Primary experiments with an HCCI engine aimed towards the direct combustion of tar loaded biomass syngas

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Introduction

The use of biomass gasification to fuel internal combustion engines became popular in the last few decades. Raw "producer gas" or "syngas" from biomass gasification is composed of CO, H2, CO2, CH4, N2, water vapor, tars along with other trace gases and impurities and exits the gasifier at high temperature at about ~500ºC. To match the knock limited intake temperature requirements of the Spark Ignition engine traditionally used in in biomass gasification systems, the syngas has to be cooled down. However, tars, which are hydrocarbons heavier than benzene, tend to condense into sticky liquid or solid forms, with the Tar Dew Points (TDP) ranging from ~300ºC to ambient temperatures. Condensed tars clog or foul critical components in the process chain and thus its filtration becomes necessary in addition to the syngas cooling process. The problems related to tars and the challenges of its filtration/destruction pose the biggest of challenges in the commercial use of biomass gasification for power generation, often leading to the significant capital, maintenance and operating costs. Thus, an alternative system is being developed where the syngas is kept above the TDP, throughout the process chain and thus, allows to bypass tar related problems. A Homogeneous Charge Compression Ignition (HCCI) engine replaces the SI engine and is adapted to operate at temperatures above the TDP.

The potential of biomass syngas has been explored as a medium of renewable energy by a number of authors, as reviewed in [1]. However syngas as a fuel for HCCI engines has been explored only recently, with specific focus on using the traditional cooled and filtered syngas [2-5]. Our novel concept differs from the aforementioned studies and thus requires to be experimentally investigated in light of the various new challenges. In this paper, three such experiments are described:

1. Exp-I: Performance of open-loop HCCI combustion with various syngas compositions (dry syngas composition H2/CO from 0.43-1.22), including tars (3-17 g/Nm3) and moisture (4 -12% of syngas volume), carried out at various intake pressures (1-1.2 bar) and temperatures (230-270ºC) [6].
2. Exp-II: Use of EGR (from 0-25%) as a method to control HCCI combustion phasing [7].
3. Exp-III: Testing the stability of open-loop HCCI combustion with time varying real syngas.

Experimental setup and details

Experiments were done with simulated syngas and simulated EGR for Exp-I and Exp-II, whereas Exp-III was carried out with real but purified and cooled syngas, supplied from a 200 kW (thermal) 2-stage downdraft biomass gasifier. For the simulated experiments (Figure 1), the syngas and EGR gas mixtures were created from gas bottles controlled by MFCs. Air was also controlled by an MFC. A single cylinder 435cc air-cooled engine was used and run at 1500 rpm for Exp-I and Exp-III and 1000 RPM for Exp-II. For Exp-III, the test bench was modified slightly.

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Figure 1: The experimental setup used for Exp-I and Exp-II. A modification of this setup was used for Exp-III, where the gas bottles and MFCs (except air) were replaced with real syngas supply line.

Main results

The main conclusions of these experiments are:

1. Syngas with low H2, high H2O, high tar content results in optimal open-loop HCCI combustion phasing.
2. Also, higher intake pressure and lower intake temperatures result in optimal performance.
3. Maximum gross IE=33% and IMEP=3.5 bar with use of EGR as control method.
4. EGR is an effective control method which results in decrease of maximum MPRR by 60% (from EGR=0 to 25%) and increase in corresponding maximum IMEP by 25%.
5. Open-loop HCCI operation with real (cooled and purified) syngas was achieved for 24 hours of continuous operation. High engine instability was observed along with high NOx emissions. Closed loop HCCI operation could help significantly.

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