Saudi Arabian Section of the Combustion Institute
Welcome

Eighth Annual Meeting

Welcome to the Eighth Annual Meeting of the Saudi Arabian Section of the Combustion Institute (SAS-CI). Under the theme of *Clean and Efficient Utilization of Fuels for a Sustainable Future*, this year’s event brings together more than 100 researchers from a range of global institutions.

In its comparatively short history, the Saudi Arabian Section has grown in both size and stature. The Section has more than 100 registered members in Kingdom. But more importantly, the annual meeting has increasingly been attracting high-profile international researchers. This reflects favorably on the standard of research undertaken within our community. We expect the growth in both local and international participation will continue its upward trajectory in future years.

The Eighth Annual Meeting is hosted by King Abdullah Petroleum Studies and Research Center (KAPSARC) in Riyadh, Saudi Arabia. Collectively, the meeting will feature four keynotes, 49 oral presentations across six different technical sessions and 10 poster presentations. A session on *Environmental and techno-economical assessment* has also been included for the first time at this meeting.

From the organizers, we hope you enjoy the event.

Maryam Altayher  
*K*ud*aa*hlah Petroleum Studies and Research Center

Kai Morganti  
*Saudi* Aramco

Sylvain Cote  
*K*ud*aa*hlah Petroleum Studies and Research Center

Adel Balatif  
*K*ud*aa*hlah Petroleum Studies and Research Center

Raheena Abdurehim  
*K*ud*aa*hlah University of Science and Technology

Robert Dibble  
*K*ud*aa*hlah University of Science and Technology

S. Mani Sarathy  
*K*ud*aa*hlah University of Science and Technology

Fethi Khalid  
*K*ud*aa*hlah University of Science and Technology

Adamu Alfazazi  
*K*ud*aa*hlah University of Science and Technology

Hong Im  
*K*ud*aa*hlah University of Science and Technology
Saudi Arabian Section Leadership

**CHAIRMAN**

**Prof. Hong Im**  
*King Abdullah University of Science and Technology*

**VICE-CHAIRMAN**

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**Prof. S. Mani Sarathy**  
*King Abdullah University of Science and Technology*

**Prof. William Roberts**  
*King Abdullah University of Science and Technology*

**Dr. Amer Amer**  
*Saudi Aramco*
General Event Information

The following information will assist you to organize transportation and access KAPSARC. Please review these instructions carefully to avoid unnecessary delays when accessing the venue.

Transportation

Participants are responsible for coordinating their own transportation to and from the venue. There are several transport options which are permitted to enter KAPSARC, including:

- Uber or Careem,
- SAPTCO taxi service (+966 55 913 1177). Please make your reservation at least 30 minutes before your desired pick-up time,
- Rental or personal vehicle (refer to information below for requirements).

Transport may also be arranged through the hotels. Please note that each hotel has a different policy for taxi reservation:

**Burj Rafal Hotel Kempinski**
Contact the Concierge (+966 11511777 or Concierge.BurjRafal@Kempinski.com). To guarantee a taxi, please book at least 30 minutes in advance.

**Holiday Inn**
Contact Junaid Hashim (+966 53 243 5843, +966 59 643 8886 or junaid.hashim@ihg.com). To guarantee a taxi, please book at least 1 day in advance.

**DoubleTree by Hilton**
Contact Mohammed Javed (+966 11 528 5302 or Mohammed.Javed@Hilton.com). To guarantee a taxi, please book at least 2 days in advance.

Please note the first presentation will commence before 9:00 on each day, so please allow enough time to reach the venue from your hotel. The following can be used as guidelines:

- Burj Rafal Hotel Kempinski (allow 35 minutes),
- Holiday Inn (allow 35 minutes),
- DoubleTree by Hilton (allow 40 minutes).

Requirements for Accessing KAPSARC

The meeting will be held in the KAPSARC Conference Center (Figure 1). Please enter KAPSARC using Gate 1 located on King Khalid International Airport Road. Ensure you have registered your Passport, Iqama or National ID with the event organizers prior to the event, otherwise you will be denied entry. An original copy of this ID must be presented upon entry to KAPSARC.

If you arrive at KAPSARC by taxi, then security will direct the driver to the drop-off location. If you are using your own vehicle, please bring along both your ID and the vehicle registration card. If you are using a rental vehicle, please bring along both your ID and a copy of the vehicle rental contract.

Once inside KAPSARC, follow the signs to the main car park area (Figure 1). You may then proceed to the Conference Center via Security Screening. Please sign-in at the the Registration & Information counter to collect your ID badge.
Welcoming Ceremony, Keynotes and Closing Ceremony
The welcoming ceremony, keynotes and closing ceremony will be held in the Auditorium.

Technical Sessions
Two parallel technical sessions will be held in Seminar Rooms 1 & 2. Each presentation slot is 20 minutes. We recommend that presenters speak for 15 minutes, and allow five minutes for questions at the end. Presenters will be notified at the 10, 14 and 15 minute points during their presentation, and must wrap-up within one minute of receiving the 15 minute notification. Please ensure you load your presentation onto the computer during the break prior to your presentation slot.

Poster Presentation Session
The poster presentation session will be held in the Lobby during the lunch break on the first day of the event.

Meals
Breakfast will be served each morning in the Lobby, so there is no need to include breakfast as part of your hotel reservation. Refreshments will also be available in the Lobby during the morning and afternoon breaks. Lunch and the Welcome Dinner (Tuesday evening) will be hosted in Seminar Room 3 (second floor).

Group Photo
A group photo will be taken during the morning break on the first day of the event. Please wait in the Lobby and await instruction from the photographer.

Emergency Contacts
Please contact Kai (+966 50 791 9854) or Adel (+966 50 420 6649) if you encounter any difficulties.
Session Chairs

Session 1: Environmental and techno-economical assessment

Sylvain Cote  
*King Abdullah Petroleum Studies and Research Center*

Session 2: Combustion chemistry and reaction kinetics

Ahfaz Ahmed  
*King Abdullah University of Science and Technology*

Tamour Javed  
*Saudi Aramco*

S. Mani Sarathy  
*King Abdullah University of Science and Technology*

Session 3: Combustion measurement techniques, diagnostics and emissions

Joshua Gray  
*King Abdullah University of Science and Technology*

Binod Giri  
*King Abdullah University of Science and Technology*

Session 4: Spray and droplet combustion

Hong Im  
*King Abdullah University of Science and Technology*

Session 5: Reciprocating engine and gas turbine combustion

Jean-Baptiste Masurier  
*King Abdullah University of Science and Technology*

Eshan Singh  
*King Abdullah University of Science and Technology*

Dimitrios Kyritsis  
*Khalifa University*

Session 6: Fuel production, properties and utilization

Ahmad Khan  
*Saudi Aramco*

Alex Voice  
*Aramco Services Company*

Nujood Mulla  
*Saudi Aramco/King Abdullah Petroleum Studies and Research Center*
## Agenda: Tuesday 1 May, 2018

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<th>Time</th>
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<td>7:30 – 8:45</td>
<td>Breakfast and Registration (Lobby)</td>
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<td>8:45 – 9:00</td>
<td>Welcoming Ceremony (Adam Sieminski, President KAPSARC; Auditorium)</td>
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<tr>
<td>9:00 – 9:40</td>
<td><strong>Keynote 1: Dimitrios Kyritsis, Khalifa University (Auditorium)</strong></td>
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<tr>
<td>9:40 – 10:00</td>
<td>Session 1: Environmental and techno-economical assessment (Seminar Room 1)</td>
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<tr>
<td>10:00 – 10:20</td>
<td>The Welfare Implications of the Rebound Effect from More Energy Efficient Cars (A. Gasim, Z. Al-fawzan)</td>
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<td>10:40 – 11:10</td>
<td>Break and Group Photo (Lobby)</td>
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<tr>
<td>11:10 – 11:30</td>
<td>The Impact of Air Conditioning Motor Loads Stalling on Voltage Recovery in the Saudi Electric Grid System (T. Alagel, A. Abou Alhajer, S. Suryanarayanan)</td>
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<tr>
<td>11:30 – 11:50</td>
<td>Indoor Environmental Sensors for Appliance Load Disaggregation (T. Alshehri)</td>
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<td>11:50 – 12:10</td>
<td>Policy options for reducing water for Agriculture in the Emirate of Abu Dhabi (M. Mansouri, D. Wogan)</td>
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<tr>
<td>12:10 – 13:30</td>
<td>Lunch, Poster Presentation Session and SAS-CI Board Meeting (Seminar Room 3)</td>
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<tr>
<td>13:30 – 14:10</td>
<td><strong>Keynote 2: Sylvain Cote, KAPSARC (Auditorium)</strong></td>
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<td>14:30 – 14:50</td>
<td>Flame Quenching Dynamics in a Rectangular Cross Section Channel for Different Velocity Regimes (A. Malekhasanzadeh, D. Lacoste, J. Danaro, E. Kuun, W. Roberts)</td>
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<td>15:10 – 15:30</td>
<td>Study on the jet-wall interaction in the partially premixed combustion (PPC) under low engine load using formaldehyde PLIF imaging (Q. Tang, Y. An, V. Raman, G. Magnotti, B. Johansson)</td>
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<td>15:30 – 15:50</td>
<td>Hydrogen/oxygen autoignition with H2O2 addition (A. Khalil, D. Kyritsis)泡沫胶带</td>
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<td>15:50 – 16:10</td>
<td>Break (Lobby)</td>
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<td>16:10 – 16:30</td>
<td>Session 3: (continued) The assessment the accuracy of the 2-lines OH thermometry method in steady-flow flames (P. Li, Z. Li, A. Malekhasanzadeh, G. Magnotti, D. Lacoste, W. Roberts)</td>
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<tr>
<td>16:50 – 17:10</td>
<td>Promoting the deflagration-to-detonation transition using nanosecond repetitively pulsed plasma discharges (J. Grag, D. Lacoste)</td>
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<td>17:10 – 17:30</td>
<td>An IH-QCL based sensor for simultaneous detection of methane and acetylene (G. Zhang, K. Khabibullin, A. Farooq)</td>
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<tr>
<td>18:00 – 19:30</td>
<td>Welcome Dinner (Seminar Room 3)</td>
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<td>Time</td>
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<tr>
<td>7:30 – 8:50</td>
<td><strong>Breakfast and Registration</strong> <em>(Lobby)</em></td>
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<tr>
<td>8:50 – 9:30</td>
<td><strong>Keynote 3: Anvita Arora, KAPSARC</strong> <em>(Auditorium)</em></td>
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<tr>
<td>9:30 – 9:50</td>
<td>Session 5: Reciprocating engine and gas turbine combustion <em>(Seminar Room 1)</em></td>
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<td>Combustion properties of biodiesel derived from Black Soldier Fly oil and its blending effects on diesel and ethanol-diesel mixtures <em>(T. Hong, N. Chandiramani, S. M. Sarathy)</em></td>
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<tr>
<td>9:50 – 10:10</td>
<td>Session 6: Fuel production, properties and utilization <em>(Seminar Room 2)</em></td>
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<td>A proposal of cetane sensitivity and its relation to octane sensitivity <em>(N. Naser, S. M. Sarathy, S. Chung)</em></td>
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<td>10:10 – 10:30</td>
<td>Session 5: Reciprocating engine and gas turbine combustion <em>(Seminar Room 1)</em></td>
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<td>HC and PPC Mode Combustion in Compression Ignition Engine with Low Octane Gasoline <em>(Y. An, M. Jaasim, V. Raman, F. Perez, H. Im, B. Johansson)</em></td>
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<td>Investigating Antagonistic effects on DCN of Gasoline-Alcohol mixtures using Gaussian model <em>(F. Shamsudheen, N. Naser, S. M. Sarathy)</em></td>
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<td>10:30 – 10:50</td>
<td><strong>Break</strong> <em>(Lobby)</em></td>
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<tr>
<td>10:50 – 11:10</td>
<td>Optimizing Injection strategy for Pre-ignition suppression in turbocharged Gasoline Direct Injection Engine <em>(E. Singh, R. Dibble)</em></td>
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<td>Screening high cetane molecules <em>(T. Javed, K. Morganti, A. Nicolle, N. Rankovic)</em></td>
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<td>Autoignition Enhancement of MeOH-Air Mixture by DME Addition <em>(W. Song, E. AlTingas, H. Im)</em></td>
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<td>Influence of Liquid Fuel Composition on The Performance of The Liquid Fueled Pulse Combustor <em>(M. Qatomah, J. Lisanti, W. Roberts)</em></td>
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<td>11:50 – 12:10</td>
<td>The ignition regime diagram of n-heptane/air mixtures with temperature and concentration fluctuations <em>(M. Luong, F. Perez, A. Sou, H. Im)</em></td>
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<td>Thermo-Neutral Reforming of Diesel for Auxiliary Power Unit (APU) Application <em>(A. Harale, M. Albuali, A. Naimi, M. Draze, S. Katikaneni, S. Ahmed)</em></td>
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<tr>
<td>12:10 – 13:00</td>
<td><strong>Lunch</strong> <em>(Seminar Room 3)</em></td>
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<td>13:00 – 13:20</td>
<td>Predict SI knock occurrence through autoignition in HCCI conditions <em>(J. Masurier, B. Johansson)</em></td>
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<td>Power Plants with No Smokestacks! Numerical Investigation of advanced engine cycles with working fluid of CO2 <em>(F. Maimani, E. Singh, R. Dibble)</em></td>
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<td>Standardized Gasoline Compression Ignition Fuels Matrix <em>(J. Bedra, R. Bakor, A. AlRamadan, M. Almansour, J. Sim, A. Ahmed et al.)</em></td>
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<tr>
<td>13:40 – 14:00</td>
<td>CFD Study of Increased Efficiency Using Multiple Injectors <em>(G. Nyrenstedt, M. Jaasim, H. Im, A. Andersson, B. Johansson)</em></td>
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<tr>
<td>14:00 – 14:30</td>
<td><strong>Closing Ceremony</strong> <em>(Auditorium)</em></td>
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Poster Presentations

The Poster Presentation session will take place during the lunch break on the first day of the event. Poster abstracts can be accessed using the blue links.

**An assessment of adding syngas generated by plasma assisted gasoline convertor with different ethanol fuel blend concentrations (E0, E5 and E10) and their effect on pollution emissions and fuel consumption using Saudi Arabian market fuel (RON95)**
Ahmed A. Al-Harbi, Saud A. Binjuwair, Ibrahim A. Alshunaifi, Abdullah M. Alkhedhair, Abdullah J. Alabduly, Miqad S. Albishi

**Unconventional oxidizers and fuels in HCCI internal combustion engine**
Abdulrahman Magdy Mohammed, Bengt Johansson, Robert Dibble, Jean-Baptiste Masurier

**Treatment of fly ash by thermal plasma: Simulation of toxic element volatility during treatment**

**Laminar Flames**
Anthony Bennett, Hafiz Amin, Emre Cenker, William L. Roberts

**Modeling turbulence-chemistry interaction**
Erica Quadarella, Alessandro Stagni, Alberto Cuoci, Alessandro Parente, Tiziano Faravelli, Hong G. Im

**Characterization of the dynamics of a small-scale bluff body stabilized lean hydrogen air flame**
Davide Del Cont-Bernard, Deanna A. Lacoste

**An experimental investigation on single Heavy Fuel Oil droplet combustion**
Paolo Guida, Abdulrahman Alkhateeb, Saumitra Saxena, Eid Barakati, William L. Roberts

**Measurement of the laminar burning velocity isochorically from a constant volume vessel using a multi-zone model**
Farha Khan, Ossama Manna, Saumitra Sexena, William L. Roberts
Keynote Speaker

*Carbon Capture in the UAE: Current status, possibilities, and research in Khalifa University*

Dimitrios C. Kyritsis
Professor and Chair, Department of Mechanical Engineering, Khalifa University, Abu Dhabi, United Arab Emirates

**Abstract:** The UAE have been consistently in the top-ten nations in CO2 emissions per capita in recent years. This is due to a combination of rapid infrastructure and manufacturing-base development as well as to serving potable water needs from desalination through reverse osmosis. There is a realization of this but to date there are no technological implementations towards addressing the issue. It is worth noting that, at the same time, UAE is a net importer of natural gas, because the largest part of gas that is extracted is re-injected for the purpose of enhanced oil recovery. This opens research and development possibilities in the field of high-pressure CO2 injection for enhanced oil recovery, as well as for efficient low-CO2-emission combustion technologies. Khalifa University of Science and Technology, which is currently emerging as a merger of Khalifa University, Masdar Institute, and the Petroleum institute has developed activities that address these needs, from which an indicative sample will be provided in the presentation.

**About the Speaker:** Dimitrios C. Kyritsis is a Professor and the Chair of the Department of Mechanical Engineering in Khalifa University in Abu Dhabi, which he joined in 2013. Before this, he served for 12 years in the faculty of the Department of Mechanical Science and Engineering in the University of Illinois at Urbana-Champaign. He received his Diploma in Engineering from the National Technical University of Athens in Greece in 1992 and his M.A. and Ph.D. from Princeton University in 1995 and 1998, respectively. Then, he served as a post-doctoral associate and a lecturer at the Department of Mechanical Engineering at Yale University. His research focuses in the areas of experimental investigation of reactive flow with laser diagnostics, electrostatically assisted atomization, combustion and flame-flow interaction, as well as near-critical flow of CO2 for carbon capture. He is a Fellow of the ASME, an Associate Fellow of the AIAA and a recipient of the NSF CAREER award, the Ralph S. Teetor Award of the Society of Automotive Engineers. He is currently serving in the Editorial Board of Combustion and Flame, the Journal of Energy Engineering, and the Proceedings of the Combustion Institute.
Keynote Speaker


Sylvain Cote

Program Director, Energy Demand, Efficiency & Productivity,
King Abdullah Petroleum Studies and Research Center, Riyadh, Saudi Arabia

Abstract: Numerous studies claim that, per unit of energy produced, renewable generation is more labor-intensive than fossil fuel-fired power plants—and thus the transition from fossil fuel to energy renewables will create net new jobs. While multiple studies provide positive estimates, few have accounted for labor market rigidities or the social context of Saudi Arabia. Given the evolution and nature of the Saudi labor markets, the implications of these constraints are important as it could also represent a missed opportunity to train and employ a rising young population in this emerging sector. After briefly assessing projected employment opportunities associated with RE deployment, the study explores some of the supply-side constraints in the Saudi labor market and highlights areas in which targeted policy action by governments could help alleviate the anticipated skills gap.

About the Speaker: Sylvain Cote is currently Program Director at the King Abdullah Petroleum Studies and Research Center where he is responsible for the Energy Demand, Efficiency and Productivity Program. He previously worked at the Federal Government of Canada, the Organisation for Economic Co-operation and Development in Paris (France) and the North American Commission for Labor Cooperation in Washington, D.C. (USA). He also taught labor economics at the University of Ottawa, Canada.

Throughout his career, he has conducted and directed economic research and provided policy advice in a multi-stakeholder environment in Europe, North America and more recently in GCC countries. His research interests have primarily been on policy issues related to industry and labor economics: Determinants of firm growth and entrepreneurship; the effects of schooling on student achievement and economic growth; the impact of education and immigration, the role and complementarity of human and social capital in the labor market; the influence of pension systems, labor market regulation and institutions on labor supply.
Keynote Speaker

*Decoupling economic growth and motorization - strategies for environmentally and socially sustainable transport systems*

Anvita Arora

Program Director, Transport & Urban Infrastructure, King Abdullah Petroleum Studies and Research Center, Riyadh, Saudi Arabia

Abstract: The Vision 2030 and the National Transportation Strategy (2011) call for reducing domestic dependence on oil while creating smart and sustainable cities. Like most parts of the world, rapid economic growth and urbanization has led to increasing use of cars for personal mobility in the Kingdom. This has led to increasing air and noise pollution, congestion, accidents and fossil fuel consumption, and will create dysfunctional cites with increasing crime and exclusion. To address some of these concerns, especially air pollution and energy security, there has been focus on improving the fuel quality and fuel efficiency of cars at one end and adoption of electric vehicles at the other end. However, the efficacy of such interventions will remain marginal if the demand for mobility keeps increasing. The presentation discusses the impact of city design and people’s choices on transport energy demand and suggests a more comprehensive framework for a sustainable transport system.

About the Speaker: Dr. Anvita Arora, is an architect and Transport Planner, with a PhD from the Civil Engineering Department of the Indian Institute of Technology (IIT). She is the Program Director of the Transport & Urban Infrastructures vertical of KAPSARC. Before joining KAPSARC, she was the Managing Director and CEO of Innovative Transport Solutions (iTrans), an incubatee company of IIT, Delhi. The company had successfully delivered over 40 applied research and planning projects for 10 years under her leadership, to clients ranging from the various city level and country level authorities to funding agencies like the UNEP, World Bank, Asian Development Bank, DFID and others. The primary focus of this work has been supporting cities to become sustainable, inclusive and climate resilient. She has also been teaching Transport Planning in the Urban Design Department in the School of Planning and Architecture (SPA), Delhi for the past 12 years and is visiting faculty at the TERI University, Delhi and Ansals University, Gurgaon. She was associated with Transportation Research and Injury Prevention Program (TRIPP), IIT, Delhi, a VREF Centre of Excellence, for nearly 12 years. Arora is a certified trainer in non-motorized inclusive planning an invited expert on several panels and think tanks. She has several publications to her credit including a book entitled Manual for Social Impact Assessment of Future Urban Transport Projects.
Session 1: Environmental and Techno-economic Assessment
The Welfare Implications of the Rebound Effect from More Energy Efficient Cars

Anwar A Gasim, Ziyad Alfawzan
King Abdullah Petroleum Studies and Research Center, Saudi Arabia

Improving the energy efficiency of an energy service, such as lighting, space cooling, or driving, makes the service cheaper, normally leading consumers to demand more of it. This additional demand is known as the direct rebound effect, and is often perceived negatively. To gain a better understanding of rebound’s welfare implications, this paper undertakes a cost-benefit analysis of the direct rebound effect. The analysis compares the consumer surplus gained from the additional demand to the associated increase in negative externalities. Using driving as an example, we find that the rebound effect from more energy efficient passenger cars is welfare reducing in most cases, as the consumer surplus gained from the additional driving is generally smaller than the cost of the exacerbated externalities, which include greenhouse gas emissions, air pollution, congestion, and accidents. However, we also demonstrate that direct rebound in other energy services, such as lighting and cooling, may be welfare enhancing because the associated negative externalities are smaller. Finally, we demonstrate that overlooking the costs and benefits of the direct rebound effect can lead to a misleading cost-benefit evaluation of energy efficiency, particularly when rebound effects are large.

Gain in consumer surplus due to energy efficiency.
We present our experience of building a general equilibrium model of Saudi Arabia’s economy by merging a bottom-up, multisector energy model and a top-down representation of the rest of the economy into a single Mixed-Complementarity Problem (MCP). The model considers administered energy prices and includes time segmented electrical load details. We explain the structural and data issues we have faced and the solutions we have adopted, some of which are novel. Our approach is a new use of MCPs as a methodology for merging different model structures and data definitions. For illustration, we use a static version of the model and produce counterfactual scenarios to show the effect of implementing energy price reform in Saudi Arabia.
Degree of Stringency Matters: Revisiting the Pollution Haven Hypothesis Based on Heterogeneous Panels and Aggregate Data

Fatih Karanfil, Thomas Jobert, Anna Tykhonenko
King Abdullah Petroleum Studies and Research Center, Saudi Arabia

Empirical studies on the trade-environment nexus that use panel data face two simultaneous challenges. One is associated with the potential presence of unobserved cross-country heterogeneity, while the other is due to the use of aggregate data. In this paper, we apply both the dynamic fixed effects and iterative empirical Bayes estimators to show first that when country heterogeneity is accurately accounted for in the estimation, it is possible to obtain significant impacts of trade variables on the environment, even though we use aggregate data. Second, using both the empirical Bayes parameter estimates and indicators of stringency of environmental regulations, we show that at low levels of stringency, the probability of having pollution-intensive foreign direct investments (FDIs) increases with a decrease in stringency. However, at high levels of regulatory stringency, more stringent regulations may lead to more pollution-intensive FDIs. This implies that pollution havens may exist only if environmental regulations are very lax or nonexistent.
The Impact of Air Conditioning Motor Loads Stalling on Voltage Recovery in the Saudi Electric Grid System

Turki A. Alaqeel, S. A. Almohaimeed, S. Suryanarayanan  
King Abdullah Petroleum Studies and Research Center, Saudi Arabia

The paper discusses the impact of air conditioning motor stalling in the Saudi electric grid. Slow voltage recovery after fault events is a result of high concentration of prone-to-stall motors in the grid. Multiple mitigation solutions are discussed from technical, regulatory, economic and planning perspectives.

![Monthly average temperature in Riyadh, Saudi Arabia.](image-url)
Indoor Environmental Sensors for Appliance Load Disaggregation

Thamir Alshehri
King Abdullah Petroleum Studies and Research Center, Saudi Arabia

Rapid increase of cost and demand of energy is a global major concern, where residential buildings are accountable for large percentage of that energy consumption. There are a number of factors driving concerns about the energy usage within buildings. These range from system wide issues, such as greenhouse gas reduction and reducing peak load (to control distribution network capital investment), through to individual consumer issues, such as reducing overall power consumption. Feedback allows home occupants to closely connect consumption decisions with their comfort, convenient and financial impacts. Real-time feedback achieves between 6 to 10 percent reduction in home energy consumption through smart-meters and dedicated display panels. Obtaining appliance-specific consumption information would improve consumers’ engagement in short and longer term and maximizing the advantages of differential tariffs where these are available. Non-Intrusive Load Monitoring (NILM) is an economical approach to profile appliance-specific consumptions. In this research we explore the feasibility of occupying indoor environmental data as independent and trusted source of information to improve NILM approach and disaggregate specific sets of appliances, which their operation can be reflected in both the power and environmental data streams.
Policy options for reducing water for Agriculture in the Emirate of Abu Dhabi

Noura Mansouri, David Wogan
King Abdullah Petroleum Studies and Research Center, Saudi Arabia

The objective is to study policy options for reducing water for agriculture in the Emirate of Abu Dhabi. The project aims to answer the question: How can Abu Dhabi reduce its water use in the agriculture sector while meeting the demand in a cost-effective way? Groundwater withdrawals in the Abu Dhabi emirate exceed several times the rate of natural recharge of the aquifers. Maintaining the current patterns of groundwater use for agriculture and forestry may lead to the depletion of usable groundwater in a few decades. A water and agriculture optimization model is being developed in GAMS environment to determine the optimal crop portfolio for a given water consumption budget (volumetric) for Abu Dhabi Emirate on an annual basis. The model will find the least-cost mix of crops that stay within the water budget while satisfying given demand without compromising food security or aggregate farmer revenues. Insights from the model will be used to inform key stakeholders in Abu Dhabi emirate to decide which water uses could be curtailed or maintained to keep consumption within the limits of the sustainable water budget. This project is undertaken by King Abdullah Petroleum Studies and Research Centre (KAPSARC) in collaboration with the Environment Agency-Abu Dhabi (EAD) and the Abu Dhabi Food and Water Authority (ADFCA).
Session 2: Combustion Chemistry and Reaction Kinetics
Plasma Assisted Combustion (PAC) is a powerful tool for combustion enhancement, emission control and extreme combustion conditions. By accurately controlling spark ignition duration and power, combustible mixture ignition delay time can be precisely controlled, especially under extreme combustion conditions like aerospace engines and extreme lean NOx/CO2 free gas turbines. Furthermore, in gasoline spark ignition engines, emissions are mainly produced during ignition through low temperature oxidation. By optimizing the ignition time and power, emissions can be minimized and well controlled. To achieve these goals, PAC kinetic model needs to be understood and developed. In this work, a comprehensive PAC kinetic model was proposed. Plasma chemistry, including ionization reactions, electron attachment reactions, electron induced dissociation reactions, electron recombination reactions, and ion-neutral reactions is combined with neutral combustion chemistry in the proposed model. Model validation was performed by comparing global (0D) simulated electron number density time history with available experimental data on pure component discharge cases (pure oxygen and pure methane). Simulations on combustible mixtures, e.g. methane/oxygen and ethane/oxygen, were performed to reveal reaction scheme on proposed PAC model. This work aims at developing a comprehensive plasma kinetic model, which is a vacant because current PAC kinetic model only has neutral chemistry.

Simulated electron density and electron temperature time history on pure component cases (oxygen, methane and ethane).
A Shock Tube Kinetic Study of Allyl + Allyl and Allyl + OH Recombination Reactions at High Temperatures

Fethi Khaled, Binod Raj Giri, Aamir Farooq
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Resonantly stablized hydrocarbon radicals, such as allyl (C3H5), play a crucial role in combustion processes. Allyl has a resonance energy of 61 kJ/mol and being thermodynamically stable, it exhibits slow reactivity towards molecular oxygen. It can, therefore, build up to high concentrations making radical-radical reactions its major loss pathways under combustion conditions. In this work, we have investigated the self-reaction of allyl radicals and its cross-reaction with hydroxyl by employing shock tube and laser absorption techniques. We carried out the experiments behind reflected shock waves over the temperature range of 800-1200 K and pressures of 1.1-2.5 bar. Allyl and OH radicals were generated by fast thermal decomposition of allyl iodide (C3H5I) and tert-butyl hydroperoxide (TBHP), respectively. Reaction progress was monitored by detecting OH near 306.69 nm and C3H5 near 220 nm using UV laser absorption. Temperature dependence of the absorption cross-sections of C3H5 and C3H5I were measured at the detection wavelength. Rate coefficient for the self-recombination reaction of allyl radicals showed a small negative temperature dependence, and no noticeable fall-off behavior over 1.15-1.96 bar, giving a mean value of $k_{C3H5+C3H5} = 1.0 \times 10^{-11}$ cm$^3$ molecule$^{-1}$s$^{-1}$. Likewise, the cross-reaction of allyl and OH radicals did not exhibit discernible pressure and temperature dependance under our experimental conditions, indicating a barrier less reaction, and the measured rate coefficients can be represented by an average value of $k_{C3H5 + OH} = 9.3 \times 10^{-11}$ cm$^3$ molecule$^{-1}$s$^{-1}$. These measurements represent the first direct experimental determinations of the rate coefficients for these important reactions at high temperatures and pressures.
Ignition Delay Measurements of GCI Blend

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Although there are several researches and studies on alternative energy resources for transportation, still internal combustion (IC) of liquid fuels is the main source of transportation energy. For example, EIA shows that, in 2016, 55% and 21% of transportation energy derived from gasoline and diesel respectively. However, Gasolines engine is known with its limitation in compression ratio and as a result it needs fuel with high octane number (ON) and hence the distillation process for such fuels require more processing steps. Diesel engine has high compression ratio but on the other hand it has high emissions. A blend of J-80 light naphtha (50%), J-80 heavy naphtha (25%) and Reformate 262 (25%) is proposed here as a promising fuel for gasoline compression ignition engine (GCI) which combined the best of gasoline and diesel engines, low emissions and high efficiency respectively. In this work, we performed experimental and modeling work to investigate the ignition characteristics of the GCI blend. A global indicator of fuel ignition and reactivity is the "ignition delay time" which is measured in ideal reactors, such as shock tube and rapid compression machine. Here, we measured the ignition delay times of the GCI blend over wide ranges of pressures, temperatures and equivalence ratios. The GCI blend used here has research octane number (RON) of 77 and motor octane number (MON) of 63.9. The ignition delay times of the GCI blend were measured over the following conditions: Temperature Range: 600 - 1200 K, Pressures: 20 and 40 bar, Equivalence ratios: 0.5, 1 and 2.

To perform computational fluid dynamic (CFD) simulations of complex real fuels, such as the GCI blend, a simpler surrogate fuel with small number of components must be proposed which matches the properties of the real fuel. In this work, we have compared the ignition of GCI blend samples with the predictions of two surrogates: (1) a two-components primary reference fuel (PRF) surrogate comprising of n-heptane and iso-octane, which matches the RON of blend, (2) a multi-components surrogate which matches the RON, MON, H/C ratio and distillation curve of GCI blend.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{Dependence of ignition delay times on octane number.}
\end{figure}
Small Ester Combustion Chemistry: Computational Kinetics and Experimental Study of Methyl Acetate and Ethyl Acetate

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Small esters represent an important class of high octane biofuels for advanced spark ignition engines. They qualify for stringent fuel screening standards and could be synthesized through various pathways. In this work we performed a detailed investigation of the combustion of two small esters, MA (methyl acetate) and EA (ethyl acetate), experimental studies of combustion characteristics and kinetic model development. The series of experiments include: a shock tube study to measure ignition delays at 15 and 30 bar, 1000-1450 K and equivalence ratios of 0.5, 1.0 and 2.0; laminar burning velocity measurements in a heat flux burner over a range of equivalence ratios [0.7-1.4] at atmospheric pressure and temperatures of 298 and 338 K; and speciation measurements during oxidation in a jet-stirred reactor at 800-1100 K for MA and 650-1000 K for EA at equivalence ratios of 0.5, 1.0 and at atmospheric pressure. The developed chemical kinetic mechanism for MA and EA incorporates reaction rates and pathways from recent studies. The new mechanism shows generally good agreement in predicting experimental data across the broad range of experimental conditions. The experimental data, along with the developed kinetic model, provides a solid groundwork towards improving the understanding the combustion chemistry of smaller esters.

![Ignition delay time as a function of temperature at different equivalence ratios.](image-url)
Gasoline oxidation chemistry in jet stirred reactors

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To achieve a better understanding and control of internal combustion engine pollutants, gasoline oxidation chemistry must be investigated. An oxidation study has been done on n-heptane, iso-octane, their binary mixtures (primary reference fuel), and nine hydrocarbons mixtures which represent the second generation of gasoline surrogates (multicomponent surrogates). This study is aiming to develop a better understanding of the combustion reaction by studying the oxidation reaction of different fuels inside the jet-stirred reactor and numerically simulate the reaction using different models under the following conditions: pressure 1 bar, temperature 500-1050K, residence time 1.0 and 2.0s, and two fuel-to-oxygen ratios (φ=0.5 and 1.0). Intermediate and product species mole fractions versus temperature profiles were experimentally measured using a GC (gas chromatograph). The experiment has been performed within the high and low-temperature regions, where the high-temperature oxidation showed similar behavior for different composition but the low-temperature oxidation showed a significant dependence on the composition of the surrogates. Moreover, the effect of octane number on oxidation chemistry has been investigated and it was found that the low octane number surrogates were more reactive than high octane number surrogates at low-temperature regime. Furthermore, the Kinetic analysis was conducted to provide an insightful understanding of different factors of fuel reactivity.
On the Thermal Unimolecular Decomposition of Glycerol Carbonate

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Policy-makers and researchers have been considering a shift from conventional fossil fuels to renewable sources due to growing concerns over global warming and diminishing oil reserves. Biodiesel can be derived from vegetable oils and animal fats, and is considered to be bio-degradable, non-toxic and environmentally friendly. Cetane number and caloric power of biodiesel are quite similar to those of conventional diesel. Crude glycerol of about 10-20% by volume appears as a byproduct in biodiesel production. Increasing demand of biodiesel has led to substantial increase of glycerol supply in the global market, and dramatic fall in the price of glycerol which has warranted alternative uses of glycerol. One potential way to deal with glycerol overflow is to convert it to glycerol carbonate (GC) and use GC as a fuel or fuel additive. Prior studies have indicated that carbonate esters can significantly reduce particulate emissions during engine combustion. In this work, we have explored possible reaction pathways in the initial stage of glycerol carbonate pyrolysis. Ab Initio/RRKM-master equation methods are employed to differentiate various reaction pathways, and to obtain pressure- and temperature- dependence of the major channels. We have found that glycerol carbonate decomposes almost exclusively to produce CO2 and 3-hydroxypropanal over 800 - 2000 K, and radical forming channels are unimportant. As 3-hydroxypropanal is one of the main products of GC decomposition, and aldehydes are known to have a very high impact on soot reduction, glycerol carbonate can potentially serve as a viable fuel additive for cleaner combustion.
Insights into the three-stage heat release of hydrocarbons

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There is a growing interest in lean burning of fuels in internal combustion engines as it can be an enabler for high thermodynamic efficiency. The extension of knock-limited compression ratio and the increase in specific heat ratio with lean combustion are the key factors for the efficiency boost. With such burning regime, there is an emerging evidence that fuels at certain conditions exhibit an unusual heat release characteristic. The fuel/air mixture undergoes three-stage heat release: starting with an initial low temperature heat release, similar to the one observed in two stage ignition, followed by an intermediate stage where thermal runaway is inhibited, and then advance to a relatively slow third stage. The radical termination reactions of H, OH, and HO2 during the second stage heat release are leading factors for the distinct third heat release stage. The focus of this study is to examine the conditions in which fuels exhibit three stage ignition. The auto-ignition of hydrocarbons is simulated in closed homogenous batch reactor where the charge is allowed to auto-ignite adiabatically at constant volume vessel under predefined temperature and pressure. The simulations covered pressures of 10-60 bar, temperatures of 550K-900K, fuel to air ratio from stoichiometry (equivalence ratio) of 0.3-1.0, and Argon dilution of up to 90% by-mole of the overall mixture. In addition, the presence of three-stage heat release is examined in engine-like conditions using zero dimensional single-zone adiabatic model of HCCI engine. Overall, three-stage ignition is present at lean fuel/air mixture, high pressures, and low temperature conditions. It is also possible to observe three-stage ignition at near stoichiometric air/fuel mixtures by introducing inert gas to the mixture to avoid thermal runaway in the second-stage heat release.

![Demonstration of three-stage ignition of n-heptane/air mixture in constant volume batch reactor.](image)
Ignition delay times and $^1$H nuclear magnetic resonance (NMR) analysis of gasoline fractional distillates

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Tailoring fuel properties to maximize the efficiency of internal combustion engines is a way towards achieving cleaner combustion systems. In this work, the ignition properties along with the functional groups of various gasoline fuel distillation cuts are analyzed to better understand fuel properties of full boiling range fuels. The different distillation cuts are obtained with a spinning band distillation system, which is then tested in an ignition quality tester (IQT) for their global chemical reactivity. The distillates are further analyzed in with a $^1$H nuclear magnetic resonance (NMR) spectrometer to obtain the various functional groups present in them. Various FACE (fuels for advanced combustion engines) gasolines were distilled and various cuts were obtained. Fuels with lower aromatic content showed decreasing ignition delay time with increasing boiling point (i.e., molecular weight). However, fuels with higher aromatic content showed an initial decrease in ignition delay time with increasing boiling point, followed by drastic increase in ignition delay time due to fractions containing larger chain alkyl aromatics. This study also provides an understanding on contribution of different fractions to the ignition delay time of the fuel, which provides insights in to on-board separation of a high octane fuel, into low octane and high octane components for octane-on-demand technology. The study has also implications in understanding fuel stratification utilized in gasoline compression ignition (GCI) engines to tailor heat release rates.

![Functional groups present in various cuts of (a) FACE I gasoline and (b) FACE J gasoline.](image)
A Shock Tube Kinetic Study on the Branching Ratio of Methanol $+$ OH Reaction

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Methanol (CH$_3$OH) is the simplest alcohol and is considered to be a future fuel, produced by solar-driven reduction of carbon dioxide. The reaction of methanol and hydroxyl radicals is important in both combustion and atmospheric systems because this reaction is the dominant consumption pathway for methanol oxidation. Hydrogen abstraction at the CH$_3$ or OH site of CH$_3$OH leads to very different products. The relative importance of these two channels is critical for combustion modeling as the subsequent chemistries of the product radicals (CH$_3$O and CH$_2$OH) are markedly different. In this work, we measured overall rate coefficients for the reaction of methanol (CH$_3$OH), methanol-d$_3$ (CD$_3$OH) and methanol-d$_1$ (CH$_2$DOH) with OH radicals over the temperature range of 900-1300 K and pressures near 1.3 atm by employing shock tube/UV laser absorption technique. We determined site-specific H-abstraction rate coefficients, and, hence, branching ratios of the two abstraction channels. Our results show that abstraction at the CH$_3$ site is the dominant channel, contributing more than 80% throughout our temperature range, 900-1300 K.

![Branching ratios for H-abstraction at the hydroxyl site (k$_{1b}$) and the CH$_3$ site (k$_{1a}$) of methanol.](image-url)

Branching ratios for H-abstraction at the hydroxyl site (k$_{1b}$) and the CH$_3$ site (k$_{1a}$) of methanol.
Global Sensitivity Analysis of n-Butanol Reaction Kinetics using Rate Rules

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In this work, we investigate the sensitivity of the ignition delay time of n-butanol to uncertainties in kinetic rates parameters at various initial temperatures (600-1000 K), pressures (10-80 bar) and equivalence ratios (0.5-2.0). To this end we utilize a global sensitivity analysis (GSA) approach. This technique is based on first building a surrogate model for the quantity of interest (QoI) using polynomial chaos (PC) expansions. The unknown coefficients in the expansion are determined using an adaptive, pseudo-spectral projection technique. By exploiting the orthogonality of the PC basis, variance-based first-order and total sensitivity indices can be readily determined that respectively characterize the direct and total contributions of individual input parameters to the total variance in the QoIs. A existing detailed chemical kinetic model is adapted to this end. The n-butanol kinetic model used in this study comprises 30 reaction classes, describing both low-temperature and high-temperature kinetic schemes for alcohol fuels. Assigned to each of these is a uncertainty factor that characterizes the variability of the corresponding rate parameter. We start by considering a 30-dimensional stochastic germ in which each random variable is associated with one reaction class, and build a surrogate model for the ignition delay time. The surrogate model is used to estimate first-order and total-order sensitivity indices characterizing the dependence of the ignition delay time on the uncertain inputs. Results indicate that ignition delay is mostly sensitive to variations in four dominant reaction classes, namely, H-atom abstraction from the fuel, addition of O2 to the fuel radicals, fuel radical isomerization including Waddington type reactions, and concerted elimination reactions. We then consider variations within the corresponding subrules of these four dominant reaction classes. We explore two approaches to define the subrules of reaction class 2, one based on the radical abstracting from the fuel resulting in eleven subrules and another based on the abstraction site resulting in five subrules. Hence, we investigate the sensitivity of ignition delay due to variability in the rate parameters of 26 and 20 subrules of the resulting models. In particular, the simulations indicate that in reaction class 2 H-atom abstraction by HO2 dominates the variability in ignition delay time at all initial conditions considered. Analysis of this finding reveals that correlations inherent in the rate rule construction plays an important role in the resulting sensitivity predictions, and suggests a hierarchical approach to the calibration of elementary reaction rates.

Total sensitivity indices of the ignition delay time with respect to the 30 reaction classes.
Theoretical Kinetic Study of the Unimolecular Keto - Enol Tautomerism Propen-2-ol ↔ Acetone. Pressure Effects and Implications in the Pyrolysis of tert- and 2-butanol

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The need for renewable and cleaner sources of energy has made biofuels an interesting alternative to fossil fuels, especially in the case of butanol isomers, with its favorable blend properties and low hygroscopicity. Although C4 alcohols are prospective fuels, some key reactions governing their pyrolysis and combustion have not been adequately studied, leading to incomplete kinetic models. Enols are important intermediates in the combustion of C4 alcohols, as well as in atmospheric processes. Butanol reactions kinetics is poorly understood. Specifically, the unimolecular tautomerism of propen-2-ol ↔ acetone, which is included in butanol combustion kinetic models, is assigned rate parameters based on the tautomerism vinyl alcohol ↔ acetaldehyde as an analogy. In an attempt to update current kinetic models for tert- and 2-butanol, a theoretical kinetic study of the titled reaction was carried out by means of CCSD(T,FULL)/aug-cc-pVTZ//CCSD(T)/6-31+G(d,p) ab initio calculations, with multistructural torsional anharmonicity and variational transition state theory considerations in a wide temperature and pressure range (200-3000 K, 0.1-108 kPa). Results differ from vinyl alcohol ↔ acetaldehyde analogue reactions, which shows lower rate constant values. It was observed that decreasing pressure leads to a decrease in rate constants, describing the expected falloff behavior. Tunneling turned out to be important, especially at low temperatures. Accordingly, pyrolysis simulations in a batch reactor for tert- and 2-butanol with computed rate constants showed important differences in comparison with previous results, such as larger acetone yield and quicker propen-2-ol consumption.

Adiabatic potential energy profile at the CCSD(T,FULL)/aug-cc-pVTZ//CCSD(T)/6-31+G(d,p) level of theory with respect to the energy of the reactant global minimum structure.
Session 3: Combustion Measurement Techniques, Diagnostics and emissions
Cavity-Enhanced Laser Absorption Diagnostic for a Rapid Compression Machine

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A sensor based on cavity-enhanced absorption spectroscopy (CEAS) was implemented for the first time in a rapid compression machine (RCM) for carbon monoxide concentration measurements. The sensor consisted of a pulsed quantum cascade laser (QCL) coupled to a low-finesse cavity in the RCM using an off-axis alignment. The QCL was tuned to probe the P(23) ro-vibrational line of CO. The pulsed mode operation resulted in rapid frequency down-chirp within the pulse as well as a high time resolution. The combination of rapid frequency down-chirp and off-axis cavity alignment enabled a near complete suppression of the cavity coupling noise. A CEAS gain factor of 133 was demonstrated in experiments, resulting in a much lower noise-equivalent detection limit than a single-pass arrangement. The sensor thus presents many opportunities for measuring CO formation at low temperatures and for studying kinetics using dilute reactive environments; one such application is demonstrated in this work using dilute n-heptane/air mixtures in the RCM. The formation of CO during first-stage ignition of n-heptane was measured over 802 - 899 K at a nominal pressure of 10 bar. These conditions correspond to the NTC region of n-heptane and such results provide useful metrics to test and compare the predictions of low-temperature heat release by different kinetic models.

Comparison of minimum detection limit of CO between conventional single-pass absorption and cavity enhanced absorption (CEAS) for RCM conditions.
Flame Quenching Dynamics in a Rectangular Cross Section Channel for Different Velocity Regimes

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Understanding the flame quenching phenomenon in different conditions at critical locations, such as the inlets to fuel tanks, is essential to guarantee systems are designed that are both safe and optimized. The fundamental parameter in understanding flame quenching phenomenon is quenching distance. The quenching distance is influenced by various parameters such as fuel, mixture fraction, pressure, surface material, surface temperature, flame front velocity, etc. However the significance of flame front velocity to the quenching distance has yet to be investigated. In our pilot study, it has been witnessed that the quenching distance is a strong function of flame front velocity. Two different velocity regimes (20 m/s and 100 m/s) were investigated in our previous study; however, to develop a predictive model of this phenomenon, understanding this behavior over a wider range of velocities is required. Experiments were conducted in a 2D rectangular channel (test section) connecting an ignition chamber to a secondary chamber. Auxiliary passage with different blockage ratio is used for achieving flame front velocities in different regimes and same quenching element is maintained throughout the study. Schlieren measurements are used to measure the flame propagation velocity in the channel and to qualitatively understand the flame nature in the channel. Dynamic pressure measurement is used to identify the quenching and re-ignition in the secondary chamber. CH4-Air mixture is used in our initial study then the study is extended to C2H4-Air mixture. Initial temperature (298 K) and initial pressure (1 bar) are kept constant throughout the study. The influence of flame front velocity on quenching distance and the risk of re-ignition is studied for two different fuels and the results will be discussed in the presentation.

Schematic of experimental setup.
Effect of Different Fuels on the Flame Describing Function of a Swirl-Stabilized Premixed Flame

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Modern gas turbines may exhibit strong instabilities of the combustion process due to the coupling between unsteady heat release from the flame and the acoustic modes of the combustor. This interaction is usually analyzed using the formalism of the Flame Describing Function (FDF) that relates the relative heat release rate fluctuations and the relative velocity fluctuations in the frequency domain. In this work, the results of an experimental analysis of the effect of different fuels on the FDF of a swirl-stabilized premixed flame are presented. The experimental apparatus is composed of a swirl-stabilized burner of 4 kW of thermal power, a hot wire to measure the velocity and a loudspeaker system to perturb the velocity field. The optical diagnostics include a photomultiplier tube to collect CH\* chemiluminescence and an ICCD camera to acquire phase-locked images of OH\* emission to analyze the flame motion. Propane/air and a methane/air flames are investigated. Five different levels of forcing amplitude, from 5\% to 25\%, are examined. The characteristic behavior of the gain for this type of flame, a local minimum followed by a local maximum, is observed. The magnitude of the gain at the frequencies around the maximum decreases as the forcing amplitude increases. Changing the fuel from propane to methane, the magnitude of the gain around the frequency of the maximum decreases. According to previous studies, the vortex roll-up at the tip of the flame is identified as the main phenomena generating the maximum of the gain. From the analysis of the phase-locked images of OH\* chemiluminescence, it is possible to conclude that the size of the vortex roll-up at the tip of the flame plays an important role in the decrement of the gain of the maximum between propane and methane.

Comparison of the gain and phase of the FDF at 25\% of forcing amplitude for propane and methane fuels.
Study on the jet-wall interaction in the partially premixed combustion (PPC) under low engine load using formaldehyde PLIF imaging

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Partially premixed combustion (PPC) using low-reactivity fuel shows great potential for high engine efficiency as well as low NOx and soot emissions. A major challenge to PPC comes from the combustion instability under low engine load when the engine operating temperature is relatively low. The early-injection strategy used in PPC can result in an interaction between the fuel jets and piston-top and/or cylinder wall in the squish region. This jet-wall interaction may produce more unburned hydrocarbon (UHC) under low load condition. In this study, the effect of jet-wall interaction in the engine squish region on PPC was investigated on an optical engine under a load about 3 bar indicated mean effective pressure (IMEP). Formaldehyde PLIF imaging was employed to explore the low-temperature heat release (LTHR) of PPC, and in the meanwhile, served as an indicator of the UHC. High-speed nature flame luminosity (NFL) imaging was used to show the high-temperature heat release (HTHR) of PPC. Four direct-injection (DI) timings of -20°, -60°, -100° and -180° after top dead center were chosen to represent typical spray-wall interaction conditions. Results show that there is more residual formaldehyde after HTHR when the DI timings are -60° and -100° because the fuel jets just hit on the corner between the piston top and cylinder wall around these two DI timings. For the case with DI timing of -20°, fuel jets hit on the piston top where the temperature is relatively high and is in favor of better combustion. For the case with DI timing of -180°, fuel jets hit on the cylinder wall, but there is more timing for fuel evaporation before the arrival of the piston, and thus resulting in less UHC emission compared with the cases with DI timings of -60° and -100°.

![Cycle to cycle IMEP variation under different DI timing.](image)
Hydrogen/oxygen autoignition with H2O2 addition

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Hydrogen-oxygen reaction is a significant contributor to fundamental chemical kinetics. The basic kinetics involving oxygen, hydrogen, hydrogen oxide, hydrogen dioxide and hydrogen peroxide is important to understand the compositions of radical pools in hydrocarbons combustion. In this study, hydrogen combustion in air was perturbed by adding different percentages of hydrogen peroxide to observe the effect on the products. The simulations were done using Cantera. GRI-Mech 3.0 mechanism was used to model natural gas combustion in Cantera. A constant volume (1 m$^3$), zero-dimensional reactor was used in the model. The gas mixture inside the combustor was assumed to be ideal. The reactants had an initial temperature of 800 K and 20 bars pressure. Three different sets of simulations were done, in each set 5 and 10 percent of hydrogen peroxide were added to hydrogen combustion mixture. In the first set of simulations, the same Hydrogen to Oxygen ratio were retained, while in the second set the same equivalence ratio was maintained. In the third set of simulations the mole ratio of hydrogen and hydrogen peroxide were manipulated maintaining the same percentage of hydrogen peroxide (5 and 10) to obtain a close final temperature. From the result, it can be observed that the change in product compositions with different percentages of hydrogen peroxide are due to chemical effect, rather than thermal. We can hence conclude that what eventually matters in previous combustion is its composition and not its final temperature.
Assessment the accuracy of the 2-lines OH thermometry method in steady-flow flames

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Two-lines OH thermometry is the favorable option to obtain the temperature information in turbulent and transient flames. One of the limitations of this method is that the measurement in actual flow should be performed at the conditions similar to the calibration flow. This limitation is resulted from the assumption that the fluorescence yield ratio used in 2-lines (like P1(7) and Q2(11) lines) OH PLIF method is constant, and independent to temperature, pressure and composition. In this study, the temperature and composition sensitivity is tested in premixed CH4/O2/N2 stagnation flames and diffusion C2H4/O2/N2 counter-flow flames. The temperature profiles obtained with 2-lines OH thermometry method are compared with those measured using thermocouple and calculated via kinetic modelling. The results showed that the fluorescence yield ratio decreases with temperature and increases at higher quenching rate. The results of this study strongly suggest that the variation of fluorescence yield ratio should be considered in 2-lines OH thermometry method.

Experimental setup.
Oxy-fuel combustion of petcoke: Analysis using TGA-FTIR

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Petcoke is a solid carbonaceous byproduct obtained at the end of crude oil refining. It has a moderate calorific value, possesses low ash content, and is inexpensive, making it a potential energy source for power generation. In the present study, combustion of a Saudi Arabian petcoke sample under air-firing (O2/N2) and in oxy-firing (O2/CO2) conditions, were investigated using non-isothermal thermo-gravimetric analysis (TGA) coupled with a Fourier-transform infrared (FTIR) spectrometer. TG and DTG (differential thermo-gravimetry) were used to study the mass loss characteristics due to the thermal degradation of the fuel at temperatures up to 1000 °C and heating rates of 10 and 20 °C/min. The evolved gaseous products were then carried to an IR cell and FTIR analysis was performed to study the composition of the evolved gases. The measured species included CO2, CO, SO2, NO and H2O, and the evolution of various functional groups, such as aromatics, alkenes (==CH2), alkanes and carbonyl groups (aldehydes and ketones) at different temperatures were also analyzed in the different combustion environments. The results showed that oxy-firing conditions, the burnout of the fuel was better and also resulted in lower emissions of pollutants. Thus, oxy-fuel combustion can be employed as a cleaner and more efficient technology for utilizing petcoke for power generation.
Promoting the deflagration-to-detonation transition using nanosecond repetitively pulsed plasma discharges

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Constant-volume combustion has gained much support in recent years as a means of drastically increasing the efficiency of the thermodynamic cycles in combustion-based machines. One such constant-volume cycle is based on the use of detonation waves as the means of combustion. However, due to energetic considerations, the detonation is not typically initiated directly, but rather a weak ignition source is used to initiate a flame which is accelerated until it transitions to detonation. This phenomenon is known as the deflagration-to-detonation transition (DDT) and is usually achieved by introducing obstacles into the path of the flame. These obstacles enhance the turbulent flame speed of the reaction wave and result in accelerated DDT. However, such obstacles are subject to intense thermal loading and subsequent failure. The authors propose a technique of applying nanosecond repetitively pulsed (NRP) plasma discharges in order to enhance flame acceleration and DDT. Two electrodes are used in a pin-ring configuration. High voltage (24.5 kV) is applied between the positive and negative electrodes during a period of 10 nanoseconds. These pulses are repeated at a frequency of 100 kHz. The reaction wave is observed using piezoelectric pressure transducers and ionization probes. The data are obtained at a sampling frequency of 30 MHz. By utilizing time-of-flight measurements, the propagation velocity is determined and verified against the theoretical Chapman-Jouguet velocity in order to confirm a successful transition to detonation. Experimental results show significant enhancement of the DDT phenomenon, compared to results in which no forcing was applied. Energy deposition measurements were conducted in order to quantify the required energy in both the initial ignition spark as well as the NRP discharges. This technique promises a novel means of promoting DDT for applications in detonative technologies in the energy sector.

![Graph showing propagation speeds for hydrogen-air flames with and without NRP forcing.](image-url)
An IH-QCL based sensor for simultaneous detection of methane and acetylene

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Usually, the conventional DFB QCL (distributed feedback quantum cascade laser) has limited electrical tuning range. Although it can be a few times wider by changing the substrate temperature of the laser, the tuning speed is limited to Hz range when changing the substrate temperature in contrast to tens of kHz tuning rate with electrical tuning. To achieve a wide tuning range as well as a high tuning speed, Bismuto et al. placed an integrated heater (IH) within a few microns to the laser active region. This arrangement allowed the control of AR temperature much faster by changing the current injected into the integrated heater. Although, commercial external-cavity QCLs can provide relatively large wavelength access in the mid-IR region, the tuning speed is limited by mechanical movement. Another widely tuning source is a super-continuum laser but such lasers are not yet available in the mid-IR beyond ~4.2 µm and measurements carried out with super-continuum sources typically require significant averaging to suppress intensity fluctuations. In this work, we utilize this novel IH-QCL to develop a gas sensor for combustion applications. The sensor is based on scanned-wavelength direct absorption spectroscopy and enables to simultaneously detect methane and acetylene. The laser current and heater resistor current are modulated simultaneously at 25 kHz to cover absorption transitions of methane and acetylene over 1279.6-1280.1 cm⁻¹. The laser was extensively characterized to understand the dependence of wavelength tuning on modulation frequency, modulation amplitude and phase difference between laser / heater modulation. This designed sensor is validated in room-temperature static cell experiments and also applied for simultaneous detection of methane and acetylene during the high-temperature pyrolysis of iso-octane behind reflected shock waves. To our knowledge, this is the first application of an IH-QCL architecture for combustion applications.

Simulated spectra for a 2.5% CH₄, 1.5% C₂H₂, balance air mixture. T = 1800 K, P = 1 atm, L = 14 cm.
Session 4: Spray and droplet combustion
Bio-Alcohols Electrosprays for Practical Propulsion Systems

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Electrosprays of ethanol, 1-propanol and 1-butanol were examined at voltages ranging from 3 to 6 kV, and flow rates ranging from 5 to 25 ml/hr. The possibility of coupling the electrostatic spraying with combustion was examined by performing burning experiments at 4 kV and 10 ml/hr. High-speed movies were taken of the light scattered by the spray from a planar laser sheet to study the general spray and flame phenomenology, and to provide measurements of the size and velocity of droplets. When spraying along the direction of gravity, four modes of spraying were obtained. However, spraying against the direction of gravity produced another five modes. The obtained velocities corresponded to low Reynolds number, low Nusselt number but high convective heat transfer coefficients. Viscosity had a negligible effect, whereas the electric conductivity was shown to play a major role in bio-alcohol electrospraying. The bio-alcohol flames operated in two distinct modes. First in a large diffusion flame, and then a flat flame near the ground plate. Group combustion number calculation showed that he flame burnt in a group combustion mode.
Spray Characterization and Modeling for Gasoline Compression Ignition Application

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Direct injection compression ignition engines running on gasoline-like fuels have been considered an attractive alternative to traditional spark ignition and diesel engines. The compression and lean combustion mode eliminates throttle losses yielding higher thermodynamic efficiencies. In addition, the better mixing of fuel/air due to the longer ignition delay times of the gasoline-like fuels allows better emission performance such as nitric oxides (NOx) and particulate matter (PM). In gasoline compression ignition (GCI) combustion mode, the spray injection of liquid fuels is one of the most critical controlling factors and detailed characterization of these sprays will significantly help understanding these engine concepts. However, very limited studies on the spray characterization and modeling using high reactivity gasoline at GCI relevant conditions have been reported. In this study, single- and multi-holes heavy duty (HD) and ten holes light duty (LD) prototype injectors designed by Aramco specifically for GCI application were characterized using fuels with varying reactivities. Commercial diesel, gasoline and RON 70 and RON 77 gasoline-like fuels, specifically blended for GCI application, were studied under non-vaporizing, vaporizing and reactive conditions in a constant volume combustion chamber. Finally, the spray models in commercial CFD code were thoroughly calibrated to match the experimental data. This calibration process involved examining the spray parameters sensitivities and detailed internal and near nozzle flows.

Spray Characterization using diesel and GCI fuel.
Towards More Predictive Spray Simulation for Efficient Gasoline Compression Ignition Engines

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Gasoline compression ignition (GCI) engine technology offers high fuel efficiency with low engine-out criteria pollutant emissions. Research focused on identifying the relationship between fuel properties and combustion performance under GCI-relevant conditions can provide valuable insight into the design requirements of GCI engine technology. Accurate characterization of fuel sprays for high-pressure fuel injection systems is essential for high fidelity 3D computational fluid dynamics (CFD) analysis. In this study, the fuel spray of diesel and a high reactivity gasoline (research octane number of 60, cetane number of 34) was modeled under typical heavy-duty diesel engine operating conditions, i.e., high temperature and pressure, in a cubical constant-volume combustion chamber. The primary goal was to accurately model the spray auto-ignition behavior and feed the resulting spray and kinetic models into the on-going simulation-driven combustion system design process to improve fuel efficiency. The model was developed using a multi-dimensional CFD software package. A recently developed user-defined transient spray cone angle model was implemented to better capture the spray transient mixture formation. A multi-component kinetic model was used to accurately represent the fuel chemical sensitivity. The predictions were validated against available experimental results generated for a single-hole, heavy-duty injector, and showed very good agreement across a wide range of operating conditions. Compared to the diesel fuel typically used in the engine, the gasoline spray exhibited longer ignition delay and lift-off length. The effect was more pronounced at lower ambient temperatures, indicating enhanced air entrainment in the upstream regions of the spray and more premixed combustion. This has the potential to lead to better mixing, lower soot formation, and improved fuel efficiency. At low-reactivity conditions, capturing ignition was challenging and need improved turbulence and combustion models to better simulate the behavior accurately.

![Comparison of ignition delay between ULSD and Gasoline for both RANS and LES along with experiments at different charge ambient temperatures.](image)

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Heavy fuel oil (HFO), a byproduct from crude oil refining process, is a common fuel for power plants in Saudi Arabia. As a result of refining process, HFO consists of a considerable amount of large molecular weight coke precursor hydrocarbons. A significant amount of spheroidal particulates known as cenospheres result from incomplete combustion of the coke precursors, with size ranging from one to a few hundred microns. Cenosphere formation causes not only environmental pollution, but also operational problems such as slagging, fouling and erosion to downstream devices. In the current study, an isolated droplet generator was developed to uniformly produce isolated droplets whose spacing was larger than 150 times of an average droplet diameter. Freely falling droplet combustion of HFO without interference of droplet-droplet interactions was investigated in a laboratory-scale drop tube furnace. The controlled size of falling droplets were determined by a high speed camera. Subsequently, impact of operation conditions (burning temperature, initial droplet size and air co-flow rate) and asphaltene content on morphology, size and surface elemental composition of cenosphere produced from freely falling droplet combustion of HFO was investigated. The results show that three types of morphology were found in the collected cenospheres. The mean diameter of cenospheres increased with increasing of both the initial droplet size and asphaltene content while it decreased with increasing of both burning temperature and air co-flow rate. The surface elemental compositions of cenosphere depended on the type of cenosphere.
Session 5: Reciprocating engine and gas turbine combustion
Combustion properties of biodiesel derived from Black Soldier Fly oil and its blending effects on diesel and ethanol-diesel mixtures

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Black Soldier Fly (BSF) larvae have proven itself to be an economically efficient and sustainable approach to upcycle organic waste in many countries. Previous studies have shown that it is feasible to rear BSF larvae with various kinds of organic waste and then subsequently extract their fat to produce biofuel. The direct use of BSF crude oil in an engine is not applicable due to several reasons such as its high acidity value, its adverse ignition quality effects, and its poor fuel properties which lead to fuel injection problems. These problems can be avoided, and the crude oil can be converted to biofuel using a common two-step transesterification process. The resultant biodiesel’s measured properties met the requirements as specified by ASTM standards, demonstrating its applicability in a compression ignition diesel engine. No comprehensive studies have yet investigated the chemical composition profile and blending effects of black soldier fly biodiesel with regular diesel and diesel-ethanol mixtures. In this study, BSF biodiesel or fatty acid methyl esters (FAME), was prepared using a two-step transesterification process. The first pretreatment acid-based esterification was done using a 1% H2SO4 in methanol solution at a 4:1 methanol to oil weight ratio at 60°C for 120 minutes. The second base-catalyzed transesterification was done using a 1.5% NaOH in methanol solution at a 4:1 methanol to oil weight ratio at 60°C for 90 minutes. Lauric acid methyl ester (C12:0) made up the major component of the saturated BSF biodiesel at 27.8%, this led to better flow properties than the unsaturated sunflower biodiesel and a slightly lower but more desirable DCN than the saturated biodiesel derived from waste kitchen oil. To study the BSF biodiesel blending effects, the ignition quality and kinematic viscosity of BSF biodiesel blended with both regular diesel and diesel-ethanol mixtures were analyzed to determine the optimal range of blending ratios.

Basic properties of BSFME and diesel blends: (1) distillation curve (°C) (2) kinematic viscosity at 40°C (mm²/s).
HCCI and PPC Mode Combustion in Compression Ignition Engine with Low Octane Gasoline

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The present study is an experimental and numerical investigation on the in-cylinder combustion for low octane 70 primary reference fuel (PRF70) by the method of the flame index during the transition from homogeneous charge compression ignition (HCCI) combustion to partially premixed combustion (PPC). Full cycle engine simulations were performed using the three-dimensional computational fluid dynamics code CONVERGETM, coupled with gas phase chemical kinetics. Good agreements between the simulations and experiments of combustion and emission were achieved at HCCI and PPC combustion modes. The fully premixed HCCI mode was achieved at the earliest injection timing of -180 CAD aTDC with the combustion temperature below 1600 K, where the formation of soot and NOx can be successfully avoided. For the injection timing of -100 CAD aTDC, the premixed charge compression ignition (PCCI) was achieved where the premixed combustion clouds were mainly distributed in the piston top-land zone and were surrounded by the diffused combustion that occurs in the piston bowl and the periphery of piston top. Less premixed flames were formed in piston top and surrounded by more diffusion mixtures at PPC mode. The in-cylinder HO2 evolution profile displayed two bumps which were distributed in low temperature zone and high temperature zone respectively. The spatial and temporal evolution of HO2 is very similar to the distribution of premixed flames.

![Graph showing the variation of flame index in the main combustion region under HCCI and PPC modes.](image)

The variation of flame index in the main combustion region under HCCI and PPC modes.
A Critical Review on Combustion Characteristics of Diesel Engines on Using Additive Blended Diesel and Biodiesel Fuels

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This paper highlights the combustion characteristics of diesel engines on using various additive blended diesel and biodiesel fuels. Various fuel combustion characteristics (such as cylinder peak pressure, ignition delay, heat release rate, maximum heat release rate, maximum pressure rise rate and combustion duration) of diesel engine reported by recent researchers have been discussed in this paper. Information reveals from the recent works that the nature of additive blended with a base fuel affects the combustion characteristics of a diesel engine considerably. Recently, many researchers have incorporated various nano-additives (such as Carbon Nanotubes (CNT), ceria nanoparticles, alumina nanoparticles, Di-Ethyl Ether, etc.) with both diesel and biodiesel fuels in specific proportions to achieve better working characteristics of diesel engines. The addition of nanoparticles to both diesel and biodiesel fuels have influenced some variations in combustion attributes of diesel engines. Nano-additive blended diesel and biodiesel fuels have reflected decrement in cylinder peak pressure and ignition delay when compared to that of neat diesel and neat biodiesel fuels at the rated load of the diesel engine. Owing to enhanced surface area/volume ratio and better ignition properties of nanoparticles, the cylinder peak pressure and ignition delay were reduced for the nano-additive blended diesel and biodiesel fuels. Further, owing to those effects, some nanoparticles (such as alumina and CNT) were also incorporated with water-diesel-biodiesel emulsion fuels and observed an appreciable enhancement in terms of performance, emission and combustion attributes of diesel engines.
Optimizing Injection strategy for Pre-ignition suppression in turbocharged Gasoline Direct Injection Engine

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Pre-ignition is a common problem for highly boosted gasoline spark ignited engines. Ignition may stochastically happen before the spark plug ignites, which may lead to high knock intensities, often termed as ‘super-knock’. A single super-knock event may lead to engine break-down and hence has been a major concern for automotive makers. Previous studies have reported reduction in pre-ignition tendency by splitting the injection into two and three pulses. In the current study, injection strategies have been investigated and optimized for pre-ignition reduction. It was observed that splitting the injection into two and three pulses drastically reduces the tendency of the engine to pre-ignite. Moreover, optimizing the duration of injection and start of injection of injection of the split pulses can yield safe operation in terms of zero pre-ignition. However, this may come with compromises on indicated mean effective pressure (IMEP) and cycle-to-cycle variation (CoV). The study further explores strategies to minimize the losses in IMEP and CoV, while maintaining safe operation. It is found that splitting the injection into two pulses, with second pulse injected close to top dead center, is a highly effective strategy to suppress pre-ignition.

Destructive run-away pre-ignition.

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This presentation discusses the results of the effect of combustion duration on the engines operating, performance and emissions characteristics of a hydrogen-ethanol dual fueled engine. The tests were conducted on a compression ignition engine (modified to run on spark ignition mode) fueled with hydrogen-ethanol dual fuel combination with different percentage substitutions of hydrogen (0-80% by volume with an increment of 20%) at a constant speed of 1500 rpm and a load of 100% in kW by adjusting the loading switches. These tests were conducted at three different compression ratios of 7, 9 and 11. The various engine operating parameters like compression ratio, equivalence ratio, spark timing, and engine’s performance parameters like brake power, brake specific fuel consumption, brake mean effective pressure, and brake thermal efficiency effect on combustion duration were studied. In addition, the various engine emission characteristics like CO, Hydrocarbon, NOx and exhaust gas temperature effects were also studied. The best operating conditions for the performance and emissions were obtained at a compression ratio of 11:1 and the optimum fuel combination was found to be 60-80% hydrogen substitution to ethanol. For better performance in terms of power and emissions, it was found from the present study that the combustion duration has to be 38° and 25° crank angle respectively. The present results revealed that at 100% load CO and HC concentration decreased with the increase in percentage of hydrogen addition and combustion duration for all compression ratios. It is also observed from the present study that the retarding combustion duration is preferred for NOx emission control and to avoid knock in the engine.
Onboard reforming for improving spark-ignition engine efficiency

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Originally proposed in the 1970s, onboard reforming has gained interest in recent years as tightening fuel economy standards push automakers towards ever-more innovative technology. Onboard reforming concepts fall into three broad technology categories: intake air reforming, in-cylinder reforming, and exhaust reforming. Although applications exist for various engine types, the most obvious benefits are for gasoline, spark-ignition engines-where onboard reforming can improve knock tolerance and dilution tolerance, while recycling waste exhaust enthalpy into fuel. In this work, recent results on onboard reforming will be presented, including those pertaining to both in-cylinder and exhaust reforming concepts. Testing on a GM 2L engine was conducted where a post-combustion fuel injection event during the exhaust stroke was used to provide fuel for reforming. A reforming catalyst was installed directly after the exhaust port. Catalyst temperatures and product concentrations were monitored over a range of engine operating conditions. In total three catalysts and two fuels were screened using this setup. The best performing catalyst generated an exhaust stream containing 9.5% H2 at the maximum condition, with an optimal oxygen-to-carbon (O/C) ratio for hydrogen yield. The fuel energy balance (heat of combustion of input fuel divided by heat of combustion of reformate products) was greater than one for most cases, with a maximum of 1.4. Fuel energy balance was also shown to have an optimal O/C ratio, which was slightly higher than the optimal OC ratio for hydrogen yield. The results are promising as hydrogen yields of 6 - 9% would potentially enable charge dilution rates of 40-50% - well beyond those (20-25%) currently possible with today’s production gasoline engines. Furthermore, the knock benefits of the reformate would yield an increase of about two knock-limited compression ratios. However, the most striking finding may be that there exists substantial potential for using onboard reforming as a waste-heat recovery device, the efficiency benefits of which appear to be as or more significant than the improvements in engine efficiency.

Onboard reforming for improving spark-ignition engine efficiency.
The ignition regime diagram of n-heptane/air mixtures with temperature and concentration fluctuations

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The ignition characteristics of a n-heptane/air mixture with temperature and/or concentration fluctuations involving the negative temperature coefficient (NTC) is studied using direct numerical simulation (DNS). In this study, n-Heptane is chosen to validate the ignition regime diagram and ignition criterion proposed by Im et al. n-Heptane exhibiting a typical NTC behavior has been widely used as a surrogate for complex diesel-like fuels. The sensitivity of the ignition characteristics to a different degree of temperature and/or concentration fluctuations in conjunction with varying mean temperature within/outside the NTC regime is systematically investigated to validate the proposed ignition regime theory. It is demonstrated that the proposed ignition regime diagram has the capability of predicting the strong and weak ignition mode with good fidelity regardless of different initial mean temperatures and the levels of mixture fluctuations. It is confirmed that with the thermal fluctuation is most effective in inducing a weak ignition at the high- and low-temperature regimes while mixture fluctuation is favored within the NTC regime in which the synergistic effect of temperature and concentration fluctuations enhances deflagration mode. In addition, statistical analysis based on Sakaran number criterion is also examined by relying on the fraction of Sa greater than 1 that is proposed to have a connection with the combustion modes. For a given field of an initial condition from DNS, Sa numbers are computed spatially such that the fraction of Sa number greater than 1 can be readily obtained. It is found that the increased propensity of reaction front propagation is strongly correlated to the increased fraction of Sa greater than 1 whereas a small fraction is more likely to induce a stronger ignition event.
Predict SI knock occurrence through autoignition in HCCI conditions

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Knock is a sharp metallic noise resulting from the autoignition of the end-gases into Spark Ignition (SI) engine which could cause serious damages to the engine. To prevent such undesired autoignition, practical gasolines are described with two octane numbers: the Research Octane Number (RON) and the Motor Octane Number (MON). These two octane numbers are rated with a Cooperative Fuel Research (CFR) engine running respectively at 52°C and 600 rpm for RON and at 149°C and 900 rpm for MON. Together, RON and MON reflect the fuels behavior in SI engines but modern SI engines tend to operate beyond those boundaries. It results that RON and MON became obsolete and they cannot fully describe fuels behaviors. As understanding the end-gases autoignition is still challenging, new attempts were developed to evaluate fuels behaviors. One recent attempt extrapolates the motoring traces and uses computed ignition delays together within the same pressure-temperature map to explain autoignition over a wide range of conditions. Despite the valuable approach, this method does not fully reflect end-gases autoignition as it is impossible to experimentally access autoignition data of stoichiometric or slightly rich air/fuel mixtures in SI engines. However, it is doable to access experimentally the autoignition of lean air/fuel mixture through Homogeneous Charge Compression Ignition (HCCI) engine experiments. Ignition delays computed under lean conditions (φ = 0.3) showed that the low temperature combustion of fuels, when it exists, are amplified compared to the stoichiometric ignition delays computed. It is therefore valuable to run lean HCCI experiments so knock occurrence in SI engines could be predicted. The present talk aims to introduce recent and ongoing HCCI experimental results obtained in a CFR engine and how these results can help to understand fuels behavior and predict knock occurrence. In particular, results obtained at 600 rpm for different fuels and for a wide range of operating conditions will be presented within a pressure-temperature diagram. The areas corresponding to the low temperature combustion and high temperature combustion will be delimited and comparison with simulations will be showed.

![Diagram](image)

Low temperature combustion domain for PRF90 (dash dot line), PRF 95 (dash line) and PRF100 (solid line).
Effect of physical properties of fuel on gasoline compression ignition

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This study presents the effect of physical properties of fuel on gasoline compression ignition (GCI) through testing of various surrogate fuels. Engine experiments were performed in a single cylinder optical engine at a compression ratio of 9.5. The engine was operated at a speed of 1200 rpm under low load (IMEP 3 bar) and lean condition (λ = 5). In-cylinder imaging of the combustion process is accomplished through an optical piston and high-speed color camera. The fuel injection pressure is fixed at 500 bar whereas the start of injection (SOI) is changed from CI mode (-10 CAD aTDC) to HCCI mode (-180 CAD aTDC) via PPC mode (-30 CAD aTDC). While the real GCI fuel (RON = 77) was tested, PRF77 and TPRF77 were investigated as surrogates for the real gasoline fuel. Furthermore, a multi-component surrogate (MCS) fuel with a composition of heptane, iso-octane, toluene, n-pentane, 2-methyl hexane and cyclo-pentane was also tested as surrogate for the real GCI fuel. In order to maintain combustion stability and IMEP ~3 bar at all combustion modes, an intake air temperature of 140°C is required. High luminous images are observed at CI mode and the intensity of images decreases as SOI is advanced to early fuel injection timings, indicating more homogenous combustion. At HCCI mode, all surrogate fuels replicate the behavior of real fuel as combustion is mostly governed by chemical kinetics. At spray driven combustion modes (PPC and CI), PRF77 and TPRF77 do not behave the same like the real fuel in terms of combustion phasing. For the same combustion chemistry, physical properties do impact the combustion phasing behavior at PPC and CI modes. The combustion phasing of the MCS was also found to be different from the real fuel at PPC and CI modes. It was identified that the MCS fuel was formulated based on the fuel chemistry and physical aspects were not taken into account. Thus, an improved MCS fuel that considers both the physical and chemical properties has to be formulated.
CFD Study of Increased Efficiency Using Multiple Injectors

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One of the major problems with internal combustion engines today is the high amount of emissions. A strategy to get rid of this is to simply increase the efficiency of the engine which leads to less fuel being used. Since a major part of the energy losses comes from heat transfer through the cylinder walls, an approach to reach higher efficiency is to keep the temperature lower close to the walls. This CFD study uses a multiple injector strategy in a Volvo D13 engine with diesel as fuel to achieve this. With multiple injectors, the impingement on the wall, normally a problem in diesel engines, can be reduced and so less hot gases will be close to the walls. This is achieved through creating a swirl motion with the sprays instead of spraying straight towards the walls. The study was performed using the 3D Converge CFD tool and no experiments have been executed. A number of different cases evaluating different placements of the injectors as well as angles of the sprays showed that by altering these parameters, higher efficiency can indeed be reached. As expected the temperature close to the walls (and so the heat transfer) were in general lower for the multiple injector cases compared to the single injector. However, some cases showed the opposite depending on various factors such as that the impingement was not reduced and the hot gases spreading over a larger wall area followed by an increased heat transfer. This means that the angles as well as placement had to be timed together to achieve minimum heat losses. The IMEP was also in general higher for multiple injector cases, further proving the benefits.
Session 6: Fuel Production, Properties and Utilization
A proposal of cetane sensitivity and its relation to octane sensitivity

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Cetane number (CN) is a commonly used metric to rate the ignition quality of distillate fuels. In this work, a concept of cetane sensitivity (CS) is proposed, which captures the temperature sensitivity in ignition delay time (IDT) obtained with an ignition quality tester (IQT). The concept is based on the determination of derived cetane number (DCN) using the ASTM D6890 standard and IDT obtained at a temperature lower than that prescribed by the standard. The IDT measured at this lower temperature is referred to as IDT$_{l}$, which is obtained via a calibration procedure similar to the ASTM standard, but with a higher reference IDT for n-heptane. The IDT$_{h}$ (measured at the DCN condition) of the test fuel and a binary mixture of iso-octane and n-heptane known as primary reference fuel (PRF) used in octane number (ON) tests is identified, such that both the test fuel and PRF (referred as PRF$_{h}$) have matching DCN. In a similar manner, a corresponding PRF (PRF$_{l}$) that matches the IDT$_{l}$ of the test fuel at the lower temperature is obtained. The CS is defined as the ratio of DCN of two PRFs: PRF$_{h}$ and PRF$_{l}$, and is observed to be correlated with the octane sensitivity (i.e., OS = RON − MON) of the test fuel. The research octane number (RON) and motor octane number (MON) values of a wide range of fuel classes that includes surrogate fuels and fully blended practical fuels were estimated, and showed satisfactory agreement with existing measured RON/MON values. The RON values of many pure components that could not be measured with standard test methods were also estimated. The CS of two certification diesels and Saudi Arabian pump grade diesel was also determined.

![Graph showing IDTs measured in IQT of fuels with similar RON but different OSs. Values in parantheses indicate RON and MON, respectively.](image)
Investigating Antagonistic effects on DCN of Gasoline-Alcohol mixtures using Gaussian model

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Studying the ignition response alcohol blending with petroleum fuels is a subject of practical and research interest. Analogous to the octane number, Derived Cetane Number (DCN) of gasoline fuels non-linearly decreases with the addition of lower carbon number alcohols. However, predicting the extent of the non-linearity is not fully established as it involves unknown inter-molecular interactions between base fuel components and the blended alcohol. There is clear evidence that the non-linearity depends on the structural composition of base fuel considered and the type of alcohol chosen. Gasoline fuels containing hundreds of different compounds making it challenging to clearly understand the antagonistic effect observed in the blending studies. In this study, the DCN of Primary Reference Fuels PRF 60, 70 and 84 and three Fuels for Advance Combustion Engines (FACE) gasoline namely FACE I, A and J were blended with two alcohols - propan-1-ol and butan-1-ol, and measured using Ignition Quality Tester (IQT) following ASTM D6890 method. A molar based Gaussian fit was used to model the antagonistic effect and it has successfully fitted the data to greater than R² = 99%. By analysing the Gaussian parameters and formulating crucial equations, the antagonistic effect of different combination of fuels is clearly explained. Finally, a linear regression tool was considered to give insights into the effects of structural composition on antagonistic blending effects.

DCN* vs. Alcohol (POH & BOH) mole-fraction for PRF 84. The IP’s x1*,x2* correspond to POH & BOH respectively.
Selective Aerobic Oxidation of Hydrocarbons Using NHPI Based Catalysts for Cetane Enhancement

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Gasoline compression ignition (GCI) utilizes gasoline-like fuels in low temperature compression ignition (CI) engines. As a result, thermal efficiency is increased compared to conventional spark ignition (SI) engine, while NOx and soot tailpipe emissions are reduced compared to diesel engine. However, this combustion strategy requires gasoline fuel with moderate ignition delay. In addition, high ignitability fuel is required for cold start and high load demand conditions. This work investigates a process to control the ignition characteristics of gasoline to widen the GCI engine operation conditions. Selective aerobic oxidation of hydrocarbons using N-hydroxyphthalimide (NHPI) catalysts under moderate reaction conditions has been suggested as an effective method to produce high cetane components. Cetane number (CN) enhancement has been studied through selective aerobic oxidation of Saudi gasoline using various NHPI-based catalysts at different reaction conditions. Ignition quality tester (IQT) was used to estimate the derived cetane number (DCN) of the oxygenated product fuel. A detailed parametric study was performed to optimize the reaction conditions as a function of cetane improvement. The bare NHPI was proved to be a robust catalyst that enhanced the cetane number of 91RON gasoline from 20 to 28, while supporting NHPI over silica can further improve the cetane number of the product. Selective aerobic oxidation of gasoline using NHPI-based catalysts is found to be a promising technology to control the ignition characteristics of fuel and hence enable GCI engine concept.

The effect of catalyst type on the cetane number of oxygenated gasoline products.
Screening high cetane molecules

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High cetane molecules can be used in several practical applications e.g., enabling gasoline and naphtha streams in gasoline compression ignition (GCI) engines. They can also serve as the blendstock with liquefied petroleum gas (LPG) for heavy duty and marine applications. Here, we first present several high cetane molecules that we have shortlisted for GCI application based on several criteria. The criteria we have set for these molecules include compatibility with gasoline and naphtha streams and viable industrial production infrastructure through conventional, bio and advanced non-bio routes. We then present some interesting ignition quality tester (IQT) based derived cetane number (DCN) and ASTM based cetane number trends for these molecules. It is shown that blending these high cetane molecules with gasoline and naphtha streams could raise the cetane of the blend for GCI application. Furthermore, we present an automated methodology which would allow us to screen for new molecules and advanced fuel formulations in the chemical space using artificial neural networks (ANN) and machine learning. Such machine learning based methodology could be similarly applied to other transportation applications e.g. for screening of high octane molecules.

Cetane number of gasoline and naphtha blended with 15\% OMEx as a function of 2-EHN.

Cetane number of gasoline and naphtha blended with 15\% OMEx as a function of 2-EHN.
Autoignition Enhancement of MeOH-Air Mixture by DME Addition

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Alternatives to the petroleum-based fuels should satisfy the energy efficiency, economical feasibility, clean combustion, and sustainability. Methanol (CH3OH, MeOH) has been considered to offer clean and efficient combustion due to the possession of an oxygen atom and fast burning velocity. Moreover, what makes MeOH more attractive is the fact that it can be produced from the solar energy, potentially being able to serve as a good alternative energy source. However, MeOH's high octane number (106) tends to limit the fuel utilization to the spark ignition (SI) mode. In this study, to ascertain the feasibility of the use of MeOH in CI engines, we adopted dimethyl ether (CH3OCH3, DME) as an ignition improver and computationally investigated the effects of DME addition on the autoignition of MeOH/air mixture in a one-dimensional counterflow configuration at CI engine relevant conditions. Different sets of parametric studies have been made; by changing the DME % to the fuel stream i) at a uniform temperature conditions (TF = TO = 850 K), and ii) at an elevated air temperature conditions (TF = 850 K and TO = 850-1300 K) for a fixed pressure, p = 40 atm. Detailed analysis has been done with computational singular perturbation (CSP), where all chemical kinetics are mapped onto the newly introduced basis vector, and by analyzing the most energetic mode (called explosive mode) among all CSP modes, the ignition process is analyzed. In the results, it turned out that while DME addition significantly advanced the autoignition of MeOH-air mixture at a uniform temperature, the effects of DME addition was diminished as the air side temperature is increased. When the air side temperature is sufficiently high (i.e., TO = 1300 K), the addition of DME retarded the autoignition timing of MeOH/air since the high temperature reaction of MeOH became more reactive in such high temperature. In the presentation, general discussions about the identified reactions and species contributing to the explosive characteristics of the CSP mode will be made.
In this study, the response of a liquid-fueled resonant pulse combustor to changes in fuel composition was investigated. Experiments were performed with gasoline-diesel and gasoline-ethanol mixtures selected to produce a meaningful variation in the ignition delay time. Through a review of ignition quality test (IQT) data, it was expected that the overall ignition delay time would increase for gasoline-ethanol mixtures relative to gasoline, and decrease for gasoline-diesel mixtures. Using the phase of peak pressure as a proxy to mark variation in heat release timing, the experimental results for the case of gasoline-ethanol displayed an agreement with the IQT data with a near linear increase with decreasing gasoline concentration. However, for the case of gasoline-diesel, there exists no linear relation with the IQT data. Furthermore, it was shown that small changes in ignition delay can significantly alter the coupling between the unsteady heat release and resonant acoustic pressure wave and thus the performance of the combustor. Dynamic combustion chamber pressure, stagnation temperature and pressure are recorded after a fixed warm-up time to characterize the performance and operation of the device. Results are interpreted in the context of fuel sensitivity and performance optimization of resonant pulse combustor for pressure gain turbine applications.
Thermo-Neutral Reforming of Diesel for Auxiliary Power Unit (APU) Application

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There is a significant interest in fuel cell technology applications due to environmental legislations for CO2 and other greenhouse gases emissions that demand the use of high efficiency energy production systems such as solid oxide fuel cell (SOFC) technology. Fuel cells are characterised by high operation efficiency, which results in decreased fuel consumption, and low environmental impact. A fuel cell is a device that converts the chemical energy of a fuel directly into electricity through electrochemical reactions, with significant waste heat making the overall system very efficient. SOFC technology has great potential of its application as auxiliary power unit (APU) for heavy duty vehicles during idling applications. Diesel based SOFC APU units are expected to be about 15-20\% more efficient compared to commercially available diesel based APUs resulting in significantly lower CO2 footprint and lower emissions of criteria pollutants with almost no noise.

Thermo-neutral reforming (TNR) of diesel to produce hydrogen-rich syngas can be a viable source of fuel for solid oxide fuel cell based auxiliary power unit (APU). The fuel reforming process, which is integrated with a SOFC for APU application, plays an important role in APU system. The reformate gas consisting mainly of hydrogen, carbon monoxide, water and carbon dioxide is generated with diesel fuel reforming. The reformate produced will be sent to SOFC stack for electrochemical oxidation operating at temperatures around 800°C. However, diesel reforming has major challenges due to its high carbon content, aromatics, and sulphur, which play a major role in catalyst deactivation. The presentation will focus on ongoing diesel reforming catalyst development research work at Saudi Aramco Research and Development Center in collaboration with King Fahad University of Petroleum and Minerals (KFUPM).
Power Plants with No Smokestacks! Numerical Investigation of advanced engine cycles with working fluid of CO2

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It is exciting times in combustion. Combustion is a cause of climate change and thus is likely part of the solution. Ideas that were heretofore considered expensive are now being considered seriously. In this paper, we examine a new engine cycle that uses working fluid different from Air. The fluid we consider is CO2 in a Brayton cycle (regenerated). Our findings include the following observations: 1. A challenging part of the CO2 cycle will be the purification section, where water, NOx, and SOx will need to be removed. However, we propose burning at stoichiometric ratios, Lambda=1, such that a 3-way catalyst can be part of the exhaust cleaning. 2. Using working fluid (CO2) near critical point greatly reduces compression work by approx. 50%. 3. The new engine cycle efficiency is comparable to that of combined cycles; i.e. gas turbines combined with steam 'bottoming cycles' (i.e. Rankine Cycle).

![Comparison of compression work of ideal a real CO2.](image)

Comparison of compression work of ideal a real CO2.
Direct injection compression ignition engines running on gasoline-like fuels have been considered an attractive alternative to traditional spark ignition and diesel engines. The compression and lean combustion mode eliminates throttle losses yielding higher thermodynamic efficiencies and the better mixing of fuel/air due to the longer ignition delay times of the gasoline-like fuels allows better emission performance such as nitric oxides (NOx) and particulate matter (PM). These gasoline-like fuels which usually have lower octane compared to market gasoline have been identified as a viable option for the gasoline compression ignition (GCI) engine applications due to its lower reactivity and lighter evaporation compared to diesel. The properties, specifications and sources of these GCI fuels are not fully understood yet because this technology is relatively new. In this work, a GCI fuel matrix is being developed based on the significance of certain physical and chemical properties in GCI engine operation. Those properties were chosen to be density, temperature at 90 volume % evaporation (T90) or final boiling point (FBP) and research octane number (RON) and the ranges of these properties were determined from the data reported in literature. These proposed fuels were theoretically formulated, while applying realistic constraints, using species present in real refinery streams. Finally, three-dimensional (3D) engine computational fluid dynamics (CFD) simulations were performed using the proposed GCI fuels and the similarities and differences were highlighted.
Existing power systems are not sufficiently clean and inadequate to meet the needs of the poor in the world and jeopardize the success of the Millennium Development Goals (MDGs). The global community should aim to provide clean energy technologies for the sustainable environment. Recently, the automotive industry is focused on clean after-treatment technologies. As an instance, SOFC technology is the type of fuel cell that is most demanded in terms of materials and which tries to develop due to potential market competitiveness. SOFCs have emerged as a serious fuel cell technology in recent times. It is envisaged that they will be extremely useful in large, high-powered applications such as FULLSCALE. Lately, the rise in energy prices and developments in material technology has led to renewed work in SOFCs, and a recent report showed that about 40 companies were working on this. More than 100 thermal cycling and less than 0.1% in a thousand hours the interest in SOFCs is increasing steadily because of voltage distortion. A SOFC mainly consists of two electrodes. Oxygen ion transport based on SOFC, O2 is also expensive to produce with high purity hydrogen and can not withstand this difficult to handle fuel. So far, SOFCs have been operating at 1000°C with the lowest fuel economy. Unfortunately, this high temperature reduces cell life and increases cost. The cost of fuel is increasing when expensive high-temperature alloys are used in the home of the plant and expensive ceramics are used for the interconnects. For several years, scientists and researchers around the world are doing research to reduce the working temperature of SOFCs without compromising their performance. The environmental impact of SOFC use depends on the fuel source rich in hydrogen used. If pure hydrogen can be used, there is no emission of fuel cells except water and heat.
Unconventional oxidizers and fuels in HCCI internal combustion engine

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Climate change and the anticipated stringent emission regulations require lower carbon footprint and higher efficiency for future internal combustion engines. Homogeneous charge compression ignition (HCCI) is a low temperature combustion technique that is utilized for efficient combustion engines. It allows the combustion of a lean mixture at relatively higher compression ratios enhancing the thermodynamic efficiency. As the name implies a homogenous charge of the oxidizer and fuel is compressed until it auto-ignites. Most engines have a brake efficiency of 30-40% due in part to the thermodynamics. Thermodynamic efficiency is directly proportional to both the compression ratio and the specific heat ratio. Using a high specific heat ratio gas like Argon (κ=1.67) as the working fluid in an HCCI engine could ensure increasing both parameters. In this study the ratio of specific heats (κ) of the charge is increased by replacing the Nitrogen in the oxidizer with Argon. The fuel used in the experiments is Iso-octane. The experiments are conducted in a standard Waukesha variable compression ratio CFR engine that has been modified to be run in HCCI mode in order to find the efficiency and assessing the possibility of commercial production of such engines. Future improvements could be replacing the fuel with hydrogen. In this way the exhaust gases will contain only Argon, Oxygen (in lean conditions), and water. Water can be condensed in a condenser and the Argon and Oxygen could be rerouted to the intake. This engine will have zero carbon emissions and also high efficiency. However, this engine concept still faces some challenges to find its way to industry. The relatively low volumetric energy density of hydrogen requires large tanks. Also, compact air separator is needed to supply oxygen to the engine. This requires a full well-to-wheel energy analysis for this idea.

Thermal Efficiency - Otto Cycle

\[ \eta_{\text{ Otto}} = 1 - \left( \frac{V_2}{V_1} \right)^{\kappa - 1} = 1 - \frac{1}{CR^{\kappa - 1}} \]

Thermodynamic efficiency.
Treatment of fly ash by thermal plasma: Simulation of toxic element volatility during treatment

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The treatment of fly ash obtained from different power plants was investigated using thermal plasma technology. The fly ash samples subjected to the plasma treatments during this work were obtained from the power plants that combust heavy fuel oils in Saudi Arabia. The elementary analyses of the fly ash samples were carried out using CHNOS analyzer and an Inductively Coupled Plasma (ICP). The results of these analyses have shown that the fly ash samples contain mainly carbon (i.e. more than 90% by weight) + different metals. A thermal plasma reactor was employed for the separation of carbon from other metals by the means of pyrolysis/combustion. The toxic elements of the fly ash were vitrified and released from the reactor in a non-leachable glassy slag form. A computer code was developed to estimate the volatility of toxic lead and arsenic during the treatment of fly ash by plasma. This model was based on the calculation of the system composition using the free enthalpy minimization method, coupled with an equation of mass transfer at the rectional interface. The model so developed, was utilized to assess the effects of plasma temperature, discharge current, gas and the chemical composition of the carrier gas on the volatility of lead and arsenic.

Reactor for treatment of fly ash by thermal plasma.
Soot is a natural byproduct of combustion and is hazardous to human health and the environment. The effects of pressure, such as those found in practical combustion devices, on soot formation is not well understood. In this study, the soot formation process was investigated at pressures up to 16 bar using a laminar non-premixed coflow flame with nitrogen-diluted ethylene. Soot is formed from polycyclic aromatic hydrocarbons (PAH). The evolution of PAH in the flame was studied using planar laser-induced fluorescence (PLIF) with the excitation laser set at 282.85 nm. The fluorescence signals were captured with an ICCD camera using bandpass filters of increasing wavelength (350 nm, 400 nm, 450 nm, and 510 nm) corresponding to an increase in PAH size. Peak signal from PAHs moved closer to the burner nozzle as pressure increased indicating soot formation processes beginning sooner as pressure increases. To measure the soot volume fraction (SVF), 2D diffuse line-of-sight attenuation (2D LOSA) and planar laser-induced incandescence (PLII) were used. At pressures below 6 bar, the diagnostics who good agreement. At pressures above 6 bar, the diagnostics began to diverge, with 2D LOSA showing peak SVF values to be higher than PLII and located lower in the wings of the flame. The differences between the two measurements were explored using Rayleigh-Debye-Gans approximation for fractal aggregates (RDG PFA). It was found that LOSA is highly sensitive to the soot primary particle diameter.
Modeling turbulence-chemistry interaction

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Reduction of combustion-generated pollutants, such as soot and soot, is becoming increasingly important due to the rising environmental concerns. Computational fluid dynamic (CFD) simulations using the Reynolds-averaged Navier-Stokes (RANS) are commonly used as a cost-effective way to predict the combustion and emission performance. In the RANS formulation, a proper closure of the chemical source terms is critical in the fidelity of the simulation. In the past, the eddy dissipation concept has widely been used, and the partially stirred reactor (PaSR) model has recently been employed as an improvement, as a way to represent the complex turbulence-chemistry interaction by accounting for the characteristics time scales of mixing and chemistry. While the PaSR approach is in general considered to yield improved results, clear validations are needed for different applications. The present study proposes and demonstrates an effective method to validate different combustion submodel without having to conduct full CFD simulations, by the stochastic reactor model as a representation of the target turbulent combustion system. A set of ordinary differential equations, describing a perfectly stirred reactor (PSR) model, were solved using both EDC and PaSR combustion submodels, and the results were compared against those obtained by the stochastic reactor model. The results show that the PaSR model yields a better agreement with the stochastic model results. In particular, as the Damköhler number of the system decreases, the slower chemical time scale becomes more important, and the PaSR model prediction shows a significant improvement over EDC.

Modeling turbulence-chemistry interaction.
Characterization of the dynamics of a small-scale bluff body stabilized lean hydrogen air flame

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Bluff body stabilization is often exploited in combustion systems and thus it has been frequently studied both numerically and experimentally. Abundant experimental works are available for this configuration for several working conditions and geometries. One of the most known is the the Volvo experiment, where the flame was characterized measuring several variables: velocity, temperature and CO mass fractions. These experimental works have been extensively used as a case test for validating several kinds of numerical simulations. Most of the available experimental data deal with dimensional scales typical of actual applications in engines, with bluff bodies of characteristic length of few centimetres. The objective of the present work is providing quantitative experimental data at a scale suitable for validating results from high fidelity fully resolved simulations. A stainless steel, square cross-section rod 1 x 1 mm has been used as a bluff body for stabilizing a 0.5 equivalence ratio flame over slot burner featuring a 20 x 10 mm nozzle with a nitrogen co-flow. Three mass flow controllers were used to achieve the desired flow velocity and equivalence ratio. The measurements carried out to characterize the flame are the following: velocity characterization by hot wire, OH*-chemiluminescence imaging with an intensified CCD camera (Princeton Instruments, PIMAX) equipped with a band-pass optical filter centered at 310 nm (ZBPA310 Asahi Spectra Co.), temporal evolution of the global OH* emission of the flame with a photomultiplier tube (Hamamatsu H10721). Some preliminary results have been collected, namely blow-off velocity and OH*-chemiluminescence for tracking the mean flame position for different flow velocities. According to this preliminary test the blow-off velocity for this configuration is $50 \pm 5$ m/s, and the mean flame position shows a light dependence on the flow speed. The upcoming measurements, will explore different equivalence ratios in the lean side and complete all the other planned characterizations.

Direct visualization of the bluff-body stabilized hydrogen-air flame (equivalence ratio 0.5, main axial velocity of the flow 35 m/s). Exposure time 1 s.
An experimental investigation on single Heavy Fuel Oil droplet combustion

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Several complexities are associated with the combustion of heavy fuel oil (HFO). A better understanding of this phenomenon is necessary to improve modern technologies in order to reduce the impact on the environment and enhance the efficiency of the process. The purpose of this research is to analyze the effect of operative conditions on the combustion of a single suspended HFO droplet. Various solutions, like emulsions and different asphaltene content, were explored in order to quantify their influence on the combustion behavior and on the stability of the evaporative process. The experiment consists in the suspension of the single droplet on a thermocouple wire in a hot environment. The whole evaporation and eventual combustion are recorded with a high-speed camera and the collected images are post-processed in order to track the interface. From the experimental findings, it is possible to identify the combustion stages and to compute the evaporation ratio and ignition delay time. Another fundamental aspect that is treated is the microexplosive behaviour that is of key importance in spray combustion and highly influenced by the above-mentioned parameters.
Measurement of the laminar burning velocity isochorically from a constant volume vessel using a multi-zone model

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A detailed understanding of flame speed is essential to provide a deeper insight into insights into heat release rates, flammability limits, propagation rates, emission and quenching characteristics. A multi-zone model has been employed to evaluate the laminar flame speed isochorically using a thermodynamic analysis of the pressure vs. time data registered during the combustion in the constant volume spherical vessel. This thermodynamic model determine the temperature distribution within the burned gas and relationship between the mass fraction burned and pressure rise confined in a constant-volume vessel. In this model, the pressure is allowed to rise due to the constant volume, and thus due to adiabatic compression, the laminar flame propagates into higher pressure and higher initial temperature reactants as the flame progresses. With this multi-zone model laminar flame speed can be computed at higher pressure at which limitations for experimental measurement exist. In the present study, various gaseous fuel (CH\textsubscript{4}, C\textsubscript{2}H\textsubscript{6}, C\textsubscript{3}H\textsubscript{8}, n-C\textsubscript{4}H\textsubscript{10}, i-C\textsubscript{4}H\textsubscript{10}) were studied at varying initial pressures (1, 3 and 5 bar) and a temperature of 300K. This multi-zone model obtained thermodynamic data by utilizing CANTERA. The pressure rise method requires a more complex analysis, but has the advantage that a single experiment generates data across a range of linked temperatures and pressures.
Saudi Arabian Section of the Combustion Institute

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