Technologies for Future Engines

The ERC is organizing a Symposium to explore the many new combustion technologies that have the potential to significantly reduce emissions. The Symposium will feature presentations by internationally recognized experts in engine research and senior executives from the major automotive/engine industries to provide their perspective on these new combustion technologies. The ERC Symposium is a biennial event that began in 1999. The theme of the 2005 ERC Symposium is "Low Emission Combustion Technologies for Future IC Engines." The Symposium will take place **June 8-9, 2005** in Madison, WI. More information can be found at the ERC website: http://www.erc.wisc.edu/

Diesel Emissions Reduction Consortium

The next meeting of the Diesel Emissions Reduction Consortium will be held in Madison on June 7, 2005 in conjunction with the next biennial ERC Symposium.

The technical progress of three consortium-directed research projects will be reviewed including new directions. ERC laboratory visit will complement project discussions. The meeting agenda and a social event will favor a productive exchange between representatives of member companies with ERC faculty, students, staff and 2005 ERC Symposium speakers.

T-25 Breakfast – Gary Borman Memorial

Once again we invite all of the ERC alumni to the T-25 breakfast. This year there will be a special remembrance of Gary Borman. 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 in the atrium at the Marriott Courtyard in Downtown Detroit on April 13th. We are very pleased that the General Motors Research and Development Center is sponsoring the event.

International Multidimensional Engine Modeling Users Group Meeting

The ERC and Cray, Inc. are co-organizing the International Multidimensional Engine Modeling User's Group Meeting in Detroit on April 10, 2005 from 12:00-6:00pm. The time and place is chosen because it is expected that many engine modeling code users will be attending the SAE Congress in Detroit, April 11-14, 2005. The purpose of this meeting is to encourage the exchange of information about engine modeling and to help promote the use of engine modeling by the engine industry. This meeting accepts papers which feature applications of CFD codes and the development of novel submodels for engine simulations. The meeting will be held in the Detroit Downtown Courtyard by Marriott, 333 Jefferson Avenue, Detroit, MI. Phone: 313-222-7700. The agenda of the meeting will be available on the ERC website (http://www.erc.wisc.edu/modeling/modeling_index.htm#meeting).

Gary Borman– his spirit lives on

(Continued from page 1)

procedure has been adopted by every engine manufacturer in the world. It is now a standard component of every engine data analysis packaged sold today. His insight into the thermophysical processes within the engine resulted in novel measurements of time and spatially resolved heat flux within the cylinder, oil film thickness measurements between the piston rings and the liner of a firing engine, and integrated time resolved, in-cylinder nitrogen oxide measurements of an operating diesel engine. This latter work was recognized by SAE with the Horning Memorial Award, an award for the best technical paper of the year in the area of combustion and fuels.

Professor Borman was dedicated to his profession, as an educator, and a public servant to the University and the technical community. He co-authored a graduate level textbook, Combustion Engineering, with Professor Kenneth Ragland. He served on the Board of Directors of SAE. Working with Professor Myers and Uyehara he helped the engine research program at the University grow from a collection of individual faculty with research contracts into an international recognized research center, the Engine Research Center, of which he served as its first director, from 1986 to his retirement in 1994. He was an SAE Fellow and he was elected to the National Academy of Engineering in 1990 “for pioneering analytical simulation of internal combustion engines and verification with advanced experimental techniques”.

His impact on the internal combustion engine community, his colleagues at the University, his students, and his many friends was immeasurable. His spirit lives on in all who knew and worked with him.

A reception to celebrate the life of Gary Borman will be held from 2 - 4:00 PM on Saturday April 2nd at Olbrich Gardens, 3330 Atwood Avenue , Madison, Wisconsin. Those wishing to make a contribution in Gary’s honor are encouraged to consider the Gary and Marlene Borman Scholarship Fund (#12573806) at the UW Foundation.

SAE AND OTHER PUBLICATIONS

"Application of Micro-Genetic Algorithms for the Optimization of Injection Strategies in a Heavy-Duty Diesel Engine,"

Kim, M., Liechty, M.P., and Reitz, R.D.,

Optimized single and double injection schemes were found using multi-dimensional engine simulation software (KIVA-3V) and a micro-genetic algorithm for a heavy duty diesel engine. The engine operating condition considered was at 1737 rev/min and 57 % load. The engine simulation code was validated using an engine equipped with a hydraulic-electronically controlled unit injector (HEUI) system. Five important parameters were used for the optimization – boost pressure, EGR rate, start-of-injection timing, fraction of fuel in the first pulse and dwell angle between first and second pulses. The optimum results for the single injection scheme showed significant improvements for the soot and NOx emissions. The start of injection timing was found to be very early, which suggests HCCI-like combustion. Optimized soot and NOx emissions were reduced to 0.005 g/kW-hr and 1.33 g/kW-hr, respectively, for the single injection scheme. Moreover, the final optimum results met the EPA 2007 mandates at the operating point considered. The use of a double injection scheme showed little benefits in terms of engine performance compared to the single injection scheme. In fact, the double injection GA simulation result converged to a single injection scheme.

"There was a very significant decrease in the level of homogeneity of gas jets into a quiescent valve-deactivated engine flow…"

"Bulk Cylinder Flowfield Effects on Mixing in DISI Engines"

M. A. Wiles, D.M. Probst, J. B. Ghandhi;,

SAE Paper 2005-01-0096

Valve deactivation followed by multiple compression-expansion strokes was employed to remove intake-generated turbulence from the bulk gas in an internal combustion engine. The result was a nearly quiescent flowfield that retains the same time-varying geometry and, to a first approximation, thermodynamic conditions as a standard engine. Mass loss, and more significantly heat loss were found to contribute to a reduction in the peak cylinder pressure in the cycle following two compression-expansion strokes. The reduction of the turbulence was verified both computationally and by performing premixed combustion studies.

Mixing studies of both liquid spray jets and gaseous jets were performed. Laser-induced fluorescence images of high spatial resolution and signal-to-noise ratio were acquired, allowing the calculation of the two in-plane components of the scalar dissipation rate. The effect of in-cylinder vaporization was found to be relatively small, but with valve-deactivated operation the effect of vaporization was found to be more significant due to the decrease in bulk gas temperature. There was a very significant decrease in the level of homogeneity of gas jets into a quiescent valve-deactivated engine flow as compared to the same gas jet into a standard in-cylinder case, which leads to the major finding of this study: the bulk in-cylinder flowfield has a controlling effect on the mixing of gasoline direct injection spray jets.

"Comparisons of Combustion Simulations Using a Representative Interactive Flamelet model and Direct Integration of CFD with Detailed Chemistry"

Song-Charng Kong, Hoojoong Kim and Rolf D. Reitz, Yongmo Kim

ASME ICES 2005-1010

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 CFD 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 turbulence-chemistry 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.

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

Long Liang, Chulhwa Jung, Song-Charng Kong, Rolf D. Reitz

ASME ICES 2005-1005

An efficient semi-implicit numerical method is developed for solving the detailed chemical kinetic source terms in I.C. engine simulations. The present numerical solver uses a stiffly-stable non-iterative semi-implicit method. The formulation of this numerical integration method 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, and the computation timestep can be orders of magnitude larger than that possible in standard explicit methods and can be formulated to be of high formal order of accuracy. 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 from the scheme are compared with those using the CHEMKIN package which uses the VODE implicit solver. Very 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 CHEMKIN.

"Effects of Mixing on Early Injection Diesel Combustion"

Rahul Jhavar and Christopher J. Rutland

SAE Paper 2005-01-0154

Ignition dwell is defined as the interval between end of fuel injection and start of combustion in early injection diesel combustion that exhibits HCCI-like characteristics. In this project, the impact of in-cylinder temperature and fuel-air mixing on the ignition dwell was investigated. The engine cycle was simulated using the 3-D CFD code KIVA-3V. Work done by Klingbeil (2002) has shown that ignition dwell allows more time for fuel and air to mix and drastically reduces emissions of NOx and particulate matter. Temperature is known to have a direct impact on the duration of ignition dwell. However, initial fuel-air distribution and mixing (i.e. at the end of fuel injection) may also impact the duration of ignition dwell. To investigate this, variations in EGR, fuel injection timing, engine valve actuation and swirl were simulated. The aim was to use these techniques to generate varying levels of fuel-air mixing and to check if ignition dwell was affected. In order to verify if fuel-air mixing had been affected by these techniques, the equivalence ratio and temperature distribution, intermediate species formation, mixing timescales and fuel vaporization were analyzed. The results showed that in-cylinder temperature distribution was primarily responsible for controlling duration of dwell. However, the initial fuel-air distribution also affected ignition dwell although to a smaller extent. It was also seen that methods that affected fuel-air distribution (in addition to just temperature), resulted in a more homogeneous mixture and potentially would allow for a faster response time. Overall, this study helped to evaluate the relative influence and importance of various mixing control strategies to achieve ignition control though increased dwell.

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

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

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 occurring 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 combustion regime was investigated experimentally and numerically. 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. With small second fuel injected amounts, better soot emissions were found. However, the determination of the dwell between the injections was found to be very important for the emissions. Since post injection leads to late-cycle mixing improvement, further reductions in soot emissions were achieved without deteriorating the NOx emissions. To explain these results, numerical analysis was also done using the KIVA-CHEMKIN code. The simulations show that optimal combustion requires that the post injection fuel avoid fuel rich regions formed from the main injection.

"Fuel Film Temperature and Thickness Measurements on the Piston Crown of a Direct-Injection Spark-Ignition Engine"

S. Park and J.B. Ghandhi;,

SAE Paper 2005-01-0649

Fuel film temperature and thickness were measured on the piston crown of a DISI engine under both motored and fired conditions using the fiber-based laser-induced fluorescence method wherein a single fiber delivers the excitation light and collects the fluorescence. The fibers were installed in the piston crown of a Bowditch-type optical engine and exited via the mirror passage. The fuel used for the fuel film temperature measurement was a 2x10-6 M solution of BTBP in isooctane. The ratio of the fluorescence intensity at 515 to that at 532 nm was found to be directly, but not linearly, related to temperature when excited at 488 nm. Effects related to the solvent, solution aging and bleaching were investigated. The measured fuel film temperature was found to closely follow the piston crown metal temperature, which was measured with a thermocouple. A detailed analysis of the fiber-based laser-induced fluorescence technique was used to ascertain film thickness based on a single-point calibration. The calibration methodology also accounted for the effects of fuel film temperature. A 4% by volume solution of 2,3-hexanedione in isooctane was found to be a suitable choice for fuel film thickness measurement because it was verified to be co-evaporative. The fuel film thickness was found to be quite small, less than 10 m, for both motored and fired conditions performed at the same piston temperature. The 2,3-hexanedione was found to leave a viscous residue on the piston crown, which carried over from cycle to cycle and limited the results.

"Improvement of a Multiple-Step Phenomenological Soot Model and Its Application to HSDI Diesel Multiple Injection Modeling"

Liu, Y., Tao, F., Foster, D., and Reitz, R.D.,

SAE Paper 2005-01-0924, 2005.

"…this provides more insight about the soot formation process which is helpful to emissions reduction studies."

Multiple injection strategies have been revealed as an efficient means to reduce diesel engine NOx and soot emissions simultaneously, while maintaining or improving its thermal efficiency. Empirical soot models widely adopted in engine simulations have not been adequately validated to predict soot formation with multiple injections. In this work, a multiple-step phenomenological (MSP) soot model that includes particle inception, surface growth, oxidation, and particle coagulation was revised to better describe the physical processes of soot formation in diesel combustion. It was found that the revised MSP model successfully reproduces measured soot emission dependence on the start-of-injection timing, while the two-step empirical and the original MSP soot models were less accurate. The revised MSP model also predicted reasonable soot and intermediate species spatial profiles within the combustion chamber. In addition, the revised MSP model provides information about the soot particle number density, soot precursor radical, and acetylene growth species concentration during diesel combustion. This provides more insight about the soot formation process which is helpful to emissions reduction studies.

"Integration of Diesel Engine, Exhaust System, Engine Emissions and Aftertreatment Device Models"

David Kapparos, Indranil Brahma, Andrea Strzelec, Christopher J. Rutland, David E. Foster, Yongsheng He

SAE Paper 2005-01-0947

An overall diesel engine and aftertreatment system model has been created that integrates diesel engine, exhaust system, engine emissions, and diesel particulate filter (DPF) models using MATLAB Simulink. The 1-D engine and exhaust system models were developed using WAVE. The engine emissions model combines a phenomenological soot model with artificial neural networks to predict engine out soot emissions. Experimental data from a light-duty diesel engine was used to calibrate both the engine and engine emissions models. The DPF model predicts the behavior of a clean and particulate-loaded catalyzed wall-flow filter. Experimental data was used to validate this sub-model individually.

Several model integration issues were identified and addressed. These included time-step selection, continuous vs. limited triggering of sub-models, and code structuring for simulation speed. Required time-steps for different sub models varied by orders of magnitude. A system of controllers were implemented which limited the triggering of sub-models with very small time-steps so that simulation speed was maintained while minimizing the adverse effects on calculation accuracy. Integration of the models allowed for the visualization of dynamic interactions between sub-models that were not seen when simulating individual components. An example of which was an interesting filter pressure drop overshoot during a speed-step transient simulation.

In both steady state and transient simulations, overall model results fit expectations. Three steady-state cases (a baseline, an increased fueling, and an increased engine speed) and two transient cases (baseline to increased fueling and baseline to increased speed) were analyzed. While numerous results were studied, pressure drop across the filter was emphasized. Reasonable trends were observed. The system developed in this study will assist in the design and optimization of diesel automotive systems for reduction of tailpipe emissions.

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

Song-Charng Kong, Yong Sun and Rolf D. Reitz

ASME ICES2005-1009

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 PCCI-like 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 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.

"Modeling the Effects of EGR and Retarded-Injection on Soot Formation in a High-Speed Direct-Injection (HSDI) Diesel Engine using a Multi-Step Phenomenological Soot Model"

Tao, F., Liu, Y., RempelEwert, B.A., Foster, D.E., Reitz, R.D., Choi, D., and Miles, P.C.,

SAE Paper 2005-01-0121, 2005.

Low-temperature combustion concepts that utilize cooled EGR, early/retarded injection, high swirl ratios, and modest compression ratios have recently received considerable attention. To understand the combustion and, in particular, the soot formation process under these operating conditions, a modeling study was carried out using the KIVA-3V code with an improved phenomenological soot model. This multi-step soot model includes particle inception, surface growth, surface oxidation, and particle coagulation. Additional models include a piston-ring crevice model, the KH/RT spray breakup model, a droplet wall impingement model, a wall heat transfer model, and the RNG k-turbulence model. The Shell model was used to simulate the ignition process, and a laminar-and-turbulent characteristic time combustion model was used for the post-ignition combustion process. A low-load (IMEP=3 bar) operating condition was considered and the predicted in-cylinder pressures and heat release rates were compared with measurements. Predicted soot mass, soot particle size, soot number density distributions and other relevant quantities are presented and discussed. The effects of variable EGR rate (0 – 68%), injection pressure (600 –1200 bar), and injection timing were studied. The predictions demonstrate that both EGR and retarded injection are beneficial for reducing NOx emissions, although the former has a more pronounced effect. Additionally, higher soot emissions are typically predicted for the higher EGR rates. However, when the EGR rate exceeds a critical value (over 65% in this study), the soot emissions decrease. Reduced soot emissions are also predicted when higher injection pressures or retarded injection timings are employed. The reduction in soot with retarded injection is less than what is observed experimentally, however.

"Modeling the Effects of Variable Intake Valve Timing on Diesel HCCI Combustion at Varying Load, Speed and Boost Pressures"

Caroline L. Dougan, Song-Charng Kong and Rolf D. Reitz

ASME ICES 2005-1020

It is well known that HCCI operated engines have the potential to provide the efficiency of a typical diesel engine, but with very low NOx and Particulate Matter (PM) emissions. One of the main challenges with this type of engine, however, is that it can be difficult to control the combustion event, especially at high loads. The development of Variable Valve Timing (VVT) technology may offer an important advantage in the ability to control HCCI combustion. VVT technology can allow for late intake valve closure times, effectively changing the compression ratio of the engine. This can decrease in-cylinder temperatures and delay the combustion event, thus allowing the possibility to employ HCCI operation at higher loads and under various operating conditions. This work investigates the potential to use VVT for the control of diesel HCCI combustion over varying load, speed and boost pressure conditions. A multi-dimensional KIVA/Chemkin model is used to evaluate combustion event phasing as both intake valve closure times and operating conditions are varied. Detailed chemical kinetics, based on an available n-heptane mechanism, is used to investigate ignition and combustion characteristics. Conclusions include a description of the major parameters controlling diesel HCCI combustion phasing and an evaluation of the HCCI operating range possibilities with the utilization of VVT.

"Multidimensional Modeling of Transient Gas Jet Injection Using Coarse Computational Grids"

Ra, Y., Kong, S.-C., Reitz, R.D., Rutland, C.J., and Han, Z.,

SAE Paper 2005-01-0208, 2005.

In spite of the efficiency of Computational Fluid Dynamics (CFD) as a design tool, numerical simulations of gaseous fuel injection have not been widely adopted because of the difficulty in modeling the complicated physical phenomena associated with high speed gas flows. In the present study, a new model for simulating transient direct injection of gaseous phase fuel, including hydrogen, into a combustion chamber using a practical computational grid was developed. The model was implemented into KIVA3V, a multi-dimensional CFD code. The new model employs several sub-models to describe the physical phenomena of high speed gas injection. The underexpanded jet issuing from the nozzle was modeled using the conditions at the Mach disk as inflow boundary conditions. The effect of turbulence is shown to lead to non-unique flow solutions. However, physically realistic flows are obtained by a new turbulence treatment that describes the turbulence length scale and turbulent kinetic energy near the gas jet exit. The model considers time-varying pressure downstream of the injection nozzle by using a hybrid combination of a theoretical jet model and the underexpanded jet model. The model was applied to simulate a single-hole nozzle gas jet injection into a constant volume chamber and the results are compared with the classical jet theory and available literature data. Excellent agreement was attained between the predictions and the theoretical and experimental penetration profiles of gas jets. Compared to the results calculated using a fine mesh, the model successfully predicts gas jet behavior with a coarse grid and thus saves computation time, and can be used in practical device simulations.

"A New Approach to System Level Soot Modeling "

Indranil Brahma, Christopher J. Rutland, David E. Foster, Yongsheng He

SAE Paper 2005-01-1122

A procedure has been developed to build system level predictive models that incorporate physical laws as well as information derived from experimental data. In particular a soot model was developed, trained and tested using experimental data. It was seen that the model could fit available experimental data given sufficient training time. Future accuracy on data points not encountered during training was estimated and seen to be good. The approach relies on the physical phenomena predicted by an existing system level phenomenological soot model coupled with 'weights' which use experimental data to adjust the predicted physical sub-model parameters to fit the data. This approach has developed from attempts at incorporating physical phenomena into neural networks for predicting emissions. Model training uses neural network training concepts. Similarity in the final weight vectors between different models trained on different sets of data suggests that the weights are adjusting the predicted (by the phenomenological model) physical (sub)quantities in a general manner to capture unaccounted for phenomena particular to the engine. The model can be a useful tool for engine/aftertreatment control, design and optimization, since it delivers reliable results and is computationally inexpensive. For example, the model developed in the current work has been used to feed into a diesel particulate filter (DPF) model as part of a larger integrated engine-aftertreatment system level model. Finally, a procedure was developed to estimate the most useful future experimental data points for improving model performance.

"Optimization of a Large Diesel Engine via Spin-spray Combustion"

Bergin, M., Hessel, R.P., and Reitz, R.D.,

SAE Paper 2005-01-0916, 2005.

A numerical simulation and optimization study was conducted for a medium speed direct injection diesel engine. The engine's operating characteristics were first matched to available experimental data to test the validity of the numerical model. The KIVA-3V ERC CFD code was then modified to allow independent spray events from two rows of nozzle holes. The angular alignment, nozzle hole size, and injection pressure of each set of nozzle holes were optimized using a micro-genetic algorithm. The design fitness criteria were based on a multi-variable merit function with inputs of emissions of soot, NOx, unburned hydrocarbons, and fuel consumption targets. Penalties to the merit function value were used to limit the maximum in-cylinder pressure and the burned gas temperature at exhaust valve opening. The optimization produced a 28.4% decrease in NOx and a 40% decrease in soot from the baseline case, while giving a 3.1% improvement in fuel economy. The improvements were found to be due to the formation of circulatory flows caused by the interaction of adjacent optimally timed injections. The resulting spinning flow field greatly enhances mixing and combustion rates, and is called "Spin-Spray Combustion". The resulting fast mixing allowed the use of retarded injection timings, thereby lowering NOx production without increasing soot beyond the target values.

"Optimizing HSDI Diesel Combustion and Emissions using Multiple Injection Strategies"

Liu, Y., and Reitz, R.D.,

SAE Paper 2005-01-0212, 2005.

Multiple injection strategies have been experimentally and computationally studied for simultaneously reducing diesel engine NOx and particulate emissions. However, injection strategies featuring three or more pulses per engine cycle have not been sufficiently studied previously. The large number of parameters to be considered, in addition to the complicated interactions among them, challenge the capability of experimental hardware, computational models, and optimization methods. In the present work, multiple injection strategies including up to five pulses per engine cycle, are computationally investigated to optimize High Speed Direct Injection (HSDI) diesel engine combustion and emissions at a single part-load operating condition. The KIVA-3V code coupled with a Genetic Algorithm were used as the modeling and optimization tools, respectively. It was found that widely separated injection with two-stage combustion appears to provide optimal HSDI diesel performance at part load. More pulses per engine cycle can lead to better engine performance through the increased flexibility and control over the heat release and fuel/air mixing. With multiple injections, traditional diesel combustion phasing provides little advantage in engine performance, especially in the resulting high NOx emission levels.

"Particulate Emissions from a Direct-Injection Spark-Ignition Engine"

J. Cromas, J. B. Ghandhi;

SAE Paper 2005-01-0103

Particulate mass (PM) emission rate and size distribution measurements were performed in a direct-injection two-stroke engine under a wide range of conditions using a venturi-type mini-dilution tunnel. Air-assisted and nitrogen-assisted liquid fuel injection were both tested to investigate subtle changes in local equivalence ratio; gaseous propane injection using the same injection system was investigated to isolate the effects of liquid fuel impingement.

Under overall lean operating conditions the PM emissions were found to decrease when the air-assisted injection was changed to N2-assisted injection with all other parameters equal. The suggested cause for this behavior was a reduction in the PM formation and oxidation rates due to lower local temperatures. A similar effect (lower particulate matter emissions with a locally richer air-fuel ratio) was observed for a light load condition where the local oxygen concentration was varied by changing the exhaust gas recirculation rate. The use of propane injection resulted in lower PM emissions for all conditions except a medium load 2000 RPM condition. The reduction cannot, however, be solely related to the elimination of liquid fuel impingement since differences in the size distributions suggest that fuel composition played a significant role. Under some conditions there were significant differences between the air- and N2-assisted injected case where there are not expected to be significant differences in the amount of liquid impingement. Thus, while impingement is likely an important mechanism for particulate matter formation, it is not considered to be controlling under all cases.

"Performance Optimization of Diesel Engines with Variable Intake Valve Timing via Genetic Algorithms"

Munnannur, A., Kong, S.-C., and Reitz, R.D.,

SAE Paper 2005-01-0374, 2005.

The strategy of variable Intake Valve Closure (IVC) timing, as a means to improve performance and emission characteristics, has gained much acceptance in gasoline engines; yet, it has not been explored extensively in diesel engines. In this study, genetic algorithms are used in conjunction with the multi-dimensional engine simulation code KIVA-3V to investigate the optimum operating variables for a typical heavy-duty diesel engine working with late IVC. The effects of start-of-injection timing, injection duration and exhaust gas recirculation were investigated along with the intake valve closure timing. The results show that appreciable reductions in NOx+HC (~82%), soot (~48%) and BSFC (~7.4%) are possible through this strategy, as compared to a baseline diesel case of (NOx+HC) = 9.48 g/kW-hr, soot = 0.17 g/kW-hr and BSFC = 204 g-f/kW-hr. The additional consideration of double injections helps to reduce the high rates of pressure rise observed in a single injection scheme. In this context, an illustration of a modified prioritization of the emission targets in optimization studies, which may be crucial to attaining aggressive emission standards, is also provided. This study provides a direction for heavy-duty diesel engines to meet future stringent emission mandates.

"The Use of Variable Geometry Sprays with Low Pressure Injection for Optimization of Diesel HCCI Engine Combustion"

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

SAE Paper 2005-01-0148, 2005.

A numerical study of the effects of injection parameters and operating conditions for diesel-fuel HCCI operation is presented with consideration of Variable Geometry Sprays (VGS). Methods of mixture preparation are explored that overcome one of the major problems in HCCI engine operation with diesel fuel and conventional direct injection systems, i.e., fuel loss due to wall impingement and the resulting unburned fuel. Low pressure injection of hollow cone sprays into the cylinder of a production engine with the spray cone angle changing during the injection period were simulated using the multi-dimensional KIVA-3V CFD code with detailed chemistry. Variation of the starting and ending spray angles, injection timing, initial cylinder pressure and temperature, swirl intensity, and compression ratio were explored. As a simplified case of VGS, two-pulse, hollow-cone sprays were also simulated. The results show that VGS is effective in minimizing wall wetting and allows wall wetting to be decoupled from ignition timing control. Using VGS, the initial gas temperature, boost/throttling pressure, and compression ratio are effective parameters in ignition timing control. Variation of swirl intensity is effective to ensure fuel vapor-air mixing, and to prevent the formation of rich regions with high NOx emissions. The results indicate that VGS is a promising methodology to be used to control diesel-fueled HCCI engine operation, and it deserves further experimental and numerical study.

Modern Diesel Particulate Matter Measurements and the Application of Lessons Learned to 2007 Levels and Beyond

John C Stetter* , David E Foster, and J. J. Schauer

SAE paper 2005-01-0194, 2005

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 University of Wisconsin Engine Research Center. Utilizing a full dilution tunnel with a second stage partial dilution tunnel, the PM emissions were characterized. Physical properties were measured with a variety of instruments including a Scanning Mobility Particle Sizer (SMPS), Tapered Element Oscillating Microbalance (TEOM) as well as traditional filter-based gravimetric measurements. Chemical composition was determined through the use of the Thermal/Optical Transmittance (TOT) Method, Ion Chromatography (IC) and Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP/OES).

"...The present NO conversion values suggest the possibility for development of de-NOx catalysts for future lean-burning engines using ZSM-5 catalysts...."

State of the Art of de-NOx Technology Using Zeolite Catalysts in Automobile Engines

Byung-Chul Choi , David E. Foster

This review focuses on recent aspects of the use of precious metal or metal ion-exchanged zeolite as de-NOx catalysts. We focus especially on the NO conversion efficiency of precious metal ion-exchanged zeolites and the reactions of NOx with hydrocarbon reactants over metal ion-exchanged zeolite catalysts as a function of reaction temperature. We discuss the possibility of realizing automotive catalysts from such metal ion-exchanged catalysts. Precious metals or metal ion-exchanged zeolite catalysts performed very well in the reduction of NOx when water vapor was present. The effectiveness of reduction reactants for the NO conversion on zealite catalysts decrease in the order aromatics>olefins>paraffins. The present NO conversion values suggest the possibility for development of de-NOx catalysts for future lean-burning engines using ZSM-5 catalysts.

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