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CCRC Clean Combustion Research Center

CONTENTS

CREDITS

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Tribute to Prof. Suk Ho Chung

In 2009, Professor Suk Ho Chung was nominated to the post of Director of the Clean Combustion Research Center (CCRC) at King Abdullah University of Science and Technology (KAUST). His mission was to build a world class laboratory that would have a major impact on one of mankind's greatest challenges: How to offer energy for all, in a clean and protected environment. After more than three decades of research in Korea and the U.S., Prof. Chung took just two years to build the world's most state-of-the-art combustion laboratory in Saudi Arabia. From advanced optical diagnostic systems to next generation optical engines, fundamental canonical models and pioneering combustion equipment, he offered the perfect environment for scientific research at CCRC. Since it opened, the properties of new fuels, behavior of high-pressure and high Reynolds flames, and new combustion concepts like plasma-assisted combustion and argon engines, have been investigated daily by the 120 researchers and students of the CCRC.

In parallel to his position as a director, Prof. Chung's impact in the areas of fundamental combustion, electrical-enhanced flames, flame structure, soot and NOx formation, low gravity flames, and alternative fuels, has been equally impressive. His dedication to teaching and transmission of knowledge has added many young scientists to the world of industrial and academic research. With more than 160 papers published, several prestigious awards, and universal recognition in the combustion community, Prof. Chung's contributions to combustion science has been of major importance.

In September of 2016, after seven years as a named Professor of Mechanical Engineering, and five years as the Founding Director of the CCRC, Professor Chung has retired. His vision of research in combustion science and his association with the Center have been invaluable and will have a long term impact. He has our sincerest gratitude for what he has built, what he discovered, and what he gave.

Yu Wang, Professor at Wuhan University of Technology, China:
"Prof. Chung was a most responsive and supportive advisor during my Ph.D. studies. He stopped at my desk almost daily to inquire about my research, offering valuable and creative suggestions for finding patterns and understanding the mechanisms behind the data I collected. From his example, I learned the satisfaction of sifting through the data surface to the core of scientific discoveries, a gift that I now share with my own students.

"Prof. Chung has always been supportive of his students' ideas and generous with his own experience. His knowledge and empathy generated our eagerness to discover and share new ideas. He is a cherished friend who made working under his supervision a true joy. I am proud and grateful to have been his student."

Suk Ho Chung: "It was a lifetime opportunity to build a new combustion center, with the full support of KAUST. I was, of course, pleased and excited, and the responsibility to establish a successful center was enormous. My objective was to create a world-leading combustion research organization by combining experimental, computational and kinetics expertise. Special focus would center on petroleum fuels, in consideration of the Kingdom's resources. It's my belief that with excellent lab facilities and the right combination of various specialties and human resources, CCRC will soon be a leader in combustion research."

Min Suk Cha, Associate Professor at KAUST, Saudi Arabia:
"It was an exciting moment for members of the Korean Combustion Society when Prof. Chung announced his invitation to build the Clean Combustion Research Center at KAUST from the ground up. I assisted him in setting up LFO 43A, and for almost two years, we worked hard to get it up and running, commissioning nearly 20 laser systems and more than 3000 items.

"Under his calm and quiet leadership, the CCRC has become one of the best organized and operated research centers in the world. His resolution to open all facilities to all CCRC members has been the seed for sharing and growing the spirit of CCRC. Thanks to his devotion and efforts, the Center feels like a family with synergistic chemistry and good harmony."

FUELCOM: A Long Lasting and Productive Collaboration

Saudi Aramco is the world's largest fossil fuel provider and CCRC's chief industrial partner since the Center began. In 2013, KAUST and Saudi Aramco joined to establish the FUELCOM program; its objective was to develop a long-term collaborative research program between the Saudi Aramco Fuel Technology team and the Clean Combustion Research Center to enable simulation-based fuel designs. The program has two basic aims:

FUELCOM-I: First Principle Based Fuel Characterization

FUELCOM-II: Fuel Design for Advanced Engines

FUELCOM-I: A successful start to a long-lasting collaboration

Conventionally, fuels are rated on a few empirical parameters, such as research octane number (RON), motor octane number (MON), derived cetane number (DCN), flash point and boiling range. However, fundamental and first-principle based fuel characterizations, such as ignition delay time, laminar and turbulent flame speed, and elementary reaction rates, can also enable high-fidelity predictive engine simulations. The FUELCOM-I program aims to provide such characterizations for conventional and unconventional fuels to aid in the design of future fuel formulations.

Figure 1: The Dual-apposed Piston Rapid Compression Machine facility in the Chemical Kinetics and Laser Sensors Laboratory at KAUST

FUELCOM-I was initiated in January 2013 as a four-year project, divided into three sub-projects with strong interplay and cross-collaboration. The first project focuses on physical processes of autoignition that may affect the ignition process in real internal combustion devices. These include compositional and temperature inhomogeneity, heat loss and flow field effects, high pressure combustion and sprays. Thus they allow detailed study of the interaction between chemical kinetics, convection, evaporation, and diffusion processes. Its sub-project examines the chemical kinetics of autoignition, the goal being a variety of fundamental chemical kinetic experiments that will aid in the development of chemical kinetic models and gain a better understanding of fundamental kinetic processes occurring during autoignition of various fuels. This task is achieved by coupling computational simulations with chemical kinetic experiments.

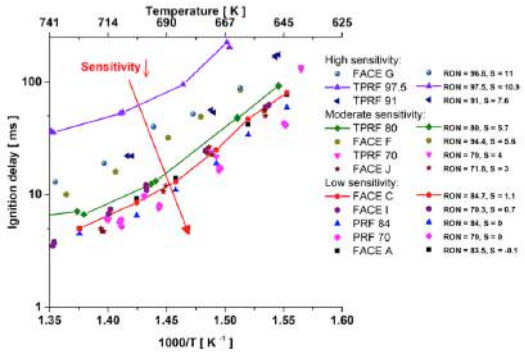

Figure 2: Low temperature octane number dependence on ignition delay times. Octane dependence is pronounced for high sensitivity fuels

The final project in the FUELCOM-I program is the study of flame speeds of real fuels; the ultimate goal is to find appropriate surrogate mixtures, matching as many properties of the real gasoline, diesel or jet fuel as possible--in particular laminar flame burning characteristics. The main goal of FUELCOM-I was to create a surrogate formulation strategy to emulate the physical and chemical characteristics of gasoline fuels, which was successfully achieved by the development of the Fuel Design Tool (available online at Cloudflame). Another important milestone achieved in FUELCOM-I has been the development of the AramcoMech kinetic mechanism.

This research has yielded 100 publications in high impact journals, establishing the CCRC as a major research institution in the combustion and energy community and triggering a successful start for a long-lasting collaboration with Saudi Aramco.

FUELCOM-II: An extension to fuel new horizons

Equipped with the right databases and facilities for fuel characterization and formulations from FUELCOM-I, the logical next step for the KAUST-Aramco collaborative effort is to convert this knowledge-based capability into a blueprint for the next generation of energy conversion tools--particularly engines. This philosophy is the spearhead of the FUELCOM-II program.

The FUELCOM-II project officially launched in January 2016 and will run over three years. The objective of this ambitious project is to develop advanced visualization and computational diagnostics for the development of new fuel formulations, matching with innovative internal combustion engine technologies. The co-optimization of fuels and engines is approached through three major tasks. First, a comprehensive study of spray mixing and combustion development in gasoline compression ignition engines will be conducted in a specifically-designed, optically accessible combustion vessel and optical internal combustion engine. The second and third branches of FUELCOM-II center around the study of complexities and instabilities in real engines, such as pre-ignition and super-knock. These issues are approached through experimental devices and high fidelity simulations.

After the achievement of FUELCOM-I goals, Aramco-KAUST collaborative efforts are expected to reach milestones in FUELCOM-II that will further demonstrate the potential of academic research projects driven by industrial partners to reach significant goals. This information, and more details about the KAUST-Aramco collaboration will be available in an informative, user friendly website, an internal preview of which can be accessed at: https://ccrc.kaust.edu.sa/Pages/aramco.aspx.

CCRC Ph.D Graduates

Since the establishment of CCRC in KAUST there have been many outstanding graduates who continue to have an impact in academia and industry. The following students graduated during the past year (Sept. 2015-Oct. 2016).

From Professor Fabrizio Bisetti's Group:

Amjad Al-Shaarawi, Ph.D.

Dissertation: Interaction of Microphysical Aerosol Processes with Hydrodynamics Mixing
Currently Research Scientist at ARAMCO, KSA

Amjad's studies focused on the interaction between condensing aerosol dynamics and hydrodynamic mixing, in which aerosol particles form (nucleate) by mixing a saturated vapor stream with a cold vapor stream. His results showed the maximum number density of condensing drops that behaved differently under various mixing rates (nucleation regime and consumption regime) and vapor scavenging, proving that the aerosol phase is key to transition between these regimes.

From Professor Min Suk Cha's Group:

Daegeun Park, Ph.D.

Dissertation: Nonpremixed Flame in a Counterflow Under Electric Fields
Currently postdoc at CCRC, KAUST

From Professor Suk Ho Chung's Group:

Yu Wang, Ph.D.

Dissertation: Sooting Characteristics and Modeling in Counterflow Diffusion Flames
Currently Professor at Wuhan University, China

Yu focused on experimental and numerical approaches to soot formation in laminar counterflow diffusion flames. He built a model describing soot inception and surface growth for the study of fuel mixing effects. He also used laser light extinction/scattering and laser induced fluorescence techniques to study the effects of strain rates on soot and PAH formation in counterflow diffusion flames, as well as the effects of CO2 addition.

Mohamed A. Ismail, Ph.D.

Dissertation: Combustion Synthesis of Nanomaterials Using Various Flame Configurations
Currently Assistant Professor at Zagazig Univ, Egypt

Yuan Xiong, Ph.D.

Dissertation: Effects of AC Electric Field on Small Laminar Nonpremixed Flames
Currently a postdoc at the Swiss Federal Institute of Technology in Zurich, Switzerland

Saeed Al-Noman, Ph.D.

Dissertation: Experiment and Simulation of Autoignition in Jet Flames and its Relevance to Flame Stabilization and Structure
Currently Research Engineer at Saudi Electric Cie, KSA

From Professor Aamir Farooq's Group:

Awad Alquaity, Ph.D.

Dissertation: Laser and Mass Spectrometric Measurements of Combustion Species
Currently a postdoc at KFUPM, Dhahran KSA

Awad worked on developing sensitive mid-IR laser sensor and mass spectrometric measurements of combustion species for shock tube and flame experiments. He also researched a fast time response time-of-flight mass spectrometer to determine time resolved species concentrations. Using this tool, reaction kinetics were determined for the decomposition of 1,3,5-trioxane.

Bilal Sajid, Ph.D.

Dissertation: Applications of a Mid-IR Quantum Cascade Laser in Gas Sensing Research
Currently Assist. Prof. at GIK Institute, Pakistan

Tamour Javed, Ph.D.

Dissertation: Combustion Kinetic Studies of Gasolines and Surrogates

From Professor William Robert's Group:

Myles Bohon, Ph.D.

Dissertation: Experimental and Kinetic Investigation of the Influence of OH Groups on NOX Formation
Currently a postdoc at Technische Universität Berlin

For his Ph.D. research, Myles focused on the chemistry and reaction kinetics of NOX formation. He observed that there is a reduction in NO formation in the presence of OH groups. Miles is currently working on the development of rotating detonation engines in relation to power generation and the mixing characteristics of coherent flow structures to develop improved injection strategies.

Scott Steinmetz, Ph.D.

Dissertation:Investigation of Laminar Coflow Diffusion Flames at Elevated Pressures

An Interview with Professor Bengt Johansson

Professor Bengt Johansson joined KAUST in January 2016 from Lund University, where he obtained his Ph.D. degree in 1995 in combustion engines. Immediately after receiving his Ph.D., he was appointed Assistant Professor. In 2003 he became Director of the Center of Competence Combustion Processes (KCFP) and Head of the Division of Combustion Engines in 2004, the position he held until joining KAUST. Prof. Johansson is world-renowned for his engine research, especially for HCCI and PPC engine modes.

Bengt recalls his first attempt and subsequent failure to tune a motorbike at the age of 15, and the question that arose years later, during his Ph.D. defense, about the prevention of chaotic early flame development in SI engines. The question, and the motorbike memory, lead him to his famous works on HCCI engines. To capture the attention of his doubtful colleagues, he presented his early work on HCCI engines during their coffee breaks. "I had to show them a factor of 1000 decrease in NOx emissions to convince them." From that unlikely stage he was introduced to dozens of industrial projects on HCCI engines. Prof. Johansson is now the most highly cited HCCI engine researcher in the world.

He has a long track record of working closely with the automotive industry; his explanation for this success is simple: "Industrial research...must solve their problems. Getting the first project is relatively easy--to get the second one you have to show results of use to the consumer/sponsor."

Dr. Johansson visited KAUST in January 2009, when it was still a construction site, visiting the CCRC buildings in a 4WD jeep. At that time, personal and professional commitments prevented him from joining KAUST. He jokes that "in hindsight I'm grateful to Sukho for doing all the hard work." Since becoming part of the team, he designed an ambitious plan to make KAUST a leader in engine research by installing 11 engine test cells and dedicating two or three of these to high-efficiency thermodynamic cycles--around six cells for PPC work--the remainder to conventional engines for fuel testing and rating work, which are important for synergy with Aramco's interests. He also plans to bring in a 20 cm bore, 10 ton Wärtsilä engine to study large engines for marine and power generation applications.

Bendt speaks candidly about his work on "the most efficient eight stroke engine," and he's targeting around 60% brake efficiency for such a concept. "The idea was always there; nearly all modern engines operate with a low-pressure unit referred to as a 'turbo'," he says; "but in this case, instead of 1-2 bars, the boost pressures will be 15-20 bars." The eight stroke engine is about basic thermodynamics, by splitting the process in two: a large engine designed for low-pressure feeds a small engine for high-pressure operation. The low-pressure engine has low friction, so expansion occurs there. Depending on the layout of this system, it can be used for both light and heavy duty applications. Prof. Johansson has already developed this concept for heavy duty applications with Volvo trucks.

He is currently working to establish collaboration between KAUST and industrial automotive companies: "A stronger collaboration with one major truck and car company will develop a much stronger relationship than collaborating with several companies and conflicting business interests." Industrial collaborations also depend on the success with which their practical problems are solved. "My aim is to demonstrate that KAUST can produce high quality combustion engine research that is the equal—or better--than any group in the world."

Prof. Johansson feels strongly about environmental responsibility and combustion-related effects; his research is at the forefront of mitigating climate change: "First, increase efficiency in conventional engines by introducing new strategies; second utilize new energy carriers by using environmentally friendly methods of creating fuel through CO2 neutral sources." He is currently working on sun fuels, which utilize photovoltaic electricity to synthesize what will probably be alcohol fuels.

Bengt advises his students and researchers to approach problems with an open mind, "the doorway to discovery, where there is always room for improvement."

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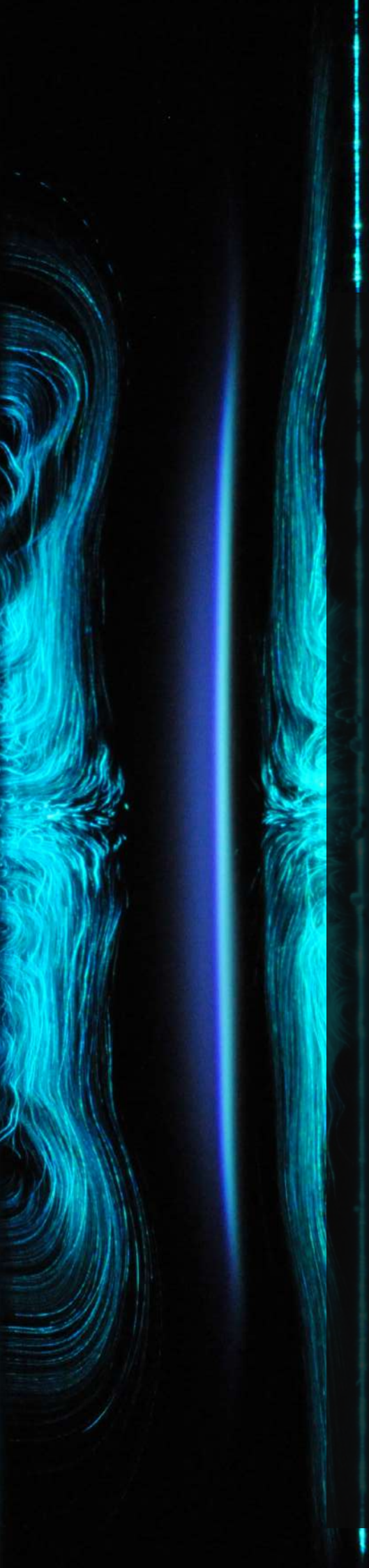

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CLEAN COMBUSTION RESEARCH CENTER

KAUST RESEARCH CONFERENCE:
NEW COMBUSTION CONCEPTS

6-8, March 2017

King Abdullah University of Science and Technology (KAUST)
Thuwal, Saudi Arabia

Delegates from academia, government laboratories and industry are invited to attend the 2017 conference on New Combustion Concepts hosted and organized by the Clean Combustion Research Center (CCRC) at KAUST.

Scope

The conference will be organized around five topical areas:

- Plasma assisted combustion
- Electrically assisted combustion
- Advanced engine combustion
- Novel engine combustion
- New combustion technology

It will bring together leading experts from academia, national laboratories, and industry to promote international collaborations in establishing the research and development direction for diverse new ideas towards clean and efficient combustion systems.

Objectives

- Organize and stimulate an open and informative discussion around the research issues connected with new combustion concepts and leverage "lessons-learnt" from experts in the field with past record of success.
- To foster collaborations and interactions between CCRC and the global research community.

Technical Program

The conference will feature a poster session, five keynote lectures and twenty invited contributions from renowned experts in academia and industry. Over 125 participants are expected.

Invited Speakers include:

- Igor Adamovich, Ohio State University, USA
- Choongsik Bae, KAIST, Korea
- Anne Bourdon, Laboratoire de Physique des Plasmas, France
- Ingemar Denbratt, Chalmers , Sweden
- Derek Dunn-Rankin, University of California Irvine, USA
- Wayne Eckele, Cummins, USA
- Yiguang Ju, Princeton University, USA
- Hyun-Ha Kim, AIST, Japan
- Shuji Kimura, Nissan, Japan
- Lucien Koopmans, Volvo Cars and Chalmers Univ., Sweden
- Tonghun Lee, University Illinois Urbana-Champaign, USA
- Staffan Lundgren, Volvo Trucks, Sweden
- Oliver Paschereit, TU Berlin, Germany
- Paul Ronney, University of Southern California, USA
- Mark Sellnau, Delphi, USA
- Joseph Shepherd, Caltech, USA
- Svetlana Starikovskaya, Laboratoire de Physique des Plasmas, France
- Noboru Uchida, A. C. E. Institute, Japan
- Robert Wagner, ORNL, USA

Travel Fellowships

Travel fellowships for students and postdoctoral researchers will be awarded on the basis of merit. Fellowships cover all costs associated with attending the workshop including airfares and accommodation. The deadline for fellowship application is Dec 1, 2016.

Online

Information on the workshop agenda and registration is available at https://ccrc.kaust.edu.sa/Pages/krcncc.aspx
Visit ccrc.kaust.edu.sa for information about the CCRC
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Facebook: https://www.facebook.com/CombustionatKAUST
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