

SI Gas Engine: Evaluation of Engine Performance, Efficiency and Emissions Comparing Producer Gas and Natural Gas

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ABSTRACT

The Technical University of Denmark, DTU, has designed, built and tested a gasifier [1, 8] that is fuelled with wood chips and achieves a 93% conversion efficiency from wood to producer gas. By combining the gasifier with an ICE and an electric generator a co-generative system can be realized that produces electricity and heat. The gasifier uses the waste heat from the engine for drying and pyrolysis of the wood chips while the gas produced is used to fuel the engine. To achieve high efficiency in converting biomass to electricity an engine is needed that is adapted to high efficiency operation using the specific producer gas from the DTU gasifier.

So far the majority of gas engines have been designed and optimized for operation on natural gas. The presented work uses a modern and highly efficient truck sized natural gas engine to investigate efficiency, emissions and general

performance while operating on producer gas compared to natural gas operation.

INTRODUCTION

Global environmental concerns have grown stronger and the demand for effective utilization of energy has increased during the last decades, making biomass resources more and more important. The combination of low emissions and high efficiencies makes biomass fuels very interesting as a fuel for combustion engines in the future. Especially in power plants biomass fuels are already used very efficiently as the waste heat of the engines is used for thermochemical processes to convert biomass into a combustible fuel. One method of biomass gas production is to gasify wood chips in a gasifier like the Viking gasifier at DTU, Denmark [9]. This so called producer gas is a low calorific gas that can be used as a fuel in internal combustion engines. The biomass gasification and the later combustion of this wood gas could play a significant role in a renewable energy economy because biomass

production removes the same amount of CO₂ from the atmosphere as is emitted from gasification and combustion if transportation and other production related issues are neglected.

In a small-scale CHP (combined heat and power) system a gasifier supplies producer gas to a combustion engine, which is connected to an electric generator. Several publications have shown high efficiencies for such applications [10]. The authors have modified a gas engine to make it suitable for operation on producer gas. Such systems could be used in local city community systems that use bio-waste/biomass and complement or replace traditional energy systems. Moreover, these applications can be used in sparsely populated regions where electrical energy is needed and electrical infrastructure is either too expensive to build or too distant in the future. Other suitable applications could be in developing regions where electrical infrastructure does not exist or even as flexible systems for catastrophe areas.

EXPERIMENTS

GAS PROPERTIES

Depending on the gasification process, the producer gas varies in its composition. The main components in dry gas are CO (carbon monoxide), H₂ (hydrogen), CO₂ (carbon dioxide), N₂ (nitrogen) and CH₄ (methane). Sometimes it also contains small amounts of higher hydrocarbons like C₂H₆ (ethane). The water content is usually very low because of filtering and drying in a scrubber. However, the producer gas exiting a biomass gasifier also normally contains small amounts of undesirable components. These particles, alkali compounds, tars and nitrogen-containing substances can cause higher emission levels as well as problems in the combustion process, deposit formations, corrosion problems and contamination of the engine oil. Therefore, it is necessary to use extensive filtering of the producer gas to achieve trouble-free engine operation. Modern gasifiers like the Viking gasifier at DTU in Denmark deliver clean producer gas in which the contaminants mentioned above are almost nonexistent. In former studies it has been found that there is no significant buildup of deposits on the piston top or the cylinder head [11]. High chlorine contents in the producer gas may shorten the lifetime of the oil and cause corrosion problems in the gas conditioning system, although these effects are marginal [1]. The mean composition of the producer gas from the Viking gasifier (dry gas, no water content) is shown in [table 1](#). In the experiments the producer gas composition is simulated in a mixture device that delivers the desired gas composition from gas bottles.

Table 1. Composition of the Viking producer gas (dry)

Component	Vol. %
CO	20
CO ₂	15
H ₂	30
CH ₄	1
N ₂	34

The ingredients of the gas mixture all have different effects on the combustion in the engine. The combustibles are CO, H₂ and CH₄, whereas N₂ and CO₂ are inert components. The inert gaseous fractions in the producer gas act as thermal buffers that lower the combustion temperature. Both gases act as inhibitors of auto ignition and knock. The content of carbon dioxide in this case has the same diluting effect on the fuel/air charge as EGR has [2].

In comparison to traditional fuels such as gasoline, diesel or natural gas (NG), the lower heating value (LHV) of producer gas (PG) is lower. Due to the low stoichiometric air/fuel ratio of PG, the energy density per unit air/fuel mixture makes PG a good engine fuel, even though it has a low LHV. This LHV is usually between four and twelve MJ/m³ for PG, depending on the production process. In this examination the gas has a LHV of about 6 MJ/Nm³. Former publications [1] have shown that the LHV of air/fuel mixtures with PG and NG have the same value at $\lambda=2.5$. For leaner air/fuel mixtures the relation between the heating value and the air/fuel ratio gives producer gas an advantage. This means that producer gas is an excellent lean burn fuel. The main advantages of lean engine operation are reduced NO_x emissions due to lower combustion temperatures and the possibility of achieving higher engine efficiency.

Producer gas has good knock resistance [3]. This is mainly due to the high hydrogen content that increases the laminar flame velocity, which reduces the tendency to knock. The laminar flame velocity is about 0.5 m/sec, which is about 30% higher than that of methane [4]. Also, the presence of inert gases (CO₂ and N₂) suppresses the pre-flame reactions, which are responsible for knocking due to increased dilution. The maximum flame temperature while burning PG is lower compared to conventional fuels, also contributing to knock-free combustion in an engine.

EXPERIMENTAL SETUP

The experiments were conducted on a modified SCANIA D9 nine liter, five cylinder truck/bus engine, operating on one cylinder only. The other four cylinders have deactivated valves and holed pistons to reduce losses caused by compression work. Other modifications to the engine include the addition of a pressure transducer in the cylinder head and blocked off coolant passages to the deactivated cylinder heads to ensure the cooling of the working cylinder.



Figure 1. Quartette piston

The displaced volume of the working cylinder is 1.858 cm³ and the compression ratio and combustion chamber geometry can be changed by fitting different pistons. In this study the ‘Quartette’ piston is used, a piston design that in previous gas engine experiments has proved to be a high swirl, fast-burning design [5], see [figure 1](#). General engine data is found in [table 2](#).

The Kistler 7061B cylinder pressure transducer is water cooled and connected to a Kistler 5011 charge amplifier. The pressure was sampled at a rate of 5 samples/CAD (crank angle degree), resolved by a Leine & Linde crank pulse encoder. All pressure traces shown in this publication are averaged over 300 cycles. The Bosch lambda sensor (0258007136) is mounted in the exhaust manifold and is connected to an ETAS LA4 lambda meter. When operating the engine on PG the lambda meter could not be used. Instead, the oxygen content was used to estimate the current lambda value. The exact value was calculated later in the post-processing. The fuel injectors are made by SPI, Model SP021S3. While running on natural gas only one of four injectors was used, but since the required fuel volume is much higher for producer gas operation all four injectors were used in that case. For emissions analysis a Horiba MEXA-9200 DF exhaust gas analyzer was used. The analysis of the producer gas was performed with analyzers from Hartmann & Braun for CO, CO₂, H₂ and O₂ and an FID analyzer for CH₄ (M+A Analysetechnik GmbH). The

producer gas composition was simulated in a mixer device from five 200 liter gas bottles containing H₂, N₂, CO, CO₂ and CH₄. The pressure in the air supply can be regulated with a remote valve. The engine dynamometer is an ABB 355 kW electric motor that kept the engine speed at 1050 rpm for all experiments. [Figure 2](#) shows a schematic view of the experimental setup.

Table 2. Engine specifications

Bore	130mm
Stroke	140mm
Cylinders	1
Displaced volume	1.858 cm ³
Connection rod length	255mm
Compression ratio	12.6
Number of valves	4
Exhaust valve diameter	41mm
Inlet valve diameter	44mm
Coolant temperature	63 °C ± 2 °C
Oil temperature	73 °C ± 2 °C
EGR	0%
Engine speed	1050 rpm

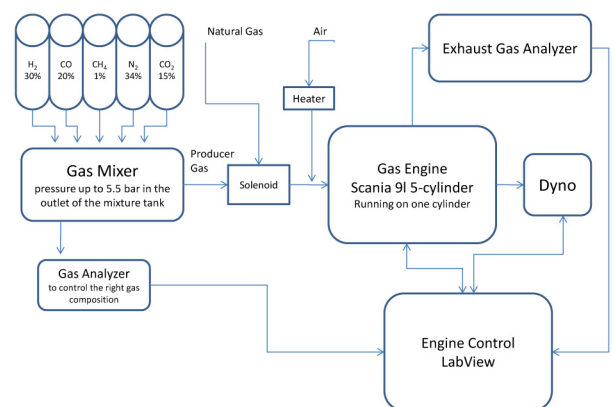


Figure 2. Schematic view of the experimental setup