SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

The STSM applicant submits this report for approval to the STSM coordinator

Action number: CM1404 - 40431
STSM title: EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF NOx - SOx ON COMBUSTION CHARACTERISTICS IN A HOMOGENEOUS SI ENGINE OPERATED WITH NATURAL GAS
STSM start and end date: 5/3/2018 to 20/4/2018
Grantee name: Mr. Dimitris Kazangas

PURPOSE OF THE STSM

Dual fuel marine engines constitute a competitive means for complying with the recent and forthcoming strict emission control regulations for ships trading in specific geographical areas (Emission Control Areas – ECAs). Dual fuel engines can be operated in two discrete operational modes; the gas mode and the liquid mode. The gas mode is commonly characterized by combustion of Natural Gas; the ignition source can be a spark or a pilot injection of liquid fuel. The liquid mode consists in the conventional Diesel cycle. In the case of most liquid marine fuels, both NO_X and SO_X trace species are present during combustion, inevitably affecting reaction paths. Further, the use of Exhaust Gas Recirculation - EGR (to reduce NO_X) recirculates exhaust NO_X and SO_X in the combustion chamber. In order to accurately predict NO_X - SO_X synergies, a hierarchical approach has been considered in the frame of the present STSM. A first step thereby, with the aim to study both Diesel and dual fuel combustion chemistry, consists in the study of methane (Natural Gas) chemistry. Further, it can be argued that even in the case of high carbon ranking fuels, such as Marine Diesel Oil - MDO, NO_X - SO_X react mainly with hydrocarbons that consist of a lower number of carbon atoms, i.e., the relevant chemistry is that of methane and syngas.
In this context, main goals of the visit of Mr. D. Kazangas at the Laboratory for Internal Combustion Engines and Electromobility of the Faculty of Mechanical Engineering of the University of Ljubljana have been:

- Deployment and analysis of first experiments for a reference case in a small homogeneous Spark Ignition engine operated with Natural Gas, aiming at understanding the effects of NO_X - SO_X species on combustion chemistry, including the interactions between the two types of pollutants.
- Initiation of the research collaboration with the research team of Prof. T. Katrašnik within the above frame.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

The whole attendance of the undersigned was successful without delays, while the provided hospitality was warm and excellent. The collaboration with the research group of Prof. T. Katrašnik was fruitful, including the following tasks:

- Familiarization with the concept of Design of Experiments, training and independent study on the AVL CAMEO software.
- Familiarization with post-processing of experimental data, training and independent study on the AVL BOOST software.
- Familiarization with safety and technical issues of the laboratory.
- Setup and deployment of an experimental campaign using an engine with the following characteristics:
  - ✓ Maker/Type: Toyota 4Y/ 4-stroke SI water-cooled in-line engine
  - ✓ Configuration: 4 cylinders with displacement of 2.2 litres and compression ratio of 10.5
  - ✓ Fuel: Natural Gas
  - ✓ Output: 39.8 KW at 2600 rpm
- Training and measurements of soot emissions.
- Participation in other experimental and data post-processing activities related to RCCI combustion.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The present experimental work included the measurement of in-cylinder pressure traces using a state-of-the-art high frequency pressure acquisition system including a capacitive TDC sensor. Also, emission concentrations (CO, CO_2, NO, NO_2 and THC) were measured using a state-of-the-art emission analyser of Messrs "SEMTECH".
The following operating points were considered:

- Measurements in two different engine loads, 25% and 100%.
- Measurements for three different values of air-fuel ratio for both engine loads, 0.85, 1.0, 1.4.
- Setup of reference case for all values of air-fuel ratio, as well as for the two engine loads.
- Measurements for different NO portions in air intake, in particular, 30, 100, 300, 1000 ppm, for all values of air-fuel ratio, as well as for the two engine loads.

First results of the experimental campaign performed during the STSM are presented in Figs. 1-4. A first outcome is the observation of elevated concentrations of NO_2 (53 and 63 ppm NO_2) for intermediate and high NO doping (300, 1000 ppm, respectively) at low engine load (25%) with the highest air-fuel ratio (1.4). This observation is considered important for the development of combustion, in particular ignition delay, mainly due to the associated increase in the concentration of OH radical (Mathieu et al., "Shock-induced ignition of methane sensitized by NO_2 and N_2O", Combust. Flame, 2015, 162, 3053-3070).

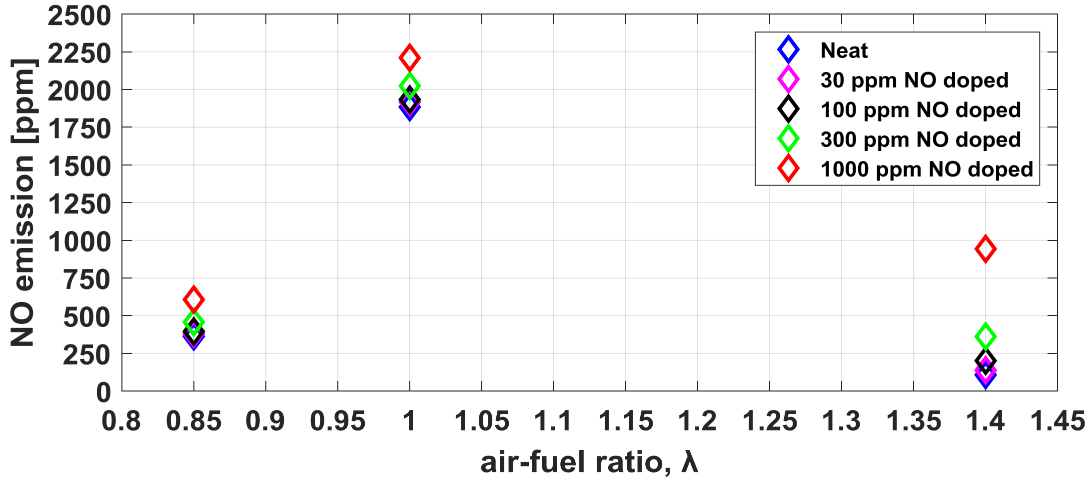

Figure 1. NO emission versus air-fuel ratio for (a) Neat case, (b) 30 ppm NO doped in intake air, (c) 100 ppm NO doped in intake air (d) 300 ppm NO doped in intake air, and (e) 1000 ppm NO doped in intake air at 100% engine load.

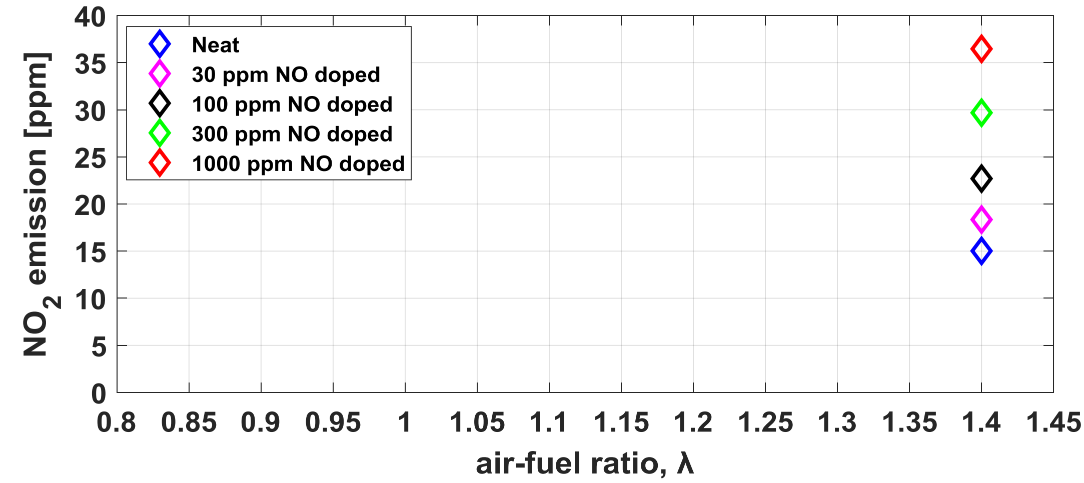

Figure 2. NO_2 emission versus air-fuel ratio for (a) Neat case, (b) 30 ppm NO doped in intake air, (c) 100 ppm NO doped in intake air (d) 300 ppm NO doped in intake air and (e) 1000 ppm NO doped in intake air at 100% engine load.

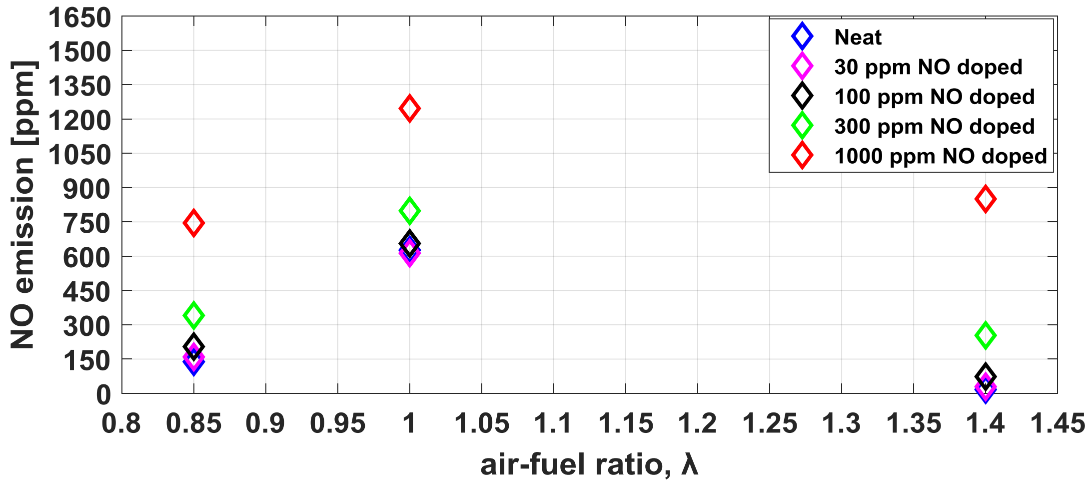

Figure 3. NO emission versus air-fuel ratio for (a) Neat case, (b) 30 ppm NO doped in intake air, (c) 100 ppm NO doped in intake air (d) 300 ppm NO doped in intake air and (e) 1000 ppm NO doped in intake air at 25% engine load.

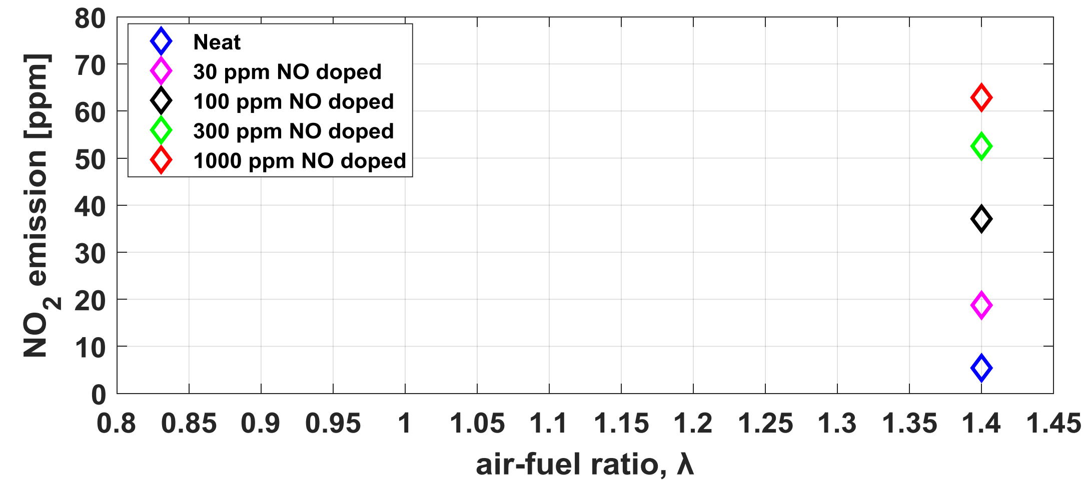

Figure 4. NO_2 emission versus air-fuelratio for (a) Neat case, (b) 30 ppm NO doped in intake air, (c) 100 ppm NO doped in intake air (d) 300 ppm NO doped in intake air and (e) 1000 ppm NO doped in intake air at 25% engine load.

Detailed post-processing is currently underway to fully characterize the doping effect.

HOW THE STSM HAS CONTRIBUTED TO THE ACTION'S AIM

The present STSM is related to the activities of Working Groups WG1 (*Smart Energy Carriers gas phase chemistry: from experiments to kinetic models*) and WG2 (*Chemistry for control of by-products in Smart Energy Carrier conversion*). In the context of WG1, the present experimental results can be used in the frame of methane combustion as follows: (a) Further validation of existing chemical kinetic mechanisms (b) Development of skeletal or reduced chemical kinetic schemes, and (c) Optimization of chemical kinetic mechanisms. Further, in the context of WG2, the present results can be utilized for the development of accurate detailed chemical kinetic mechanisms regarding NO_X – SO_X formation and their synergistic effects. Thus, the present study of the effects of NO_X - SO_X trace species on marine engine combustion will support the aims of COST Action CM1404, which include the increase of fuel flexibility and carbon efficiency in IC engines by means of experimental measurements and numerical simulations.

FUTURE COLLABORATION

Following the present research visit, the established experimental campaign will be further expanded by doping NO_2 and SO_2, as well as blends of NO_x and SO_2, to study their synergies. All results will be further interpreted in the frame of combustion chemistry by means of chemical kinetics calculations, involving chemical kinetic mechanisms incorporating hydrocarbon chemistry, NO_X and SO_X chemistry, and their interactions. An objective in the frame of this collaboration is the submission of peer-reviewed journal publications, based on the results obtained and their interpretation.

Following on the present fruitful visit, another attendance in the frame of the Short Term Scientific Missions (STSM) program of the COST Action CM1404 may be scheduled, focusing on characterizing an implementation of the RCCI combustion concept in dual fuel engines, by means of experiments and thermodynamic modelling.