TESTING AND NUMERICAL ASSESSING OF A MILD-BASED STIRLING ENGINE

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Introduction

Nowadays, in the field of energy production, particular attention must be paid to improving efficiency and reducing pollutants.

Cogeneration systems based on Stirling cycles appear particularly appealing to this goal, as they ensure high efficiency, fuel flexibility, low emissions, low noise/vibration levels and good performance at partial load [1]. Moreover, it is possible to couple such engines with MILD (or flameless) burners.

MILD combustion is a rather new technology that provides high efficiency in fuel consumption with low NO and soot emissions [2]. It requires the reactants to be preheated above their self-ignition temperature and enough inert combustion products to be entrained in the reaction region, in order to dilute the flame. As a result, the temperature field is more uniform than in traditional non-premixed combustion systems, and it does not show high temperature peaks. Hence, NO formation is suppressed as well as soot formation, due to the lean conditions, low temperatures and the large CO_2 concentration in the exhausts. The increasing interest in flameless combustion is motivated by the large fuel flexibility, representing a promising technology for low-calorific value fuels, high-calorific industrial wastes as well as in presence of hydrogen. Recently several studies showed also the compatibility of such regime with biogas [3-5].

The growing trend today is that combustors should be fuel flexible. These different fuels are typically of Low Caloric Value (LCV), such as biofuels, syngas and landfill mixtures.

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The industrial company Cleanergy provides energy solutions based on the Stirling engine. Cleanergy currently focuses on renewable, gaseous mixtures that are relatively difficult to burn since the energy content is small compared to natural gas. One such gas is Landfill gas. In a landfill gas extraction, the methane content is decaying with time.

The objective of the present study is to evaluate the performances of such Stirling engine when the gas mixture fed to the engine itself and the operating conditions (namely the engine pressure) are changed. Experimental tests are performed at Chalmers University of Technology, in Gothenburg (Sweden).

The engine power output is 7.2 kW electric power and 16 kW heat power. The burner, called GasBox, consists of a main burner and a heat exchanger. The gas is injected from one location and there are 6 main injection holes at the entrance of the burner for the air, which is preheated above the auto-ignition temperature of the fuel. The air and the fuel are also diluted by exhaust gas recirculation.

The controlling parameter for the combustor is the value of the air-fuel equivalence ratio (λ).

λ is kept constant at 1.3, by opening or closing the throttle for the air inlet.

The effect of several parameters can be investigated during the experimental campaigns. Those parameters are:

- Fuel composition.
- Engine pressure.
- Engine speed.
- Duration of the test.

Only the first two parameters were investigated during this experimental campaign. The engine speed has been kept constant at 1500 rpm.

As far as the engine pressure is concerned, 3 different set points were considered: 75, 100 and 125 bar.

The main variation concerns the fuel composition.

The fuel flow is regulated with a pressure regulator whose loading mechanism is a spring. The stiffness of the spring can also be changed to achieve different flows and compositions.

The engine starts in flame mode with pure methane. Once that the chamber is warmed up, it switches to MILD mode. Once in MILD mode it is possible to change the fuel composition.

To achieve the different fuel compositions, it is necessary to slowly decrease the methane and at the same time increase the percentage of the other component, one at the time. It can take up to one hour to reach the desired composition.

Seven different mixtures were investigated. The lower heating value of such mixtures ranges from 193 kJ/mol to 481 kJ/mol, as shown in Figure 1.

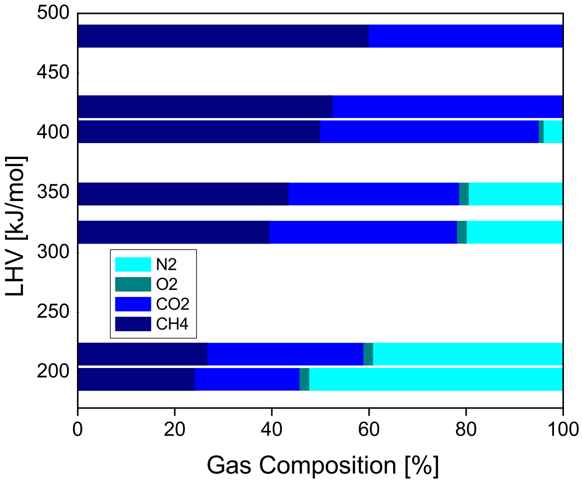

Figure 1: Lower heating value for the different gas mixtures.

Conclusions

The engine performs well at all the conditions analysed, despite the high variation on the parameters.

The engine pressure does not have a great influence on the performances of the combustion chamber.

Emissions for the experimental run at 125 bar are shown in Figure 2.

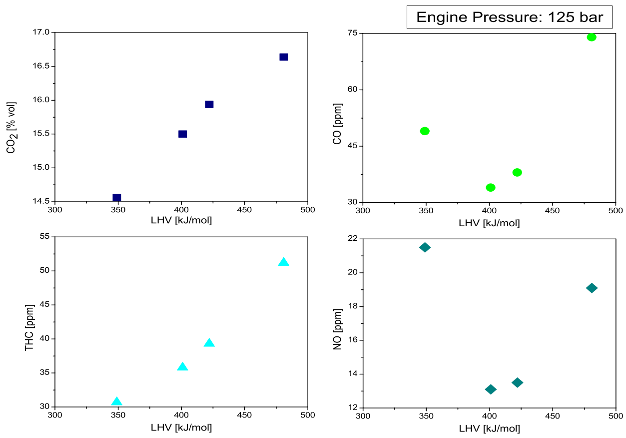

Figure 2: Emissions of the engine at 125 bar.

For all the three values of the engine pressure, NO emissions are very low, below 20 ppm. Their value increase when the N_2 level in the fuel increases.

This is true also for the CO_2 value. It does not change in the three cases, but it increases when the CO_2 percentage in the fuel increases.

As far as CO and THC are concerned, the emissions slightly increase at 125 bar.

Numerical simulations on the combustion chamber of this engine are also carried on.

The main objective is to validate models in presence of different fuel compositions.

The simulations are run with the commercial code Fluent as well as with the open source code OpenFOAM. Due to the specific features of the flameless combustion regime, particular attention must be paid to the choice of the physical models, especially the turbulence-chemistry interaction model.

Another key parameter is the choice of the kinetic mechanism, since it is still an open issue choosing to which extent they can be reduced.

As far as the pollutants are concerned, in MILD regime different routes become more relevant than the traditional ones. The reduced kinetic model for the quick evaluation of NO emissions from MILD combustion of H_2-enriched fuels, proposed by Galletti et al. [6], has been also evaluated.

Acknowledgements

The results presented in this paper have been obtained within the Short Term Scientific Mission program founded by COST action CM1404.

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