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Performance and emission comparison of a supercharged dual-fuel engine fueled by producer gases with varying hydrogen content

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ABSTRACT

This study investigated the effect of hydrogen content in producer gas on the performance and exhaust emissions of a supercharged producer gas–diesel dual-fuel engine. Two types of producer gases were used in this study, one with low hydrogen content ($H_2 = 13.7\%$) and the other with high hydrogen content ($H_2 = 20\%$). The engine was tested for use as a co-generation engine, so power output while maintaining a reasonable thermal efficiency was important. Experiments were carried out at a constant injection pressure and injection quantity for different fuel–air equivalence ratios and at various injection timings. The experimental strategy was to optimize the injection timing to maximize engine power at different fuel–air equivalence ratios without knocking and within the limit of the maximum cylinder pressure. Two-stage combustion was obtained; this is an indicator of maximum power output conditions and a precursor of knocking combustion. Better combustion, engine performance, and exhaust emissions (except NO_x) were obtained with the high H_2-content producer gas than with the low H_2-content producer gas, especially under leaner conditions. Moreover, a broader window of fuel–air equivalence ratio was found with highest thermal efficiencies for the high H_2-content producer gas.

1. Introduction

The use of alternative fuels in engines has been the focus of much attention because of increasing concerns about environmental protection and the shortage of crude oil. Producer gas and hydrogen are two potential alternative fuels. Hydrogen engines have many attractive features, but they tend to suffer from premature ignition, especially under high load conditions [1–3]. Premature ignition is a much greater problem in hydrogen fueled engines than in other internal combustion (IC) engines, because of hydrogen's lower ignition energy, wider flammability range and shorter quenching distance. This problem is less severe in producer gas engines although producer gas contains about 12–20% hydrogen [4]. This study focused on engines fuelled with producer gases with different hydrogen contents.

Thermo chemical conversion (also referred to as gasification) turns solid organic matter into producer gas that can be

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Nomenclature

°ATDC	degrees after top dead centre
°BTDC	degrees before top dead centre
BTG	boiler-turbine-generator
°C	degrees Celsius
°CA	degrees of crank angle
CH_4	methane
CI	compression ignition
CO	carbon monoxide
CO_2	carbon-dioxide
$(COV)_{imep}$	coefficient of variance in indicated mean effective pressure
cm^3	cubic centimeter
EGR	exhaust gas recirculation
η_i	indicated thermal efficiency
H_2	hydrogen
HC	hydrocarbon
IC	internal combustion
IMEP	indicated mean effective pressure
kPa	kilopascal
mg/cycle	milligram per cycle
MJ/m^3	megajoule per cubic meter
mm	millimeter
MFB	mass fraction burned
MPa	megapascal
N_2	nitrogen
NO_x	nitrogen oxides
O_2	oxygen
ppm	parts per million
Φ	fuel–air equivalence ratio
R.O.H.R.	rate of heat release
rpm	revolutions per minute
SAE	Society of Automotive Engineers
SI	spark ignition
TDC	top dead centre

used for fuelling compression ignition (CI) engines in dual-fuel mode or spark ignition (SI) engines in gas only mode. Harnessing energy from biomass via gasification is not only proving to be economical, but is also environmentally benign [5]. In the past, producer gas was an important substitute for oil-based fuels in IC engines, but fell into disuse after the Second World War because of the economic and technical disadvantages compared to the relatively inexpensive imported fuels. The increase in oil prices since the mid-1970s has led to a renewed interest in wood gasification technology, especially in countries dependent on oil imports that also have adequate supplies of wood or other biomass fuels. Sweden is such a country, where the technology is maintained and developed as a matter of policy.

Using biomass as a source of energy can not only reduce the dependence on imported oil, but may also benefit the environment by reducing emissions of greenhouse gases and pollutants that affect the air quality. Producer gas from biomass has attracted considerable attention in recent years. Producer gas consists of about 40% combustible gases, mainly carbon monoxide (CO), hydrogen (H_2) and some methane (CH_4). The rest are non-combustible and consist mainly of nitrogen (N_2) and carbon-dioxide (CO_2). The composition of producer gas depends on the condition of the raw materials and the gasification conditions in the plant where it is produced. These variables have a considerable effect on gas engine performance.

There are two types of power plants that use producer gas: boiler-turbine-generator (BTG) systems and IC (gas) engine systems. The BTG system is suitable for large capacity power plants; however, when a BTG is used in a small co-generation system, the initial cost is relatively high and the thermal efficiency is low. Gas engine systems play an important role in small co-generation applications. Producer gas is suitable for relatively small gas engines because they have a higher thermal efficiency. Several gas engines fueled by producer gas have been developed recently [6–16]. Most of them have a SI combustion system. An SI engine is not suitable for this kind of fuel under high load conditions because of the difficulty in achieving stable combustion due to the fluctuation of the producer gas components. Producer gas has been used to run dual-fuel engines in some applications [15,16]; however, these are naturally aspirated engines.

There is a general perception that producer gas is a low-energy density fuel and that the extent of power derating is large when compared to high-energy density fuels like gasoline and natural gas. This is true for naturally aspirated engines. Conversion of a naturally aspirated engine to producer gas or dual-fuel operation will generally lead to a reduced power output due to the lower heating value of the combustible mixture. The heating value of producer gas and air stoichiometric mixtures is around 2.5 MJ/m^3. When this value is compared to the heating value of a stoichiometric mixture of gasoline and air (about 3.8 MJ/m^3), the difference in power output between a given engine fueled by gasoline and by producer gas becomes apparent. A power loss of about 35% can be expected as a result of the lower heating value of the producer gas/air mixture [4]. The stoichiometric mixture energy density for producer gas is 20–25% lower than that of CH_4. The main way to improve engine power is to increase the amount of combustible mixture in the cylinder. Therefore, a higher inlet mixture pressure plays a significant role in producing high engine power, which was achieved in this study by supercharging the engine. A supercharged engine not only helps to increase the output power, but it also creates the possibility of lean burning, which can reduce NO_x emissions. The engine used in this study was previously the subject of co-generation experiments in dual-fuel mode [17–19]. In [17], experiments were conducted at an injection pressure of 40 MPa with a pilot injection quantity of 2 mg/cycle. The effect of intake pressure was investigated by changing the intake pressure over the range of 101–200 kPa. An intake pressure of 200 kPa resulted in the highest indicated mean effective pressure (IMEP) and good indicated thermal efficiency. The effect of injection timing was examined over the range of 4–12 °BTDC at a constant fuel–air equivalence ratio. No attempt