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KAUST
SUMMER 2017

CCRC Clean Combustion Research Center

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Towards Cleaner Combustion

The 2017 KAUST research conference, "New Combustion Concepts" (March 6-8) included Saudi Arabian and international experts from academia, national laboratories and industry, to consider new theories in combustion. The three-day conference focused on new approaches to cleaner combustion in the next generation of industrial devices. Twenty experts shared recent progress in electrically-assisted combustion, unique advances in internal combustion engines and new combustion concepts, such as steam gas turbines. Young researchers were major contributors to this event, with a stimulating poster session that included over 60 international students and post-docs, presenting their research.

For engine applications, development of high-pressure volumetric non-equilibrium plasma discharges is the key," he added.

Dr. Anne Bourdon, from Ecole Polytechnique, presented her team's recent work on modeling and simulation of the influence of fuel on nanosecond discharge structure in different fuel/air mixtures.

With yet another approach, U.C. Irvine's Prof. Derek Dunn-Rankin presented recent challenges for three new combustion concepts--the electrical aspects of flames, burning methane hydrates, and miniature combustors.

Igor Adamovich

Yiguang Ju

Anne Bourdon

Derek Dunn-Rankin

Progress in electrically-assisted combustion

Prof. Igor Adamovich, from the Department of Mechanical and Aerospace Engineering at Ohio State University, discussed energy conversion in transient molecular plasmas at high specific loading. "We want to find the mechanisms behind energy conversion. When it comes to electron detection and electron temperature measurements, measurements in a flame are more challenging," Adamovich said.

The challenges in understanding plasma-assisted combustion have also been noted by Princeton Prof. Yiguang Ju, who discussed the kinetic effects of plasma on ignition and flame stabilization. "Plasma can enhance combustion, particularly at low temperatures—there is magic in plasma-assisted combustion applications. It seems that plasma really works, and works efficiently; and coupling plasma with combustion enhances the ignition process," Prof. Ju explained.

"Plasma can break down the ignition limits. It is extremely effective in activating low-temperature chemistry and enabling cool flames. Plasma directly enhances ignition and reduces minimum-ignition energy.

"When we try to make a hydrate, it doesn't form sweetly. You never know what you'll get. It takes eight to twenty hours to get a hydrate—a typical nucleation frustration problem," Dunn-Rankin said.

The next generation of engines

In his conference address, Dr. Lucien Koopmans, from Volvo and Chalmers University in Sweden, discussed the Euro seven-diesel emission system and low cooling loss combustion (LCLC) and posed the question of whether the internal combustion engine will eventually be replaced by electric motors.

"There are too many hurdles for electrical vehicles right now. Electric cars are expensive in Europe--around €76,000, compared to a combustion engine vehicle at €58,000--so there must be some combustion in the future—but the technological solution must also be made available," he said.

Saudi Aramco's Dr. Junseok Chang highlighted the importance of the next generation of fuels. "The next generation of engines will not burn fuel from the past; they will require a new generation of fuels to tackle the problems of pollutant and carbon dioxide emissions," he explained.


Lucien Koopmans


Junseok Chang


Oliver Paschereit


Jason Damazo

Prof. Oliver Paschereit, from TU Berlin, showed how dilution by water steam could improve the efficiency of the next generation of gas turbines. "If you want to increase the efficiency of gas turbines by 20 or 40%, it will not be by changing the design of the engine. The current gas turbines are already very well optimized. There is a need for new combustion strategies--and adding water steam to the combustion process is one of them," he concluded.

In his presentation "High-flying combustion: Keeping airplanes safe," Jason Damazo, from The Boeing Company, described the crucial role of combustion in air travel and transport in the 21st century. "Airplanes have a very impressive track record and they're also built to survive crashes. In fuel system development, many systems have gone into making planes safe. If a new technology can make planes safer, that really resonates. Developing a quantitative interest in safety is both fun and difficult," he said.

Director of CCRC, Prof. William Roberts summarized the conference as "an experiment that brought together two research communities who don't ordinarily overlap. I think it was remarkably successful in generating conversations and potential collaborations."


The sunset dinner at Al Marsa Restaurant

CCRC lab tour


Poster session

New CCRC Faculty

The CCRC gained two new Assistant Professors in Fall 2016, Deanna Lacoste and Gaetano Magnotti. They will expand the CCRC's research capabilities into new areas, including advanced laser diagnostics and new combustion concepts. We look forward to growth in these research disciplines, which are critical to the overall vision and mission of the Center.

Deanna Lacoste

Dr. Deanna Lacoste

Dr. Deanna Lacoste became acquainted with the research program at CCRC during a conference on plasma assisted combustion in France, where she met Prof. Sukho Chung, CCRC's Founding Director. She was with the Ecole Centrale in Paris at the time, and recalls, "I was looking for new challenges and opportunities in research. I was very impressed by Prof. Chung's description of the work being done at KAUST, and I applied to join the program."

"It's exciting to be part of something new and to watch it grow, working with the talented and receptive group at CCRC to achieve scientific excellence," said Dr. Lacoste. Her goal is to develop plasma-assisted combustion technologies so that practical combustors can be operated with greater efficiency and lower emissions. "We can use plasmas to overcome many combustion challenges, like flame anchoring, fuel reactivity modulation, and elimination combustion noise and instability."

A unique aspect of Dr. Lacoste's research is the use of nano-second repetitive-pulsed discharge plasmas--essentially cold plasmas that consume little energy. "We can pulse plasmas at a frequency of 10-100 kHz, orders of magnitudes faster than the frequency of flame instabilities," she says. Such a high repetition rate device, that can alter the physical and chemical state of a gas, makes it possible to improve combustion processes. "For example, pulse detonation engines have faced many practical challenges, but with plasmas we're exploring the possibility of stabilizing detonations so that these high efficiency engines can be realized."

Dr. Lacoste is leading the development of strong research collaboration between Boeing and the CCRC. "Boeing is concerned with static charge buildup on polymer composites, which is a safety concern. We're performing fundamental experiments, using plasmas to understand the ignitability of dielectric materials, and helping Boeing design safer aircraft." In addition to plasma research, Dr. Lacoste has a strong background in experimental studies of flame phenomenon. She is also working with Boeing to develop flame arrestors to quench flames propagating in a channel.

"I enjoy the details of applied problems; I start by investigating fundamental aspects, and try to make simple models that are efficient for industrial design processes," says Lacoste. Her research is inherently multidisciplinary in order to solve a variety of problems. "We're building a team of individuals who work hard and are passionate about that work; these are the drivers for discovery." With new research avenues and industrial partnerships, we look forward to having Dr. Lacoste and her team take the CCRC to new frontiers.

Gaetano Magnotti

Dr. Gaetano Magnotti

Dr. Gaetano Magnotti recalls the technical challenges he faced preparing his Ph.D. in Aerospace Engineering at NASA Langley. "I was developing new laser diagnostics to study scramjet combustors; the learning curve was steep, but the end result was extremely rewarding." After several years at Sandia National Lab in California, exploring turbulent jet flames with lasers, Dr. Magnotti brought this passion for problem solving to the CCRC. He says, "CCRC encourages collaborations; the dedication and quality of its students, its environment of research freedom, and the University's resources--comparable to any national lab- are part of what drew me to KAUST".

Dr. Magnotti's work will focus on the development of novel laser diagnostics to investigate combustion processes in extreme environments. Future combustion technologies will target higher pressure and leaner combustion regimes to reduce emissions and increase efficiency. However, challenges from air/fuel mixing, flame stabilization, and heat release control inhibit combustion under such conditions. "My goal is to utilize interaction between light and matter to visualize the combustion process and improve combustor design," he says.

The problems posed by laser diagnostics in high pressure environments make it unapproachable to many. "There are more collisions between molecules at high pressures, making it difficult to study using lasers; I use new, ultra-fast laser technologies to probe light-matter interactions before collisions occur." Modern gas turbine engines at high pressures may also produce more soot and particulate emissions, so Dr. Magnotti is developing new optical techniques to study optically dense sooting flames.

The CCRC focuses on advanced internal combustion engines, and Dr. Magnotti is collaborating with engine researchers to apply laser diagnostics in optical engines. "We need to visualize mixture fraction stratification in these modern engines. My team is combining pulse-burst lasers, capable of firing 1000 pulses in just 10 ms, and ultra-high-speed cameras for measuring the evolution of mixture fraction distribution and concentrations of major combustion intermediates within a single engine cycle."

Combustion has been the impetus for laser technology development for the past 40 years, but many improvements are still required. Dr. Magnotti's lab will push technology development with high speed, high powered lasers to probe combustion processes in new environments. "I'm looking for students and researchers who are not afraid of challenge; when we overcome them, the opportunities for exploration and discovery are boundless," he says.

HFO: From Poor Fuel Quality to Clean Combustion

The HFO lab

The Clean Combustion Research Center [CCRC] and the Saudi Electricity Company [SEC, the national electricity generation corporation of the Kingdom of Saudi Arabia] have joined in a collaborative research agreement aimed at improving the efficiency of SEC's power generation units while reducing carbon and sulfur emissions. The SEC utilizes diverse technologies to generate electricity in their power plants, many of which are powered by heavy fuel oil [HFO] steam boilers. HFO (also known as heavy oil, marine fuel or furnace oil) represents a fraction of the fuel obtained from petroleum distillation, either as a distillate or a residue from various petroleum refineries in the Kingdom; thus, HFO is a cheap and abundant source for electricity generation.

Abdulrahman A. Alkhateeb

HFO is a poor quality, distinctively dense and viscous fuel with high asphaltene content, making it difficult to vaporize and inhibiting the combustion process and mixture formation. In addition, HFO has high sulphur and inorganics content that result in sulfur dioxide and particulate emissions, which are severely detrimental to the environment. To approach these challenges, SEC and CCRC have designed a methodology to prepare emulsion of desulfurized HFO and water to be used as fuel. The project will also study the effect of different percentages of asphaltenes of HFO on combustion behavior; this will help reduce overall specific fuel consumption while maintaining the heat rate and assuring a consistent rate of energy generation, improving HFO quality, higher plant efficiency and clean combustion.

Eid Barakati

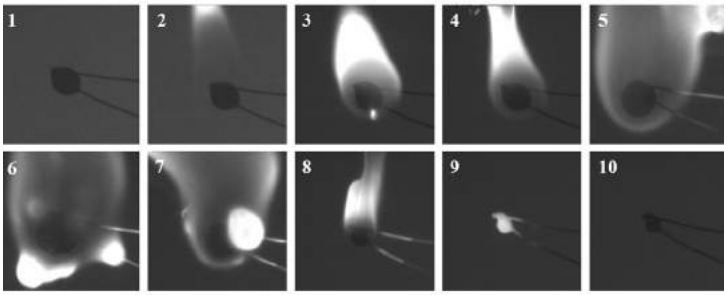
At the CCRC, three fundamental experiments examine the effects of emulsification on various aspects of combustion:

1. Swirling flames: This experiment aids in understanding spray behavior and subsequent droplet breakup and the effects of further emulsification on these parameters.
2. Suspended droplets: Holds an HFO droplet on a pair of fine thermocouples to study ignition and combustion behavior of droplets generated from spray.
3. Falling droplets: Studies and mitigates the formation of pollutants--especially particulate matter and cenosphere morphology--generated from HFO combustion.

At present, the level of H2O emulsification attained is 6%, and researchers are systematically reaching the targeted 25%. The results of these two-year investigations will be directly applicable to SEC power plants, with improved cost, environment and efficiency.

Eid Barakati, SEC's Power Generation Specialist, with more than 20 years at SEC, is currently working with CCRC researchers on the HFO collaborative project:

"CCRC at KAUST is a world-leading combustion research center with world class lab facilities and outstanding scientists. With the cooperative efforts of SEC power generation experts and CCRC researchers, I believe that this joint research will soon yield results that will enhance SEC's power generation efficiency across the Kingdom with lower production costs and carbon emissions."



Combustion of HFO suspended droplet

CCRC MS Students 2017

Abdullah Al Omier
Adviser: Prof. Mani Sarathy
Title: "Ozone Activated Cool Diffusion Flames of Butane Isomers in a Counterflow Facility"
Abdullah designed and built a fundamental counterflow experiment for cool flame studies, to better understand low-temperature reactivity and cool flame properties of butane isomers under atmospheric pressure conditions. The ignition and extinction limits of butane isomers' cool flames have been investigated under a variety of strain rates.

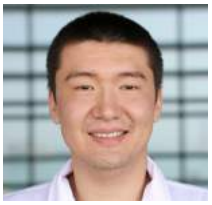
Aibolat Dyuisenakhmetov
Adviser: Prof. Robert Dibble
Title: "Feasibility Study on Supercritical Methane Recuperated Brayton Cycle for Waste Heat Recovery"
Aibolat evaluated the performance of methane compared to carbon dioxide in a recuperated Brayton cycle for waste heat recovery.

Bayan Wasfi
Adviser: Prof. Robert Dibble
Title: "Cetane Number of Biodiesel from Karaya Oil"
The focus of Bayan's work is experimental transesterification of karaya oil using a batch reactor in subcritical methanol conditions, and its comparison with biodiesel derived from karaya oil. IQT was used to determine the DCN's of these fuels. Viscosity, density, flash point and heat of combustion of these fuels were also measured.

Jui-Yang Wang
Adviser: Prof. Mani Sarathy
Title: "Experimental and Modeling Study of Ethyl Levulinate in a Jet-stirred Reactor"
Jui-Yang designed, built and validated the jet-stirred reactor (JSR) using n-heptane, iso-octane oxidation, and cyclohexene pyrolysis as benchmarks. Oxidation of ethyl levulinate was conducted in the JSR under a wide range of conditions, and a chemical kinetic model was developed.

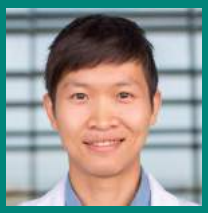
Maya Alhashem
Adviser: Prof. Robert Dibble
Title: "Optimization of Paper Discoloration via Pyrolysis Using Lasers for Inkless Monochrome Printing"
Maya's thesis focused on the use of laser-induced pyrolysis in decomposition reaction of standard copy paper, which is mostly comprised of cellulose.

Muhamad Firdaus Bin Hamzah
Adviser: Prof. Mani Sarathy
Title: "Characteristics of Butanol Isomers Oxidation in a Micro Flow Reactor"
Firdaus investigated the ignition characteristics of air mixtures with n-butanol, 2-butanol and iso-butanol at stoichiometric and lean conditions, and pressures of 1 atm and 5 atm, in a micro flow reactor.



Nurzhan Mukhadiyev
Adviser: Prof. Hong Im
Title: "Computational Enhancements for Direct Numerical Simulations of Statistically Stationary Turbulent Premixed Flames"
Nurzhan's work focused on the development of KAUST's adaptive reacting flow solver (KARFS) for a high order compressible reacting flow solver using detailed chemical kinetics, and on numerical tools for direct numerical simulations of planar premixed flames such as linear turbulence forcing and dynamic inlet control. He also investigated the implementation of pseudo-spectral methods into KARFS.

CCRC Interns 2017



Frank Hong
National Taiwan University of Science and Technology, Taiwan
Project: Biodiesel from insect oil.
"One of the best things about the Clean Combustion Center is that there is always someone to talk to and to discuss your ideas with. Brainstorming can happen anywhere."

Vincent van Oudenhoven
University of Waterloo, Canada
Project: Machine learning models to predict combustion phenomena.
"The environment at CCRC offers me the freedom to find the work that I am truly interested in, and to excel at it. At the same time, everyone I work with is ready to help, and genuinely interested in what I am doing."

Paolo Guida
Politecnico di Milano, Italy
Project: Heavy Fuel Oil Combustion
"The environment, and people from all over the world make an exciting atmosphere. You can find an expert in any research field, and when you need help, there is always someone to ask. I am free to follow my intuition and my personal research goals. To express your own ideas and to be able to follow them is a very different experience from European schools."

Andrea Secco
University of Bologna, Italy
Project: Using TOF-MBMS in counterflow setup
"One of the things I enjoy most about the CCRC is its connection with so many other universities that work on combustion."

Roman Kashtanov
University of Bundeswehr, Germany
Project: Postprocessing data using Shaheen
"Everyone here is open to questions and takes the time to help you. People are interested in your progress and you have a rare opportunity to experience Saudi Arabia and to travel to neighboring countries."

Tony Bissoonauth
Glasgow University, Scotland
Project: Kinetic modeling and experiments using a jet stirred reactor
"I love the low stress environment, the fact that the labs are always open, and that people are available to ask for help. I also appreciate how safe the community is."

Alberta Detogni
University of Padua, Italy
Project: Micro Flow Reactor
"KAUST is an amazing place to live; you meet so many people from different countries and cultures; and you can learn so much--not just from an academic point of view (thanks to research funding)--but from a human perspective as well."

Sylvain Heitz
Technische Universität Berlin, Germany and CentraleSupélec, France
Project: Numerical-experimental study of nanosecond plasma discharges influence on a laminar premixed stagnation flame
"With so many international students and modern facilities with state-of-the-art equipment, CCRC has by far the best work environment I've come across. And KAUST is a great place to live!"

CCRC at the Global Summits

Fethi Khaled and Ehson Nasir at the 10th US Combustion Meeting

During the second quarter of 2017, CCRC actively participated in several combustion events around the world. This issue of the CCRC newsletter highlights four events: The 8th European Combustion Meeting (ECM 2017), The 10th United States Combustion Meeting (USNCM 2017), the 17th SAE World Congress, and the 7th Saudi Arabia section of the Combustion Institute meeting (SASCI 2017).

Unlike other combustion conferences, ECM focuses on presentations in a poster format so that researchers, scientists, engineers and students have maximum opportunity to share experiences, ideas, and research results for all aspects of combustion science and technology. The conference has been held biennially since 2003. The 8th European Combustion Meeting (ECM 2017) took place from the 18th to the 21st of April 2017 in the Hotel Valamar Lacroma in Dubrovnik, Croatia. ECM2017 topics ranged from fundamental physical and chemical aspects of traditional and novel fuel sources to new concepts in combustion technology and many other areas.

Thirty-one of the 458 poster presentations were from the CCRC. In the 6th and 7th ECM conferences, CCRC offered nine and 34 poster presentations, respectively.

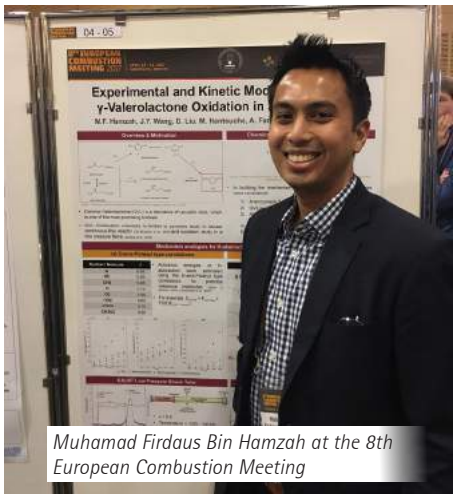
Mayada Alhashem at the 7th SASCI meeting

The U.S. National Combustion Meeting is the premier combustion science gathering in the U.S.; it has been organized biennially since 1999 by the joint U.S. sections of the Combustion Institute. The 10th U.S. National Combustion Meeting (April 22-26, 2017), was held by the University of Maryland, at the Marriott College Park Hotel.

It was an active event, with over 494 presentations and 50 posters in ten parallel sessions. Of those, 15 presentations and two posters represented the CCRC. At the 9th USNCM there were 359 presentations and 32 posters, nine presentations and two posters were from the CCRC. In 2013, CCRC participated with four of the total 316 presentations.

The 17th SAE World Congress took place in Detroit, Michigan from April 4 through 6, 2017. The congress is the premier research event for the automotive community and includes active participation from industry, research labs and academia.

From powertrain, fuels, battery development, interiors, and chassis structure to novel engine concepts, nearly all aspects of the automobile sector were well-represented and showcased in the exhibition that accompanied the congress every year.



Muhamad Firdaus Bin Hamzah at the 8th European Combustion Meeting

CCRC presented seminal research at this event, including the work of two post-doctoral fellows and four Ph.D students. CCRC is building a strong foundation for world class engine research, and its participation in the SAE World Congress is expected to increase.

The 7th SASCI (Saudi Arabian Section of Combustion Institute) annual meeting was held on May 21 and 22, 2017 at KAUST. SASCI was founded in 2011 to promote fundamental and applied combustion and energy science within the Kingdom through active engagement with local and international research communities in academia and industry. Approximately 50 members are currently registered with this local chapter. The theme of this year's meeting is "Combustion to Enable an Efficient Future", with discussions on "Emissions and Pollutants," "Combustion Chemistry and Reaction Kinetics," "IC Engines and Gas Turbine Combustion," "Experimental Combustion and Fuels," and "Delivering More Energy for Less CO2."

Jing-ling liu at the 7th SASCI Meeting

Several invited keynote lectures were delivered during this meeting: Nicholas Chase from KAPSARC, Saudi Arabia talked about the energy demand in the transportation sector. Assaad Masri from University of Sydney, Australia presented a talk on compositional inhomogeneities in turbulent flames. Aqil Jamal from Saudi Aramco, Saudi Arabia gave an overview on recent trends in CO2 capture and utilization technologies. Baki Cetegen from the university of Connecticut, presented the effects of flow turbulence and fuel type on the structure and blowoff characteristics of bluff-body stabilized lean premixed flames.

The CCRC's contribution to SASCI was notable, with more than 50% of all presentations and participants coming from KAUST (18 out of 35 presentations). The meeting was concluded with an award for the best presentation and a tour of CCRC laboratories.

Since its inception in 2011, the Clean Combustion Research Center has increased its presence at key meetings and conferences, both nationally and internationally, consistent with KAUST's vision of global leadership in energy and combustion science.

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