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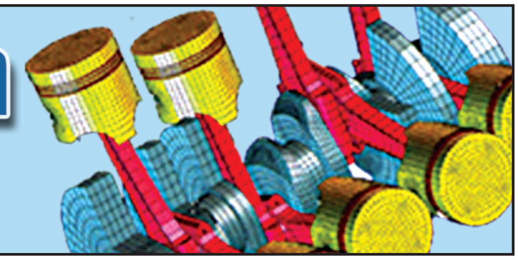
Internal Combustion Engine



SPRING 2013

INCOMING CHAIR'S MESSAGE

Steve Ciatti

Did you know that the Internal Combustion Engine Division of ASME has been promoting the art and science of mechanical engineering of engines for mobile, marine, rail, generation and stationary applications since 1921? I am truly grateful to serve as ICE Division Chair during a period of tremendous growth and change in the IC Engine industry.

Over the past few years, the ASME Board of Governors has identified three critical areas for the organization to play a leadership role in matters of global impact. They are energy, engineering workforce development and global impact. So what is the ICE Division doing to support this vision? As we all know, the ICE Division focuses heavily on improving the energy efficiency of the internal combustion engine. This is of critical importance since the transportation sector currently accounts for 25% of world energy demand and consumes almost 2/3 of the petroleum used each year. We are also at the forefront of finding alternative fuels to reduce our dependence on petroleum. In 2012, we hosted two technical conferences – one in the Spring in Torino, Italy, hosted by Politecnico di Torino, and one in the Fall in Vancouver, B.C. hosted by Westport Innovations.

The Spring Conference, which took place at the NH Ambasciatori in Torino, drew 151 attendees and 92 presented papers. The IC Engine Division presented our "Meritorious Service Award" to Prof. Andrea Catania, the esteemed engine combustion researcher from Politecnico di Torino. Prof. Catania has given many years of loyal service to the Division and it was my pleasure to personally present him with this award! The keynote address was provided by Mr. Michael Potter from General Motors Powertrain – Europe, entitled "Development Trends for the Next Generation of Highly-Efficient Diesel Engines for Passenger Car Application."

Our Fall Conference in Vancouver, BC featured 200 attendees and 98 presented papers. The keynote address by Dr. Patric Ouellette from Westport Innovations, entitled "Technology Choices for Up and Coming New Applications of Natural Gas as an Engine Fuel" (http://files.asme.org/Divisions/ICE/33490.pdf). In this newsletter, you will also find an interesting article regarding advanced engine combustion and its potential in the transportation sector, taken from ASME's "Mechanical Engineering" magazine from September 2012 (http://files.asme.org/Divisions/ICE/33204.pdf).

I am happy to report that several recent initiatives to improve our impact in the area of engineering workforce development have been rather successful. We have drastically reduced our registration fees to attract more graduate students to our conferences, resulting in students comprising almost 20% of our conference attendees, which is up from roughly 5% a few years back. We have also implemented a highly successful, fast-track procedure for rapid publication of high-quality conference papers in the ASME Journal of Engineering for Gas Turbines and Power (GTP), which helps graduate students and young professors to widely publicize their research results in a timely manner. Working with the editor-in-chief of GTP we have been streamlining and improving this fast-track process to make it more smooth and equitable for all of our participants. The process has already improved markedly and we expect further refinements and improvements over time. At the Vancouver conference, we had the opportunity to hear about the work of two undergraduate student winners of our annual undergraduate student competition – Mr. David Vuilleumier and Mr. Zak Tilocco.

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The third area, global impact, is perhaps the most challenging for the ICE Division, given that we have a relatively small group of volunteers. I would be remiss if I did not start off by stating that many of our members work for companies that develop and sell products for global markets. Although we hold conferences outside of North America every three years and routinely have participants from 20 or more countries, our conferences are not accessible to many engineers working in our field. My perception is that perhaps we could do a little more to meet the ASME challenge, which is to improve the quality of life throughout the world. The Executive Committee would like to hear your ideas on this important subject.

Some of you may be familiar with ASME's *Engineering for Change* (E4C)

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Incoming Chair's Message

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initiative. E4C is a dynamic and growing community of engineers, technologists, social scientists, non-governmental organizations, local governments, and community advocates whose mission is to improve people's lives around the world. E4C features a user-friendly online platform (www.engineeringforchange.org)that facilitates collaboration and knowledge exchange for the development of appropriate solutions to issues such as sanitation, access to clean water, energy, transportation, food, education and housing. Perhaps the Division or some of our members could offer their expertise to this worthy initiative.

At this stage, I would like to thank my colleagues on the Executive Committee for their hard work during the past year. In particular, I would like to recognize our past Chair, Mr. Stuart Neill(National Research Council - Canada), for his prescient leadership of the Division. One of Stuart's lasting contributions involved building an excellent relationship with the GTP journal and making the fast-track process actually happen. Stuart was also instrumental in modifying our Division's protocol regarding student registration and participation and for that, his efforts are to be commended! In addition, Dr. Frank Aboujaoude (Fairbanks Morse Engine)has taken over as our Division Treasurer. Having worked with Frank on several conferences, I can confidently state that our Division is in excellent financial shape and will continue to be in good shape, as a result of Frank's dedication and leadership. On the technical side, I would like to thank the Track Chairs, Session Organizers, Authors, and Reviewers who work so hard to put together excellent technical programs. We also have fantastic support on the administrative side to put together our newsletters, Division website, and our Honors and Awards Banquet. Please visit the Division website for a fairly comprehensive list of our volunteer leaders.

Lastly, I must thank the hard-working staff at ASME, especially Mr. Vince Dilworth (former liaison) and our current ASME liaison, Ms. Erin Dolan, and Ms. LaShion Pettiford, for their continuing support of the ICE Division. Unfortunately, I must report that we have lost one of our colleagues in the past year. Prof. Dilip Ballal, the editor-in-chief of the Journal for Engineering for Gas Turbines and Power recently passed (late November 2012). Looking to the future, I would like to welcome Dr. Diana Grauer (Cameron Corp.), our incoming member to the Executive Committee. Diana joins a dedicated team of volunteers on our Executive Committee who are excited to be able to serve the internal combustion engine community. On behalf of the Executive Committee, I would like to thank the membership for the trust you place in us to carry the torch for the ICE Division. Like many of you, we are extremely proud to be a part of the ASME organization.We are looking forward to putting together an excellent conference for the Division in the upcoming year: Dearborn, MI – October 13-16, 2013, hosted by Wayne State University. We strongly encourage you to participate in this important event and we look forward to receiving your feedback, both positive and constructive, so we can better serve the needs of our members in the future. Alternatively, you may also reach us by phone or email (see http://divisions.asme.org/ICE/Executive_Committee.cfm for contact information).

In closing, I would like to say that the future of the IC Engine Division, along with our industry as a whole, is quite bright! As more of the world becomes industrialized, the need for reliable, environmentally friendly and efficient power is going to rise. The members of this Division and this community are dedicated to making these goals a reality!

Past Chair's Message

Stuart Neill

I am extremely proud to report that the ASME ICE Division has completed a very successful 91st year, thanks to the efforts of numerous volunteers that contributed their enthusiasm and talents to promote the art and science of internal combustion engines.

Undoubtedly, the two highlights of the year were our excellent conferences in Morgantown, WV and Torino, Italy. At this time, I would like to recognize the leadership of John Hedrick and Steve McConnell (Administrative Programs), Steve Ciatti and Tim Jacobs (Technical Programs), as well as our wonderful local hosts - Professor Hailin Li (West Virginia University) and Professor Andrea Catania (Politecnico di Torino) in organizing the conferences.

The ASME procedure for organizing a conference has changed significantly over the past year and it is noteworthy that we were able to seamlessly run successful conferences despite the numerous changes. I would like to thank Vince Dilworth and LaShion Pettiford for their guidance to help us survive the procedural changes.

I would also like to recognize the contributions of two former Division Chairs. Neil Blythe continues to help the Executive Committee run smoothly through his stellar work as Secretary. Frank Aboujaoude has done an admirable job replacing Victor Wong as our Treasurer. As well, he was always a reliable source of helpful insight to me as Past Chair of the Division.

Brad Zigler (National Renewable Energy Laboratory) and Diana Grauer (Cameron) became the new voting member and new member on the Executive Committee, effective July 1st. The Division is exceedingly lucky to have such talented individuals volunteer their services.

Of course, there are numerous other volunteers needed to run the Division. I would like to personally thank our colleagues for putting out our newsletter, placing content on our website, running our technical

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Past Chair's Message

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committees, reviewing papers, leading our technical sessions, interacting with other parts of ASME, and organizing our Awards Banquet. Their efforts have contributed greatly to the success of the Division!

Peter Drucker, the father of modern management, saw volunteerism as essential to society and a way for individuals to ensure that their day job doesn't consume their life. Drucker recommended that everyone should find an organization and cause you believe in – and get to work. If you want to follow his sage advice, volunteer some of your time to the ASME Internal Combustion Engine Division!

In closing, I am very grateful for having had the opportunity to serve on the Executive Committee of the ICE Division for the past several years. It has been a wonderful learning experience and a lot of fun too!

Incoming Executive Committee Member Dr. Diana Grauer

Dr. Diana Grauer is the incoming member to the ICED Executive Committee. She is employed as a Senior Engineer with the Process and Compression Systems Division of Cameron. Her work involves design of new horsepower as well as retrofit equipment for Cameron's international fleet of reciprocating engines and compressors.

Dr. Grauer received her B.S. and Ph.D. from Kansas State University in 2006 and 2010, respectively. Her doctoral research involved the development and implementation of a transient, non-adiabatic, compressible flow model to capture pulsation and pressure losses in the engine charge air distribution and exhaust removal flow paths.

Dr. Grauer has been an active member of ASME-ICED since 2004 in numerous capacities including authoring and reviewing technical papers, organizing conference sessions, and co-chairing the "Large Bore Engines" technical committee. She assisted past Executive Committee Chairman, Dr. Kirby Chapman in coordinating the technical programs for the Fall 2005, Spring 2005, and Fall 2006 technical conferences. She was also awarded ICED Fall 2007 conference "Best Paper" for her paper "Active Air Control System Development using Charge Air Integrated Manifold Numerical Simulation (CAIMENS)" which was later selected for publication in the ASME Journal of Engineering for Gas Turbines and Power.

Commenting on her recent opportunity with the division, Dr. Grauer said, "I am honored to be selected to become a part of the Executive Committee. I look forward to continuing to address the challenges facing our technical community by providing a quality conference at which to share our technical knowledge and experiences. I promise to work hard to attract the best and brightest in our field to ICED. I believe that our conferences provide an important opportunity for young engineers to share their ideas and enthusiasm while learning from some of the greatest contributors to our field – I will work to enhance this valuable professional experience."

Plan to Attend the 2013 Fall Technical Conference in Dearborn, Michigan

Brad Zigler

The ASME Internal Combustion Engine Division is pleased to announce details of its upcoming 2013 Fall Technical Conference to be held October 13th-16th, 2013 in Dearborn, Michigan and hosted by Wayne State University. The venue for this year's conference will be The Dearborn Inn. Initial interest has been outstanding, with a record 205 abstracts submitted. The technical program is planned to include the following:

1. Technical papers presented by leading researchers from around the world,
2. Keynote address,
3. Two panel discussion sessions focusing on fuels and controls topic areas,
4. Presentations from undergraduate students who will compete through an international competition for awards to attend and participate in the conference,
5. Lunch presentation by Dr. Robert Wagner, Director of the Fuels Engines and Emissions Research Center at Oak Ridge National Laboratory,
6. Technical tours of Wayne State University, including the Center for Automotive Research.

The technical presentations, exhibits, and collegial atmosphere foster networking, discussion, and collaboration that advance engineering and science for internal combustion engines. Reduced registration fees encourage student participation, offering employers a unique opportunity to recruit next-generation experts to their organizations. The Honors and Awards Banquet on Monday, October 14th is a special annual event to recognize the outstanding achievements and dedicated efforts of Internal Combustion Engine Division colleagues.

Registration will soon be open, with early-bird registration rates initially available through the 2013 Fall Technical Conference website: http://www.asme conferences.org/ICEF2013/

For more information, please contact:

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(including sponsorship or exhibitor opportunities):

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2012 Spring Technical Conference Highlights

Courtesy of DieselNet

The ASME 2012 Internal Combustion Engine Division Spring Technical Conference was held May 6-9 at the NH Ambasciatori hotel in Turin, Italy. The conference was hosted by Politecnico di Torino. There were over 150 registered attendees and about 100 technical papers. The two-day technical program addressed a number of current trends in internal combustion engine development in seven parallel tracks: Large Bore Engines; Fuels; Advanced Combustion; Emissions Control Systems; Instrumentation, Controls, and Hybrids; Numerical Simulation; and Mechanical Design, Analysis, Vibration, and Lubrication. The conference concluded with a technical tour on the third day to the Politecnico di Torino Engine Research Center.

The conference started with a keynote address by Michael Potter, Chief Engineer, Diesel Advanced Engineering, GM Powertrain Europe. He discussed GM's perspective on development Trends for the Next Generation of Highly-Efficient Diesel Engines for Passenger Car Application. In order to demonstrate the potential of light-duty diesel engines, in 2010 GM started a demonstration project aimed at developing a highly efficient engine prototype based on an upgraded version of its popular 2.0 L diesel powertrain, which was then integrated into the Opel Insignia, with the objective of reducing CO2 emissions below 100 g/km at Euro 5 emission certification.

In order to reduce the motoring torque, base engine hardware was upgraded with low-friction and low-parasitic loss components including a high-efficiency low-friction vacuum pump, an electronically controlled variable displacement oil pump and camshafts supported by needle bearings. The combustion system performance and thermodynamic efficiency was enhanced as well by introducing a new-generation omega-shaped combustion bowl with low flow number 2000 bar piezo-injectors.

The EGR system was equipped with a high efficiency, dual temperature cooler with the low temperature loop cooled by an independent, low temperature liquid circuit. The EGR system can be operating in three modes: at high load, both high and low temperature coolers are used.

At medium and low load, only the high temperature cooler is used to avoid excessive CO and THC emissions. During warm- up, both coolers are bypassed entirely to provide uncooled EGR to the engine.

Thermo-management of the engine was controlled via a Valeo Themis 3-position valve instead of the conventional thermostat to allow engine coolant flow and temperature control based on engine power output and elapsed time after cranking. The coolant circuit incorporated three coolant pumps: a mechanical pump driven by the engine, an electric pump for start/stop operation and an electric pump for the low temperature EGR circuit. In addition to the powerplant changes, the vehicle incorporated start-stop and an optimally matched 6 speed transmission.

Compared to the current-production 2.0 L diesel Euro 5 engine, an improvement of ~10% of steady-state total engine efficiency was achieved in the NEDC relevant area of the engine operating map. This represents roughly 2/3 of the theoretical potential efficiency improvement in that area. An interesting observation was that over the NEDC, a major share of the input chemical energy was necessary to warm up the engine components and aftertreatment system to their operating temperature. In total, about 57% of the fuel energy was directed towards component warm-up and heat rejection. The low exhaust temperatures would also present a major challenge for NOx aftertreatment, with an underfloor SCR catalyst being particularly critical.

Efficiency Improvements

A number of papers focused on engine efficiency improvement, with friction reduction and waste heat recovery (WHR) being the most widely discussed technology approaches.

Friction Reduction - Loughborough University presented several papers on their attempts to better understand and model piston/ring/liner friction. These papers dealt with: the effect of gas forces behind the top ring on ring/liner contact and friction [paper number ICES2012- 81021], the effect of transient ring deformations throughout the engine cycle on top ring friction [81045] and the validation of modeling results using the floating liner principle [81028]. They also presented work done in collaboration with industrial partners. With Aston Martin they looked at the effect of wear on the ring/liner tribological conditions to allow the resulting influence of friction and fuel consumption to be estimated [81201] while with Capricorn Automotive, they studied thermo-structural effects on piston skirt lubrication [81125].

Conventional oil pumps sized to ensure sufficient oil flow at hot-idle tend to oversupply the engine at higher engine speeds and account for about 15% of engine friction. A variable displacement pump that is better able to match the lubricant flow requirements of the engine can reduce this friction significantly. The University of Bath in cooperation with Ford [81044] found the resulting fuel consumption benefit of this component of friction reduction to be 4% in a light-duty diesel engine driven over the NEDC. The benefit is due not only to the lower oil pump torque but also to reduced engine friction resulting from lower oil flow. Other impacts of the variable displacement oil pump included a lower rate of oil temperature rise, lower oil sump temperature, higher cylinder liner temperatures, a 3% NOx increase and a 3-5% HC/CO decrease.

Chevon Oronite studied the effect of engine oil viscosity and friction modifying additives on natural gas engine fuel economy [81052]. They found that going from a high viscosity SAE 40 grade to low viscosity SAE 30 grade engine oil can provide a 1.6-1.8% fuel consumption benefit. Additives can provide an additional 0.3-0.4% improvement. No impact on wear was observed in the short duration tests that were carried out. Results from long duration wear tests were unavailable.

Mahle investigated the applicability of a steel ring pack to reduce friction from high-speed, large bore engines [81115]. Compared to cast iron rings, steel rings enable the reduction of ring tangential load, reduction of ring axial width and the use of low friction coefficient materials. A potential ring friction reduction of more than 30% combined with wear improvements of up to 50%, depending on engine operation, appear possible.

Politechnico di Torino, Loughborough University and GM Powertrain summarized their work on the development of a model to predict valve train friction based on key design parameters that is easy to use and allows for rapid scenario-building simulations [81050].

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Waste Heat Recovery - West Virginia University determined the waste heat recovery available from a heavy-duty diesel engine with an organic Rankine cycle over the heavy-duty European stationary cycle (ESC) [81112]. A second law analysis demonstrated that not all of the waste energy transferred to the environment as heat rejection can be converted to useful power. Energy sources which appear to offer a large amount of waste heat, such as the engine coolant for example, may be inappropriate for recovery purposes due to the low operating temperature and consequential lower value of exergy. The analysis revealed that a standard organic Rankine cycle, operating on R245fa that adsorbed heat from the intake air intercooler in order to pre- heat the fluid and from the EGR heat exchanger to reach complete vaporization could recover up to 1.8% of the fuel inlet energy as useful work.

Waste heat does not necessarily need to be converted into useful work to improve fuel efficiency. Chrysler and Ohio State University showed [81160] that waste heat from the engine can be distributed to the engine oil and transmission to rapidly raise oil/transmission fluid temperatures to reduce viscosity related friction. A 4% fuel economy improvement in a light-duty vehicle over the conventional thermal management system was shown. However, system control becomes more demanding; maintaining coolant temperature stability and avoiding disturbances is critical to avoid knock issues in SI engines.

In order to optimize the thermal characteristics of internal combustion engines, it is important to understand the heat transfer behavior within the structure of a modern production engine. While empirical correlations exist, they are often outdated or too general to provide sufficiently accurate results for a particular engine design. As an alternative, a minimap steady-state test procedure that segments a transient cycle into a number of steady-state operating conditions was developed by the University of Bath and Ford to estimate total energy transfer to the coolant over the NEDC [81192]. Using this approach, it was possible to estimate the total energy transfer to within 10% of the transient tests.

Villanova University and Chevron compared the thermal performance of aqueous ethylene-glycol mixtures with and without additives commonly used to improve material compatibility [81134]. Apparently this work has not been carried out before for modern engine coolants. Experiments revealed that additives yield as much as a 50 C lower wall temperature at maximum heat flux. This results from a combination of improved corrosion protection, wetting ability and the minimization of mass diffusion induced suppression of heat transfer.

Numerical Simulation

Numerical simulation played an important role in many of the papers presented at this year's conference. In addition to the 19 papers in the numerical simulation track, there were an approximately equal number scattered in other sessions. In total, over 40% of the papers relied on numerical simulation in lieu of experiments. Numerical simulation was especially popular in papers dealing with combustion and piston/ring/liner friction. In addition to being used instead of experimental methods, numerical simulation was used to help interpret experimental results when considering difficult to measure aspects of a particular problem.

While very detailed mechanisms and computational approaches are available that can yield accurate results, these are often computationally intensive and require expense computing facilities and/or long computing times in their application. This makes them impractical in many cases. "Low computational cost" simulation approaches are an option to make simulation more practical by allowing a large number of cases to be run in a relatively short time on relatively inexpensive machines. Many of the numerical simulation papers discussed such approaches. Some examples included work by the National Technical University of Athens on the evaluation of a semi-empirical two-zone combustion model for diesel applications [81101], work by the University of Bologna on a large eddy simulation (LES) methodology that allows a reduction in total computational mesh size [81119] and work by the Politecnico di Milano on a quasi-3D approach that can be integrated into a 1D code to allow geometrically complex shapes such as intake and exhaust manifolds to be modeled with 1D codes [81181].

Full chemical mechanisms are often too computationally intensive and reduced chemical mechanisms, provided they are available, are often desirable alternatives. Work utilizing reduced chemical mechanisms for biodiesel [Chalmers U./Reaction Design - 81162] and ethanol for a partially stratified charge CI engine [U. of Basilicata - 81104] was presented. Many existing reduced mechanisms for natural gas have only been validated at pressures and air-fuel ratios not suitable for CFD simulations of high BMEP, lean-burn natural gas engines. In an attempt to address this, Prometheus Applied Technologies and Colorado State U. presented a reduced chemical kinetic mechanism applicable to high pressures and lean air-fuel ratios [81109].

Combustion

As in past conferences, combustion related material played a very prominent role in the program. While "Advanced Combustion" has been a major theme in recent years, papers related to more "Conventional Combustion" were also prominent at this meeting. Under the Advanced Combustion or Low Temperature Combustion (LTC) theme, the focus was on addressing outstanding challenges while under the more Conventional Combustion theme, the focus was on refinements potentially required in near-term commercial applications. Important combustion-related topics such as combustion feedback for control were also prominent.

Advanced Combustion - The University of Michigan and GM discussed a methodology for studying the effect of thermal stratification on HCCI combustion and emissions [81208]. They then applied the methodology to study the temperature-mass distributions over a coolant temperature sweep and found that very small changes to compression heat transfer can shift the distribution of mass and temperature in the cylinder enough to significantly affect HCCI burn rates and emissions.

Sandia discussed the effect of swirl ratio and injection pressure on mixing during the mixture preparation period (i.e., between start of injection and onset of high temperature heat release) in light-duty LTC diesel combustion using early injection of fuel and high rates of EGR [81234]. They found that as the swirl ratio or injection pressure is increased, the amount of over-lean mixture within the squish volume and within the upper, central portion of the combustion chamber also increased. Unexpectedly, increased injection pressure resulted in a greater quantity of over-rich mixture within the squish volume.

The impact of fuel properties on advanced combustion continues to be a

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challenge that researchers are still grappling with. Lund University presented work on the effect of fuel composition on emissions and the achievable range of combustion phasing where stable operation could be achieved for partially premixed combustion using four fuels in the gasoline boiling range and Swedish MK1 diesel fuel [81184]. At the mid-load point tested, combustion phasing range was limited by combustion instability for high RON fuels. The largest difference in engine-out emissions between the fuels was the filter smoke number (FSN) with the gasoline fuels producing less smoke than MK1.

The University of Michigan and Chevron summarized work on the robustness of HCCI operation with the range of commercially available E10 gasoline available in the US [81207]. Though the injected energy content per cycle was matched at the baseline point across the test fuel matrix, thermodynamic differences resulted in a spread of specific fuel consumption for the fuels tested with denser aromatic fuels providing better indicated specific fuel consumption. They were also able to minimize the relative impact of changes due to kinetics between fuels by varying intake temperature. However, very different levels of intake temperature and its variation over a range of loads were required in to cover the range of currently available fuel composition.

A number of papers considered different approaches such as EGR, residual gas, air and intake air temperature control strategies for combustion control. Argonne and Columbia University characterized the effect of EGR at high load operation with low cetane number fuels (gasoline) [81010]. They found that EGR does not have the same influence upon gasoline LTC as it does upon conventional diesel combustion, NOx production was more dependent upon intake oxygen concentration than upon intake air temperature and CO and HC production was more dependent upon intake air temperature than intake oxygen concentration.

The National Research Council of Canada examined the effect of dilution on emissions, combustion and fuel consumption at low-load with partially premixed combustion using different combinations of excess air and EGR [81236]. For a given level of charge dilution, there was an optimal EGR rate to minimize BSFC. NOx emissions decreased significantly as the proportion of dilution by EGR was increased, but CO and HC emissions increased.

The University of Michigan and the Czech Technical University studied how controlling combustion phasing with either internal residual gas or elevated intake temperature affects the phasing limitations of HCCI combustion in lean-burn gasoline HCCI [81127] while Hanyang University (Korea) examined the use of low intake air temperature as alternative to heavy EGR in for premixed compression ignition engines [81083].

Dual fuel operation that involves in-cylinder fuel blending of low and high reactivity fuels is a concept that was also discussed at this year's meeting. Mississippi State University and Caterpillar investigated a dual fuel (NG/diesel) LTC concept as a means to address the NOx/fuel consumption trade-off with conventional dual diesel combustion [81145]. The focus was on understanding the nature of cyclic combustion variations. The University of Windsor considered the used of port-injected ethanol/direct injected diesel to expand the load range [81067] while the University of Minnesota investigated effect of combustion phasing on efficiency in a strategy with gasoline fumigation and a diesel pilot [81106].

Considering the complexity of the control problem for advanced combustion, there is considerable interest in applying model-based control techniques. Argonne National Laboratory summarized the development of a low computational cost empirical ignition timing correlation that could be suitable for engine control applications with gasoline type fuels in kinetically-modulated combustion regimes [81079]. Politecnico di Torino discussed the assessment of a predictive zero-dimensional low-throughput combustion model for feed-forward control in DI diesels featuring LTC/PCCI and capable of estimating real-time heat release rate, in-cylinder pressure and temperature and NOx on the basis of a few estimated quantities [81094]. The University of Michigan and Bosch investigated cyclic variability of combustion phasing in a multi-cylinder, lean burn HCCI gasoline engine with the objective of improving model-based control [81107]. The Petroleum Institute (Abu Dhabi, UAE) presented a model based methodology for estimating engine cylinder pressure imbalance for combustion feedback control using the crankshaft speed sensor and a single in-cylinder pressure sensor [81110].

Conventional Combustion - Under the Conventional Combustion theme, an interesting paper was presented by the University of Bologna along with VM Motori on the combustion chamber redesign required to achieve a better interaction between flow field, fuel spray and bowl geometry in a 77 kW, two-valve diesel engine for Tier 4 off-road applications [81217]. The bulk of the work was carried out through CFD simulations. They achieved approximately 50% soot reduction while avoiding the need for NOx aftertreatment. In a more general sense, the study showed that a two-valve engine can provide axis-symmetric flow conditions similar to those provided by four-valve engines. It was also demonstrated that diesel engines working with a retarded fuel injection strategy should operate with a lower swirl ratio at IVC. The low swirl along with a properly matched fuel spray can provide a significant decrease of the raw soot emissions due better oxygen utilization for combustion and soot oxidation.

Other papers under this theme included one by the University of New South Wales on the effect of pilot injection timing and duration on diesel knock in a small bore optical engine [81023] and another by the University of Sussex on the effect of injection timing on the combustion process and emissions characteristics of a 2.0 L diesel engine [81137].

Several papers on fuel injection were also presented. CMT-Motores Termcos and GM summarized investigations into the effect of injection rate shaping on spray development with a prototype direct acting piezoelectric injector [81206]. Sandia, Argonne and CMT-Motores Termicos investigated oscillations in the observed rate of injection from hydraulic measurements on a common rail diesel fuel injector, to find their origin and determine their impact on flow at the outlet of the orifice [81223]. The Roma Tre University modeled the behavior of injector tip layout and the response of off-axis needle operation on small injection quantities [81120].

Combustion Feedback - Combustion feedback is an aspect of engine control that appears to be increasing in popularity. This can be important for not only controlling emissions but to meet customer requirements related to such aspects as noise, on-board diagnostics and fuel efficiency. However, one challenge is to identify a sufficiently low cost sensor that can be used to reliably and accurately provide the necessary

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combustion parameter required for the feedback signal and enable active combustion control. This year's conference included several papers exploring several different possibilities. Delphi, the University of Cambridge and the University of North Carolina at Charlotte examined two solutions to estimate in-cylinder pressure based on crankshaft position and instantaneous speed: a frequency-analysis based method and a dynamic-model-based method [81240]. The University of Bologna and Magneti Marelli presented a methodology for estimating combustion generated acoustic noise by processing the in-cylinder pressure signal [81203]. Wayne State University discussed the application of fuzzy logic control of diesel combustion phasing with an ion current signal/glow plug sensor that could offer a more economical option to direct pressure sensing or optical devices [81211]. Roma Tre University applied an accelerometer to characterize combustion development in a 2-cylinder multiple injection diesel engine. Block vibration can be used to locate the different combustion phases (start of combustion, start of the main combustion event and peak cylinder pressure location) in the crank-angle domain and to quantify in-cylinder pressure development [81235].

Locomotive Engines

A significant amount of development work is conducted in the locomotive engine industry, as manufacturers are finalizing their US EPA Tier 4 engine technology pathways. EMD presented an interesting investigation of the NOx reduction potential using dedicated cylinders as the source of EGR on a locomotive engine [81041]. The study was conducted for a 2-stroke EMD 16-710 engine using analytical modeling techniques. In the dedicated cylinder EGR concept, a group of cylinders is exhausted into a separate manifold. The exhaust gases from this manifold are cooled and routed into the inlet manifold, common to all cylinders, providing the EGR for the engine. Configurations with 3 and 4 dedicated EGR cylinders in the 16 cylinder engine were analyzed. The study showed that through the use of dedicated cylinders NOx could be reduced more than in conventional EGR, and that the system has the potential to meet Tier 4 emissions. Because the dedicated cylinders, while contributing to the engine power, do not contribute to tailpipe emissions, they can be designed and timed as if they were a different engine, with the focus on cylinder power. This could help minimize the decrease of engine power due to EGR.

GE analyzed the potential for improving engine efficiency by a combination of Miller cycle and turbocompounding [81159]. Four configurations were studied—with and without turbocompounding, each case with standard and with 40 degrees early IVC—using an engine simulation model. It was concluded that the BSFC effects of the two technologies were not additive (i.e., the combined effect was less than the sum of the BSFC effects when the processes were used separately). This is explained by the fact that both methods improve the expansion process in the engine cylinder and draw on essentially the same pool of energy.

Faced with commercial pressures, manufacturers were not specific which of the engine and aftertreatment technologies will find their way into the Tier 4, ultra-low emission locomotives that become mandatory in the United States from 2015. There are indications that manufacturers will offer more than one configuration, for example an EGR+DPF and SCR+DPF engine, and allow customers to choose their preferred technology approach.

Emissions & Aftertreatment

University of Michigan and Peaker Industries [81135] looked into the impact of injection timing on combustion and emissions on a 2-stroke locomotive engine fitted with an early development version of a Tier 0+ emission kit. NOx and PM emissions were measured, and PM samples were analyzed for 'fuel-like' (C9-C21) and 'oil-like' (C22-C30+) SOF. Retarding injection timing increased BSFC, decreased NOx, and increased PM. The increase in PM was found to be the net result of increased insolubles and fuel-like SOF, and decreased oil-like SOF. For the range of injection timings tested (notch 5 operating condition), the majority of PM mass was comprised of insolubles (81-89%), while the SOF accounted for a smaller fraction (11-19%) of total PM mass. This finding was in contradiction to PM emission analyses from 2-stroke locomotive engines in some earlier studies.

Two studies of retrofit aftertreatment systems for locomotives were presented by the SwRI. John Hedrick discussed a DPF screening test on a 1500 kW genset locomotive [81195]. Two DPF systems were tested, both utilizing catalyzed filters for passive regeneration (there are three independent gensets on the genset locomotive, engaged depending on the load requirements, so the load factor and exhaust temperatures on a genset are relatively high). Both DPF suppliers intend to pursue field demonstrations targeting California ARB verifications. The other paper [81157], presented by Dustin Osborne, talked about an SCR demonstration project on a long-haul locomotive. The demonstration was started in 2009 on five Union Pacific locomotives. The SCR system included a DOC and a vanadia-based SCR catalyst with a Grundfos urea system. One of the locomotives was tested, with the SCR system yielding 80% NOx reduction over the line-haul cycle and 59% reduction over the switch cycle.

MIT reported on their ongoing research on the characterization of ash in diesel particulate filters [81237]. This part of the study focused on the impact of lubricant additive chemistry on ash properties affecting DPF performance. Among many interesting conclusions, it was found that ash containing calcium compounds resulted in the greatest degree of exhaust flow restriction and highest filter pressure drop, relative to ash that did not contain calcium. Measurements of the pressure drop for ash loaded filters as a function of soot load showed a reduction in pressure drop, relative to the baseline filter with no ash, for the DPFs containing ash consisting only of Mg- and/or Zn-based compounds. On the other hand, an increase in pressure drop, relative to the baseline filter with no ash, was observed with increasing soot load for filters containing ash composed of Ca compounds. These effects may be related to the high packing density of Ca ash relative to Mg/Zn ash.

Large particles in diesel exhaust were studied by a team from the University of Michigan led by John Hoard [81232]. The experiments were conducted in an existing test rig for the evaluation of EGR cooler deposits, with special techniques developed to process microscope camera images to characterize the particles. While diesel particulates typically have sizes in the 10-200 nm range, the reported tests observed small numbers of particles with sizes on the order of tens of microns, with the largest particles on the order of several hundreds of microns. These particles probably originate from the re-entrainment of combustion chamber and exhaust system deposits. While not a health concern, they can affect intake and exhaust

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valve seating, EGR cooler fouling and EGR valve sealing.

An interesting aspect of emission measurement using portable emission measurement systems (PEMS) was reported by the Technical University of Prague [81168]. In engines operated extensively at low load, such as some locomotive engines, substantial amounts of solids and liquids accumulate inside the engine and in the exhaust system. These deposits are then driven-off during subsequent operation at high load. As a result, the emissions of particulate matter may be elevated for a rather long time, up to about one hour, which is longer than the duration of most field emission tests. Therefore, PM emissions measured during short tests may be significantly affected by the accumulated deposits and may depend on the engine operating history prior to the test. These conclusions were based on PEMS measurements of truck, tractor, construction equipment, marine and locomotive diesel engines with rated power from 130 to 1550 hp.

Other Topics

Engine technology trends such as dual turbocharging and the increasing focus on CO2 emissions make it increasingly more challenging to ensure exhaust temperature levels necessary for the light-off and operation of catalytic aftertreatment systems. FEV summarized the results of their experimental, multi-parameter study of exhaust temperature management in diesel engines [81003]. Experiments were carried out on a 4-cylinder, light-duty research engine with the FEV high efficient combustion system (HECS). Different engine hardware configurations and calibration strategies were evaluated for their impact on exhaust temperature, fuel consumption and emissions under both warm and cold start conditions. The most effective methods were late post-injection, exhaust cam-phasing and retarded main injection with intake air throttling. The latter strategy, however, produced a significant increase in CO/HC emissions.

The main components of cooled EGR system—the control valve and the cooler—were investigated in an in-depth numerical/experimental study by the Politecnico di Torino [81202]. Two shell-and-tube EGR coolers were tested on an engine dynamometer using a 1.6 liter, prototype GM Euro 6 engine at conditions relevant to the NEDC. The thermal effectiveness and pumping losses of the coolers were evaluated. An aging procedure conducted to characterize the deterioration of the thermal effectiveness and to verify whether clogging of the EGR cooler occurred. Another paper by the Politecnico di Torino discussed their research on hydrogen addition to CNG blends [81187], showing results with 0, 15% and 25% H2/NG fueling. For stoichiometric operation, BSFC reduction up to 7% was possible with H2 addition. Combustion was becoming unstable at lean air-to-fuel ratios.

Argonne reported on a preliminary modeling and experimental study with a heavy alcohol called phytol (C20H40O) [81169], which can be produced in large quantities by photosynthetic bacteria from sugar and other feedstocks. Several properties of phytol are similar to those of diesel fuel. The viscosity of phytol, however, is much higher than diesel, potentially requiring higher injection pressures. The study covered spray formation, combustion visualization using endoscopy, as well as nozzle flow and cavitation characteristics for phytol, diesel and phytol-diesel blends. It was concluded that low phytol blends up to some 5-10% result in little discernible differences compared to using diesel fuel. Higher phytol blends, above some 10-20%, influenced spray formation, combustion and increased emissions. ▶

WHAT'S INVOLVED IN CARBON CAPTURE AND SEQUESTRATION?

Issue: As fossil fuels, such as coal, oil and gas are processed and combusted, greenhouse gases, including CO_2, are emitted. While renewable and other low-carbon energy technologies will help to reduce CO_2 in the atmosphere, for the foreseeable future the utilization of fossil fuels will continue. Due to the economic value, convenience, and strategic value of fossil fuels, the use of fossil fuels will continue for the foreseeable future. Carbon Capture and Sequestration (CCS) technologies capture CO_2 before it is released into the atmosphere, and sequester (i.e., store) it underground in geological formations. CCS is a major engineering undertaking requiring substantial research, development, demonstration, and financial investment to support deployment at a scale that could significantly aid the reduction of CO_2 emissions to the atmosphere. On a global basis, anthropogenic1 Greenhouse Gases (GHG's) come from a variety of sources, as listed below with their respective contribution to CO_2 emissions [1].

Electric generation	41%
Transportation	22%
Manufacturing and construction	20%
Other	17%

Carbon capture and sequestration (CCS) involves the separation and compression of CO_2 from emissions streams, the transport of the CO_2 to a suitable storage site where it is injected into geologic formations, and the subsequent monitoring and verification of storage system integrity. Processes and component technologies for the compression and transport of CO_2 exist, although there is significant room for integration, improvement, and cost reduction of this process [12].

The capture of CO_2 is applicable to a variety of stationary energy and industrial processes including fossil fueled power generation, oil and chemical refining, natural gas processing, etc. CO_2 capture from power plants may be achieved by precombustion, post-combustion, or oxy-combustion technologies. Current capture technologies require considerable energy input to achieve meaningful levels of CO_2 capture.

Pre-combustion removal technologies typically require high-concentration of CO_2 associated with gasification systems [9]. Post-combustion technologies utilize a nitrogen-based solvent to scrub the CO_2 from the flue gas and require significant heat input to release the CO_2 and regenerate the solvent. This represents a significant reduction in overall plant efficiency and a substantial increase in cost compared to systems without CO_2 capture [2]. A third process, oxy combustion systems require expensive and energy intensive air separation units. There are also a variety of membrane based and other experimental systems that are in the development, stage with the potential for lower parasitic loads and overall costs.

Depending on the technology, these costs can be estimated as US \$30 to \$90/t CO_2 for a specific site and/or at a desired level of CO_2 purification. These estimates include the costs of capture purification & compression to 2,200 psi (\$20-\$80/t), transportation (\$1-\$10/t/100km), and storage (\$2-\$5/t). The associated increased energy cost is estimated at an additional 2-4 ¬¢/kWh

[10] [11] passed on to the consumer. From a 2012 NETL study of retrofit to existing coal fired Power plants for amine based CO_2 capture, the installation cost, taking into account the need for new NOx and SOx control of 347 plants, were from $6.50 to $23/t of CO_2. The parasitic load was about 210 kw/t of CO_2, and the cost of capture from $35 to $120/t. The mid point in the study was the design NETL Conesville plant at $65/t at an 85% Capacity Factor (CF) [13].

CO_2 capture from certain industrial processes such as ethylene production, gas processing, and coal liqufaction can be accomplished at a low cost because CO_2 separation is already a necessary part of these processes [6].

After the CO_2 has been captured and purified, it must be compressed, transported, and stored in suitable locations such as: depleted oil and natural gas fields, deep coal beds, saline formations, and salt domes. Studies have estimated that the U.S. (along with many parts of the world) has adequate geological storage to meet the expected volume of CO_2 from industrial and electric generation sites for many years. The petroleum industry has accumulated extensive experience with CO_2 transportation and injection for enhanced oil recovery and with demonstrations of geological sequestration of CO_2. This experience makes storage of CO_2 in underground geological formations the most likely near-term approach for CO_2 sequestration [7].

Transportation of CO_2 utilizing dedicated pipelines has the greatest potential toward delivering captured CO_2 to storage facilities. Although CO_2 is currently transported through pipelines for enhanced oil recovery, technical challenges remain to ensure safe and reliable transport [8]. Other methods (e.g., barges or ships) have also been suggested [3].

Numerous policy and regulatory issues related to the legal and financial liability, the environmental and other permitting requirements, and design and operating standards must be developed for all phases of CCS, including the large capital investments required. These requirements are needed, from capture to ultimate storage, to enable the timely and cost effective deployment of CCS technologies. These regulatory and policy issues are key barriers to additional pilot and full-scale implementation.

Summary

CCS technologies to remove CO_2 from combustion flue gases for long-term storage exist and are in use today; however, significant challenges remain. Integrated systems must be developed and demonstrated at scale and within the variety of industries and geologies that will be needed. The costs of installing and operating these technologies remains substantially higher than is currently considered acceptable and further technical improvements are needed to develop, demonstrate, and deploy CCS technologies at a lower cost.

While there appears to be adequate geological storage capacity to meet the projected of captured CO_2 for many years, advances in technologies and policy changes are needed before there can be wide-spread use of CCS.

ASME has recognized the need for successful CCS demonstration plants as a necessary step in assessing commercial viability and fully developing CCS technologies to address the challenge of meeting the growing energy demand with a reduced carbon footprint [4].

This public statement represents the views of the Energy Committee of Technical Communities of the ASME Knowledge and Community Sector. It does not necessarily represent the views of ASME as a whole. Energy Talking Point (ETP) papers are produced and reviewed by the Energy Committee to address fundamental questions that should be asked regarding the future of energy.

ASME, the American Society of Mechanical Engineers, is a nonprofit, worldwide educational and technical society representing more than 120,000 members in over 140 countries. It conducts one of the world's largest technical publishing operations, holds more than 30 technical conferences and 200 professional development courses each year, and sets some 500 industrial and manufacturing standards, many of which are considered to be global technical standards.

References

[1] IEA report, Paris, 2011

[2] "Research, Development, Demonstration and Deployment Issues in the Power Sector," Rising, B., in "Global Climate Change ‚Äì the Technology Challenge, F. Princiotta (ed.), Springer, New York (2011).

[3] "Prospects for Carbon Capture and Storage Technologies", S. Anderson, R. Newell, January 2003

[4] "ASME General Position Statement on Technology and Policy Recommendations and Goals for Reducing Carbon Dioxide in the energy sector", April 2009

[5] http://www.eia.gov/oiaf/ieo/wcde.html

[6] Carnegie Mellon Study (CCSReg_12_28.pdf)

[7] "CO2 storage in geological media: Role, means, status and barriers to deployment," Bachu, S., Progress in Energy and Combustion Science, 34, 254-273 (2008).

[8] "Carbon Dioxide Pipelines: A Preliminary Review of Design and Risks," Barrie, J., et al., in 7th International Conference on Greenhouse Gas Technologies, Vol. 1, E.S. Rubin et al. (eds.), IEA Greenhouse Gas Programme, Cheltenham, UK (2004).

[9] http://www.ipcc.ch/pdf/special-reports/srccs/srccs_chapter3.pdf

[10] http://www.iea.org/speech/2009/Kerr_NCCSA.pdf

[11] SFA Pacific, Inc. report, referenced by U.S. Dept. of Energy at http://www.fossil.energy.gov/programs/sequestration/capture/

[12] IPCC, 2005. IPCC special report on carbon dioxide capture and storage, in: Metz, B., Davidson, O.,de Coninck, H.,Loos,M.,Meyer,L.(Eds.), Cambridge University Press for the Intergovernmental Panel on Climate Change, Cambridge.

[13] http://www.netl.doe.gov/energy analyses/refshelf/PubDetails.aspx?Action=View&Source= Main&PubId=289

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