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Operating Agent for the Gas Engine Collaborative Task

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Summary

Established in 2013 at the IEA Task Leader Meeting (TLM) in San Francisco, the Gas Engine Collaborative Task (GECT) was seeks to establish new collaborations and foster existing ones in the field combustion of gaseous fuels in internal combustion engines (ICE) and to coordinate reporting from task members to the TCP ExCo secretary. The GECT is embedded in the “clean and efficient combustion” Technology Collaboration Programme (TCP) of the International Energy Agency (IEA). The combustion TCP seeks improve combustion technology with respect to Efficiency, its Environmental impact; ensuring Energy security while remaining Economically viable (4E).

The GECT is focussed on gaseous fuels, which may stem from conventional exploration, from biomass conversion or power-to-X processes (e-fuels, e.g. hydrogen and methane). Environmentally, the low C/H ratio of natural gas renders it the least CO_2 intensive fuel from fossil sources. Furthermore, combustion of natural gas enables ultralow NOx and soot emissions due to lean pre-mixed combustion in ICEs in conjunction with very high efficiencies. From an energy security perspective, local availability leads to considerably reduced dependence on liquid fuels sourced primarily by OPEC.

The main goal of the GECT is to establish new collaborations among task member, foster and develop existing ones and coordinate all reporting activities at the task level for subsequent consolidation at the TCP level. Combustion of gaseous fuels in IC engines is a proven technology, due to straightforward implementation using broadly established engine components. Nonetheless a number of challenges remain, for which considerable research efforts are underway. These include in particular the development of improved ignition systems, incresed engine efficiency and the reduction of unburned hydrocarbon emissions. For the latter, in particular methane slip presents a challenge, due to its low conversion efficiency in aftertreatment systems. Furthermore, the advent of e-fuels with very different reactivities (e.g. H2 and NH3), necessitates considerable research and development efforts. The GECT seeks to bundle these research efforts and provide a platform for international exchange between academia and industrial R&D; complementing activities in the other tasks in the “clean and efficient combustion” Technology Collaboration Programme (TCP) of the International Energy Agency (IEA).

Project goals

Within this project, all activities relating to the Gas Engine Collaborative Task – within the Technology Collaboration Programme "clean and efficient combustion" of the International Energy Agency – are coordinated.

Specific duties of the task leader comprise I.) Further development of the task w.r.t. collaboration between members; II.) Improving visibility of the Task (and TCP); III.) IEA reporting, and, IV.) Organization of the gas engine presentation and break-out sessions, poster contributions at the TLM.

In addition, a workshop on gas engine combustion fundamentals is foreseen on a biennial schedule.

Work undertaken and findings obtained

Participation to the ExCo 83 and Strategy meetings held in Paris, May 13th and 14th 2019. As of 2019, Task Leaders are encouraged to participate to ExCo and Strategy meetings and present an overview of the current state of their respective tasks and update the task template.

Coordination of the GECT session at the 41st IEA TLM in Montreux, November 3rd - 8th, 2019, Switzerland: A record breaking number of short talks/posters and corresponding abstracts were contributed:

- C. Rousselle, C. L'Huillier, P. Brequigny, Université d'Orléans: "AMMONIA as one future e-fuel"
- Q. Cheng, Z. Ahmad, O. Kaario, M. Larmi, Aalto University, Finland: "Optical investigation of dual-fuel combustion using chemiluminescence and natural luminosity imaging"
- C. Bae, S. Kang, W.Y. Kim, S.U. Lee, KAIST, Korea: "Dual-Fuel Combustion Strategies with Diesel and Natural Gas"
- S. Moon, K.D. Min, Seoul National University, Korea: "Combustion characteristics of low reactivity fuels under dual-fuel combustion"
- William Northrop, Hye Won Lee, Ying Lin, Seokwon Cho, University of Minnesota: Twin Cities, U.S.A.: "Concept for Natural Gas Reactivity Enhancement using Catalytic Oxidative Coupling of Methane"
- P. Kranz[1], D. Fuhrmann[1], M. Goschütz[1], and S.A. Kaiser[1], S. Bauke[2], K. Golibrzuch[2], and H. Wackerbarth[2], P. Kawelke[3], J. Luciani[3], L. Beckmann[3], and J. Zachow[3], M. Schütte[4], O. Thiele[4], and T. Berg[4], [1]University of Duisburg-Essen, [2]Laser-Laboratorium Göttingen e.V., [3]Volkswagen AG, [4]LaVision GmbH (all Germany): "In-cylinder LIF imaging, IR-absorption point measurements, and a CFD simulation to evaluate mixture formation in a CNG-fuelled engine"
- K. Herrmann[1], S. Wüthrich[1], P. Süess[1], P. Cartier[1], C. Schürch[2], [1]University of Applied Sciences FHNW, [2]ETH Zurich (all Switzerland): "Characterization of dual-fuel combustion processes"
- M. Musculus et al., Sandia National Labs, U.S.A.: "Fundamental Advancements in Pre-Chamber Spark-Ignition and Emissions Control for Lean-Burn Natural-Gas Engines"
- K. Stork[1], G. Singh[1], M. Weismiller[1], M. Musculus[2], J. Zador[2], G. Roberts[2], Z. Li[2], C. Rouselle[3], [1]DOE, U.S.A.; [2]Sandia National Labs, U.S.A.; [3]Uni Orléans, France: "OH* Chemiluminescence Imaging and 0-D Chemical-Kinetic Modelling of End-Gas Autoignition for Spark-Ignited Natural Gas"

- J.M. Garcia-Oliver[1], P. Martínez-Hernandiz[1], M.P. Musculus[2], R. Rajasegar[2], Z. Li[2], Y. Niki[3], [1]CMT Valencia, Spain; [2]Sandia National Labs, U.S.A.; [3]National Institute of Maritime, Port and Aviation Technology, Japan: "Chemiluminescence and infrared imaging of pre-chamber jet penetration, ignition, and combustion in a heavy-duty natural-gas engine"

- C. Frouzakis et al., ETH Zurich, Switzerland: "DNS and LES of engine phenomena"

- J. Koch, C. Schürch, Y.M. Wright, K. Boulouchos, ETH Zurich, Switzerland: "H_2/CH_4 admixtures in IC engines for decentralised co-generation"

In addition, **one invited talk from industry by Dr. Guoqing Xu, Liebherr Machines Bulle SA, Switzerland** (former PhD candidate at ETH,) could be secured, reporting on the know-how transfer from academia to engine optimisation and development "Unscavenged prechamber: from fundamentals to engine development". During the **break-out sessions the task template was further evolved**. Changes included predominantly the inclusion of a new task sub-topic "e-fuels", focussing on carbon-free fuels such as ammonia and hydrogen. In addition, the "chemical kinetics" sub-topic was renamed to "knock and pre-ignition" to better highlight the focus within the gas engine task and for differentiation of the sub-topic from the "Chemical Kinetics" task itself.

Participation to the ExCo 84 virtual meeting at the 41st TLM on November 7th, 2019 and the excursion to Liebherr Machines Bulle.

Participation to the Strategy and ExCo 85 spring meetings postponed to June 11th and 12th 2020 and held online due to the COVID-19 pandemic.

Coordination of the GECT session at the 42nd combustion TLM, held on-line due to the COVID-19 pandemic from August 23rd – 26th, 2020. A total of seven presentations were contributed to a pre-TLM workshop:

- Yasuo Moriyoshi, Chiba University, Japan: "Update of Japanese Consortium overview"

- Rajavanasanth Rajasegar, Sandia National Lab., USA: "Fundamental insights on Ignition and Combustion of Natural Gas in an Active Fueled Pre-Chamber Spark-Ignition System"

- Riccardo Scarcelli, Argonne National Lab., USA: "Modeling Lean-Burn MD/HD Natural Gas Engines Enabled by Pre-Chamber"

- Christine Rousselle, Université d'Orleans, France: "Ammonia combustion specifics in SI engines"

- Christos Frouzakis, ETH Zurich, Switzerland: "DNS of pre-chamber combustion"

- Walter Vera-Tudela, ETH Zurich, Switzerland: "An experimental study of high-pressure gas injection by means of optical diagnostics"

- Will Northrop, University of Minnesota: Twin Cities, USA: "Controlling NG autoignition in engines using C2 molecules from catalytic OCM"

Following the pre-TLM workshop, separate "office hours" of the speakers and interested task members were held during the TLM with lively discussions. In particular **for the pre-chamber ignition system topic, two follow-up webinars were held with participation from ANL, SNL, NREL and ORNL, ETH and FHNW**.

Participation to the ExCo 86 virtual meeting after the 2020 TLM on August 27th, 2020.

Participation to the online workshop for TCP combustion and ETSAP members on August 30th, 2020.

Participation to the IEA Energy Technology Perspectives webinar with focus on "long-distance transport", October 2nd, 2020.

Participation to the Strategy and ExCo 87 spring meetings held online, May 3rd and 4th, 2021. It was decided to end the current "Low-Temperature Combustion" task and set up three new tasks, namely a "high-efficiency, clean, lean-burn engines", to be led by Antonio Garcia, CMT, Valencia and Magnus Sjöberg, Sandia National Labs. A task on "Hydrogen and its Vector Fuels (H2&V)" is to be established, led by Alex Taylor, Imperial College and Phil Bowen, Cardiff Uni. In addition, a "Systems Analysis" task will be set up, lead for one year by Martti Larmi, Aalto Uni. while the follow-up task leadership will be defined in due time by the Systems Analysis team. An "Exhaust gas After Treatment Systems (EATS)" is still in discussion and Stephan Renz, SFOE was designated to carry out a survey, hold a workshop and organize a session at the 43rd TLM. Discussions on how to partition work between the new LTC follow-up task, the H2&V tasks and the Gas Engines collaborative task were held in an on-line workshop.

Coordination of the GECT session at the 43rd Combustion TLM held on-line September 20th – 23rd, 2021, due to flash flooding of the conference venue in Bad Neuenahr, Germany. A total of eight contributions were received, presented at a pre-TLM workshop on September 13th:

- Kai Herrmann, FHNW, Switzerland: overviews of activities/upcoming projects; specific study "Pre-Ignition in Gas Engines"
- Laura Merotto, Empa, Switzerland: “Ignition Diagnostics in Gas Mixtures with Optical Techniques: Nanosecond Pulsed Ignition”
- Nobuyuki Kawahara, Okayama University, Japan: “Visualization of the end-gas auto-ignition in dual-fuel gas engine”
- Öivind Anderson, Lund University, Sweden: “New gas and hydrogen projects at Lund University”
- Will Northrop, University of Minnesota: Twin Cities, USA: “Controlling Natural Gas Autoignition in Engines using Products from Catalytic Oxidative Coupling of Methane”
- Vyaas Gururajan, Argonne National Labs., USA: “Non-equilibrium Plasma Assisted Ignition of Gaseous Fuels: Simulations and Modeling”
- Rajavasanth Rajasegar, Sandia National Labs., USA: “A highlight of recent efforts and future directions of pre-chamber spark ignition research at Sandia”
- Fabrice Foucher, Université d'Orléan, France: “Overview of current and upcoming H2 research in optical and HD engines and kinetics”

Participation to the ExCo 88 virtual meeting after the 2021 TLM on September 23rd, 2021.

Due to the COVID-19 pandemic, the third ETH/IEA workshop ”Gas engine combustion fundamentals” planned for June 3rd, 2020 was cancelled and is rescheduled for 2022.

National cooperation

The **Swiss Federal Office of Energy project “DNS gas engine”** (grant no. SI/501301-01) has been **successfully completed in 2019**, where fundamental investigations on prechamber combustion were studied by means of Direct Numerical Simulation.

Generation of a dual fuel data-base by LAV/ETH together with project partners from PSI took place in the framework of the **Swiss Federal Office of Energy project “Dual Fuel combustion systems”** (grant no. SI/500970-01) was **concluded in 2019.** This project extended previous activities in the Swiss Competence Centre Energy and Mobility (CCEM) projects “ScheDual” and “Flex-FI-dual”, co-funded by SFOE, which were successfully concluded in 2017.

Together with the University of Applied Sciences North-West (FHNW), micro-piloted natural gas combustion was studied in a newly developed test rig in the framework of the **Swiss Federal Office of Energy project "Adapted Fuels"** (SI/501628-01), for which the **final report was submitted 2021**.

International cooperation

- **The EU H2020 project "GasON" was successfully concluded** at the final workshop in Aachen, Germany on March 26th, 2019: participation of LAV took place in work package 5 "New non-DI CNG combustion process and on-board gas sensor-concept" and resulted in three papers with ETH involvement, which were presented at the SAE World Congress Experience 2019 [1-3].

- **FVV project "Diesel auf homogenem Grundgemisch"**, co-financed by the Swiss Federal Office of Energy project Dual Fuel combustion systems" (grant no. SI/500970-01), **carried out in collaboration with the University of Stuttgart was successfully completed. The final report** was **presented at the FVV spring conference 2019**; a paper was presented at the SAE World Congress Experience 2019 [4] and an MTZ article published in [5].

- **FVV project "Gas-Diesel combustion" was successfully completed in collaboration with the UniBW of Munich** and the **final report was presented at the FVV autumn meeting September 21st, 2020**. This project has resulted in several publications, some of which jointly with the UniBW Munich, Germany [6-11].

- **FVV Project "Otto wall heat transfer", has been successfully completed in collaboration with the Technical University of Darmstadt (TUD)** and the **final report was presented at the FVV autumn meeting September 21st 2020**. Results have been presented at the LES4ICE conference in Dec. 2018 [12] as well as at the 38th International Combustion Symposium and resulted in two journal papers [13, 14].

- **The FVV follow-up project "Otto wall heat transfer II." in collaboration with the TU Darmstadt**, co-financed by the Swiss Federal Office of Energy (grant no. SI/501930-01) was **successfully completed**, where higher engine speeds and loads were studied. The **final report was presented at the FVV autumn meeting 2021**, held at the Nürburgring, Germany on November 8th. Several papers have already been published [15-17] while others are in preparation, e.g. [18].

- **Project "GIHPCO", in collaboration with Karlsruhe University of Technology** jointly financed by the Swiss Federal Office of Energy (grant no. SI/502206-01) and FVV is underway; the kick-off meeting was successfully held on November 18th, 2021.

- **Project "H2DI", in collaboration with Stuttgart University** jointly financed by the Swiss Federal Office of Energy (grant no. SI/502205-01) and FVV is underway; the kick-off meeting was held on July 6th, 2021.

- A **Co-Research project with Hyundai Heavy Industries** (HHI) looking into modelling of dual-fuel combustion in medium-speed engines using the Flamelet Generated Manifolds methods developed in the "Dual Fuel" projects listed above is close to completion and final reporting is underway. HHI is further funding the PhD of Hyunchun Park, where fast models for dual fuel combustion are developed for engine optimization purposes. A paper was presented hereto at the 29th CIMAC congress [19] and a journal paper published in FUEL [20].

- At the 2019 TLM, Prof. Christine Rouselle and Y.M. Wright discussed opportunities for a **collaboration on Ammonia Combustion in ICE between Université d'Orléans and ETH**

Zurich. Following successful signature of an NDA, a numerical setup for the engine installed at Orléans was provided and first simulation of ammonia combustion were carried out at ETH.

- Following the 2019 TLM, Mark Musculus from Sandia National Labs had expressed interest to discuss a **possible collaboration on pre-chamber combustion between ETH and all four U.S. national labs (Oak Ridge, National Renewable Energy, Argonne and Sandia)**. A first web-ex **was held on Dec. 5th, 2019**, where C. Frouzakis and Y.M. Wright were offered a slot to summarize activities underway at ETH using RANS/LES/DNS as well as optical diagnostics. **A follow-up webex was held on Dec. 19th, 2019**.

- Following the 2020 TLM, **a webinar to discuss pre-chamber ignition system activities and promote exchange between Argonne National Lab. and ETH was held on September 24th, 2020**.

- Following the 2021 TLM, **a webinar to discuss activities on Nano-second Repetitively Pulsed Discharge (NRPD) ignition systems was held between ANL, SNL and Empa was held on October 11th, 2021**. A follow-up meeting is foreseen for early December 2021.

Conclusions and Outlook

Gas engine combustion is a promising and important avenue to pursue in view of lowest-emission, highest-efficiency conversion of conventional, bio-derived and PtX gases in IC engines. In view of increasing fluctuating renewables, CHP plants running on e-fuels are expected to play an important role (seasonal storage/sector coupling).

In this project, the operating agent for the Gas Engine Collaborative Task has

a) Provided consolidated input for reporting purposes

b) Participated to strategy and ExCo meetings and assisted in the development of mission statements and elaboration of required documents

c) Compiled contributions from task members in the form of posters and talks and presenting summaries thereof at the annual Task Leader Meetings

Although not formally part of the contractual funding agreement, the following activities carried out within other projects also clearly contributed to the mission and targets of the combustion TCP of the IEA, namely

d) Fundraising, collaboration and reporting in the context of a variety of national and international joint projects (funded by FVV/CORNET, SFOE, CTI/KTI, EU)

e) Dissemination of results in leading journals, conferences and workshops

The third ETH/Empa/IEA “Gas Engine combustion fundamentals” workshop originally planned for 2020 will be re-scheduled for 2022.

Based on the extension granted for the combustion TCP, a follow-up proposal will be submitted to the Swiss Federal Office of Energy for the period Feb. 2021 – Feb. 2023.

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