Modelling the emissions of a dual fuel engine coupled with a biomass gasifier – Supplementing the Wiebe model

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Extended abstract

An open top small scale biomass gasifier has been installed at the Bioenergy Laboratory of the Free University of Bozen-Bolzano. It is fed with wood chips and produces a gaseous fuel, i.e. producer gas, which consists from carbon dioxide, nitrogen, hydrogen, carbon monoxide and methane. On one hand, the latter three gases primarily contain the heating value of the producer gas but they have relatively moderate concentrations, i.e. hydrogen and carbon monoxide below 15 % and methane below 2 %. On the other hand, the producer gas contains almost 70 % of the two inert gases, i.e. nitrogen and carbon dioxide. As a result the overall heating value of the producer gas is very low at the range of 3 -3.2 MJ/ Nm^3. The open top gasifier is scheduled to be connected with an internal combustion engine for the production of combined heat and power. The poor quality of the producer gas has driven the decision to operate the internal combustion engine in a dual fuel cycle which is commonly known as Sabathe. As a result, the producer gas will be co-combusted in the engine along with biodiesel.

Recently, Caligiuri & Renzi (2017), developed a zero-dimensional model in order to simulate the operation of the dual fuel engine. The authors used the triple Wiebe function to simulate the heat release of dual fuel combustion and thus to calculate the overall performance of the engine. The model is in good agreement with experimental results that can be found in the literature. Ultimately, the model will be validated by means of experimental results after the installation of the dual fuel engine at the Bioenergy Laboratory of the Free University of Bozen-Bolzano.

In principle, the proposed model by Caligiuri & Renzi is ideal for simulating the performance of the engine and this is the first important parameter for the assessment of an engine. The second important aspect is the simulation of the produced emissions and their minimization in order to reduce the environmental impact from the operation of the engine. Therefore, this study introduces a multistage thermodynamic model which aims to work in parallel with the Wiebe model and returns the concentrations of a wide range of gases with pollution potential. This study will focus on the production of nitrogen oxides. The proposed model can be found in Fig. 1.

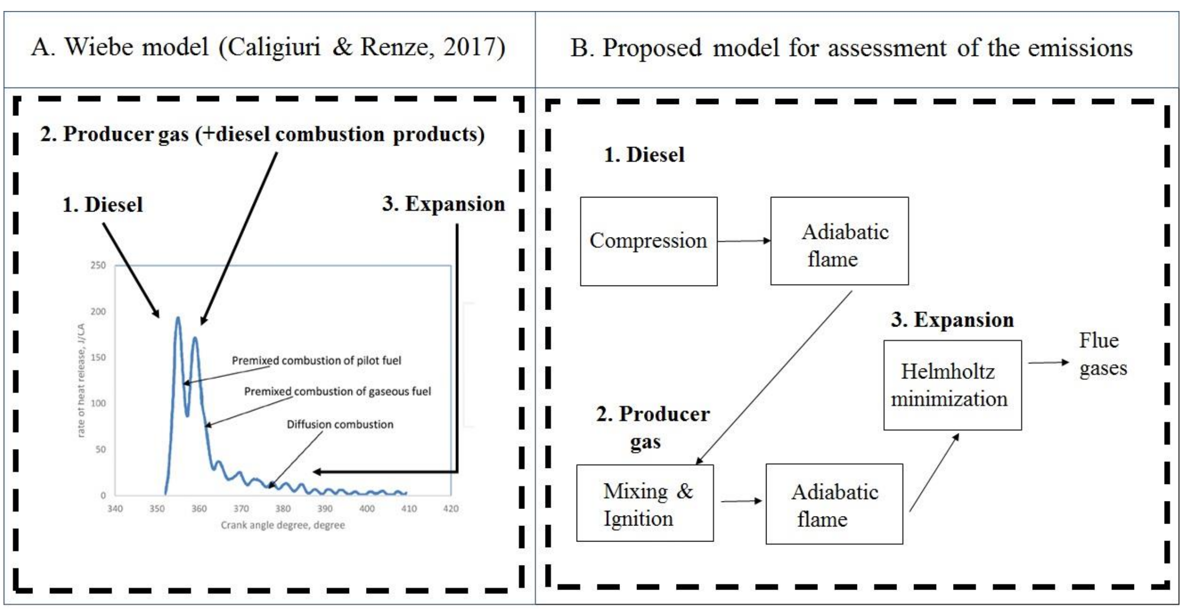

Fig. 1. Proposed model that works in parallel with the Wiebe model for the simulation of the produced emissions.

As shown in Fig.1, the model simulates initially the adiabatic flame that is produced from the compression of the biodiesel. The mixture of the combustion products and the producer gas undergo a second combustion and thus the second adiabatic flame is simulated. It has to be denoted that the delay between the two ignitions can be calculated with the Prakash model. The proposed model has as input 30% biodiesel and 70% producer gas. Biodiesel has the chemical formula $C_{12}H_{22}$ and the composition of the producer gas is shown in Fig.2.

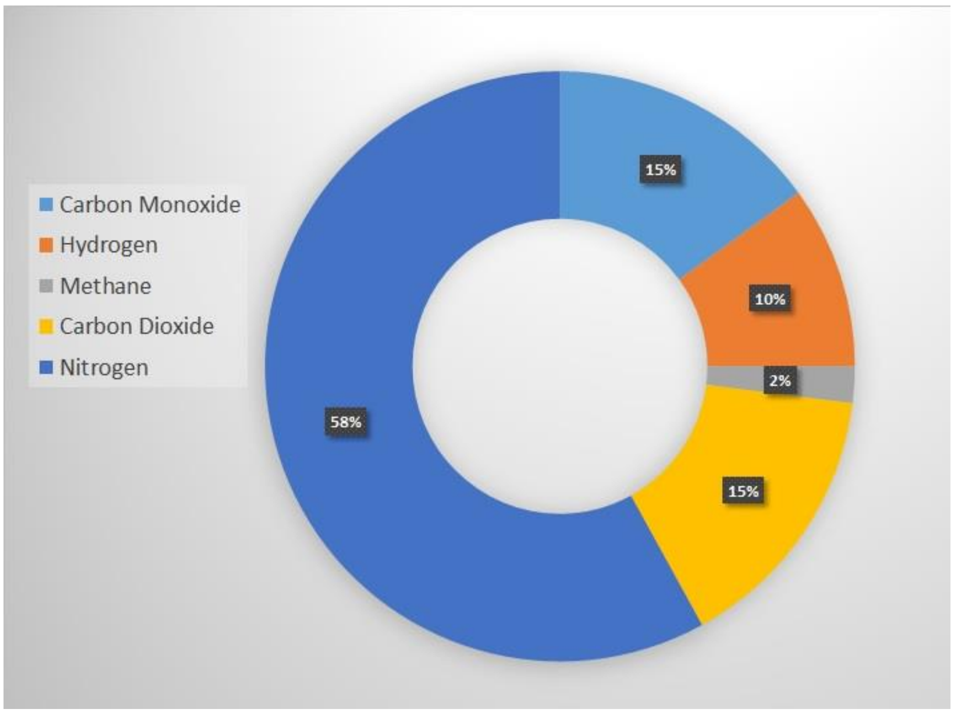

Fig. 2. Composition of the producer gas that is used as input for the model.

The engine operates with a compression ratio of 18:1. The two consecutive ignitions increase the pressure and the temperature in the cylinder and are calculated with the Wiebe model and shown in Fig.3. The values are utilized for the final equilibration that simulated the expansion of the piston and thus assessing the composition of the mixed flue gases.

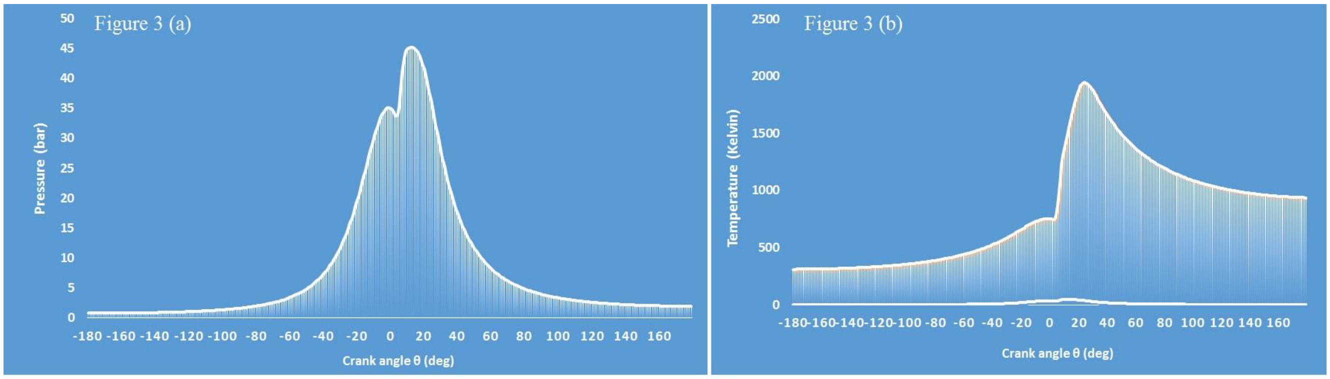

Fig. 3. Calculated pressures (left) and temperatures (right) inside the cylinder by means of the Wiebe model. The values are presented in both cases in respect to the crank angle.

The proposed model has been developed in MATLAB/ Cantera environment and uses the CRECK mechanism. The results of the modelling can be separated in two groups. On one hand the emissions with concentrations in the range of several mg/ Kg and these are carbon monoxide and nitrogen monoxide. These results are shown in Figure 4. On the other hand, other emission-gases of interest, i.e. nitrogen dioxide and nitrous oxide, are in the concentration range of μg/ Kg and are shown in Figure 5.

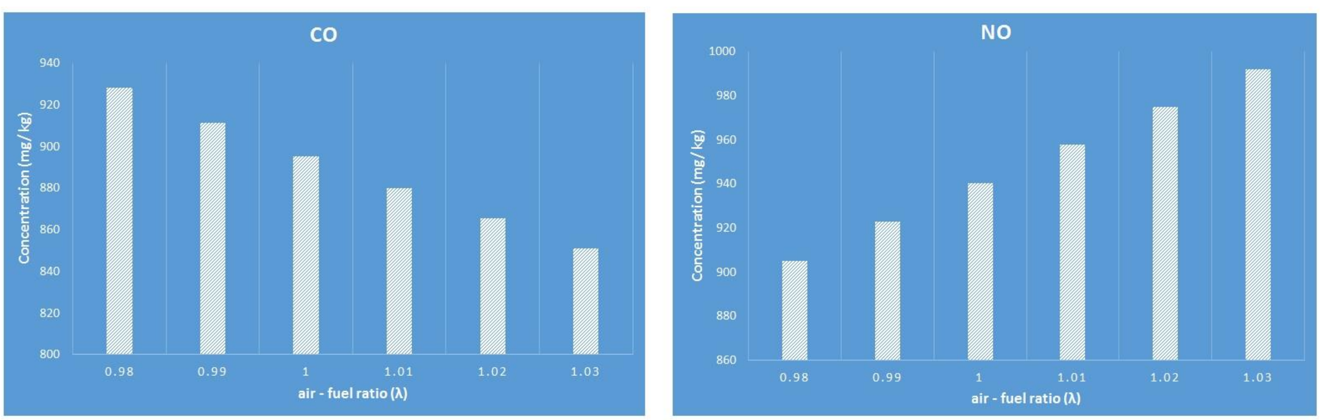

Fig. 4. Simulated concentrations of carbon monoxide and nitrogen monoxide.

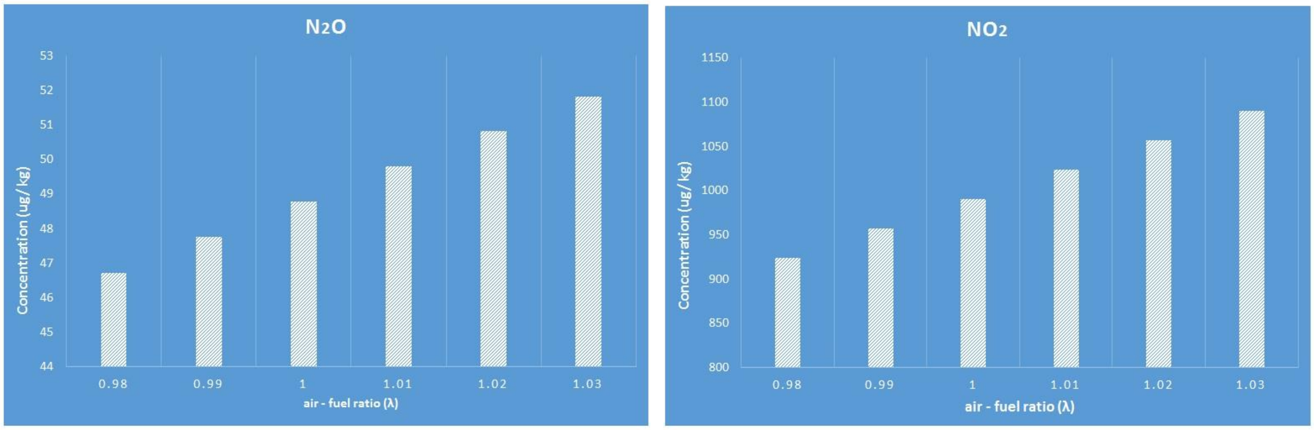

Figure 5. Simulated concentrations of nitrous oxide and nitrogen dioxide.

The proposed model is able to successfully work in parallel with the Wiebe model and simulates concentrations of the most significant emission gases. The proposed model not only follows the exact "thermodynamic pathways" with the Wiebe model but also uses as input the results that are extracted from the Wiebe model. The scope of this work is to provide an integrated tool for the optimization of dual fuel engines.

Reference

C. Caligiuri, M. Renzi, 2017. 0D Thermodynamics combustion simulation tool for a dual fuel diesel – producer gas compression ignition engine. 9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK.