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Effect of compression ratio on performance, combustion and emission characteristics of a dual fuel diesel engine run on raw biogas

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ABSTRACT

The energy consumption of the world is increasing at a staggering rate due to population explosion. The extensive use of energy has led to fossil fuel depletion and the rise in pollution. Renewable energy holds the key solution to these aforementioned problems. Biogas, one such renewable fuel, can be used in a diesel engine under dual fuel mode for the generation of power. This work attempts to unfold the effect of compression ratio on the performance, combustion and emission characteristics of a dual fuel diesel engine run on raw biogas. For this investigation, a 3.5 kW single cylinder, direct injection, water cooled, variable compression ratio diesel engine is converted into a biogas run dual fuel diesel engine by connecting a venturi gas mixer at the inlet manifold. Experiments have been conducted at various compression ratios (18, 17.5, 17 and 16) and under different loading conditions fixing the standard injection timing at 23° before top dead centre. At 100% load, the brake thermal efficiencies of the dual fuel mode are found to be 20.04%, 18.25%, 17.07% and 16.42% at compression ratios of 18, 17.5, 17 and 16, respectively, whereas at the same load, the diesel mode shows an efficiency of 27.76% at a compression ratio of 17.5. The maximum replacement of the precious fossil fuel is found to be 79.46%, 76.1%, 74% and 72% at compression ratios of 18, 17.5, 17 and 16, respectively at 100% load. For the dual fuel mode, on an average, there is a reduction in carbon monoxide as well as hydrocarbon emission by 26.22% and 41.97% when compression ratio was increased from 16 to 18. However, for the same setting of compression ratios, there is an increase of oxides of nitrogen as well carbon dioxide emissions by 66.65% and 27.18% respectively. In all the test cases, carbon monoxide and hydrocarbon emissions under dual fuel mode are found to be more than the diesel mode due to the reduction of volumetric efficiency of the former. The experimental evidence suggests to operate the dual fuel diesel engine at high compression ratios.

1. Introduction

Internal Combustion (IC) engines are the main life line of the human race for generating power. The power that is produced by IC engines is utilized for production of electricity, transportation, locomotives, irrigation, construction, marine, defence, telecom sectors, etc. In order to run the IC engines, we need fossil fuel whose reserves are depleting at a faster rate due to over exploitation due to population explosion. As a result, the price of fossil fuel is increasing at an alarming rate. Apart from that, there are some other issues related to this like global warming, acid rain, etc. Even though every nation is trying to curb the problem of global warming by imposing more stringent emission laws, the problem of oil and gas reserves depletion needs to be addressed in an appropriate way. Two things needs to be done: firstly, to save the precious fossil fuel by limiting its usage, and secondly, to focus our attention towards renewable energy for generation of power.

Bioenergy is one form of renewable energy, derived from the conversion of biomass. Biodiesel, bio-oil, producer gas, biogas, etc. are different forms of bioenergy which can be successfully used in IC engines for generation of power. Biogas is produced by fermenting organic material in absence of air with the help of bacteria to break the materials to intermediates such as alcohols and fatty acids and finally to methane, carbon dioxide and water. The process is called anaerobic fermentation. Biogas is also known as swamp gas, sewer gas, fuel gas, marsh gas, wet gas, gobar gas. A period of 15 days is sufficient for anaerobic bacteria to convert organic matter into biogas. Animal and human wastes along with agricultural crops and residue, municipal wastes are excellent feedstock for biomethanation. The potential for generating gaseous fuel through biomethanation is immense. This can bring economic development of a nation [1].

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Nomenclature

A_{den}	density of air (kg/m^3)
AFR	air flow rate (kg/h)
ATDC	after top dead centre (°)
BP	brake Power (kW)
BSFC	brake specific fuel consumption (kg/s/kW)
BSEC	brake specific energy consumption (kJ/s/kW)
BTDC	before top dead centre
C_d	coefficient of discharge
CI	compression Ignition
CO	carbon monoxide
CO_2	carbon dioxide
CR	compression ratio
d	diameter of orifice (m)
D	engine cylinder diameter (m)
DAD	data acquisition device
DFDE	dual fuel diesel engine
DI	direct injection
Euro	emission standards for European union
g	acceleration due to gravity (m/s^2)
h	manometer reading across the orifice (m)
HC	hydro carbon
IC	internal combustion
ID	ignition delay (°)
IT	injection timing (°)
K	number of cylinders
L	engine stroke length (m)
LHV_{BG}	lower heating value of biogas (MJ/kg)
LHV_d	lower heating value of diesel (MJ/kg)
LHV_{fuel}	lower heating value of fuel (MJ/kg)
$\dot{m}_{bg}$	mass flow rate of biogas (kg/h)
$\dot{m}_d$	mass flow rate of diesel (kg/h)
$\dot{m}_f$	mass flow rate of fuel (kg/h)
$\dot{m}_{pd}$	mass flow rate of pilot fuel (kg/h)
n	number of revolution per cycle
N	RPM
NHRR	net heat release rate (J/° CA)
NO_X	oxides of Nitrogen
P	instantaneous cylinder pressure (bar)
p	pressure measured on the manometer (Pascal)
PCP	peak cylinder pressure (bar)
PFR	pilot fuel replacement (%)
PT100	platinum resistance temperature detector with a typical resistance of 100 Ω at 0 °C
R	dynamometer arm radius (m)
SI	spark ignition
TDC	top dead centre
W	engine load (N)
W_{den}	density of water (kg/m^3)
V	instantaneous cylinder volume (m^3)
VCR	variable compression ratio
VE	volumetric efficiency (%)
W	dynamometer load (N)
Z	diesel replacement (%)
η_{bth}	brake thermal efficiency (%)
γ	specific heat of the combustion gases (kJ/kg K)
θ_{CS}	crank angle at which combustion of the fuel starts (degree crank angle)
θ_{IN}	crank angle at which injection of fuel starts (degree crank angle)

Biogas can be used in IC engines as fuel by modifying the engine suitably. The higher Octane number of biogas makes it suitable for engines with a relatively higher compression ratio in order to maximize thermal efficiency [2]. In addition, the carbon content in biogas is relatively low compared to that of the conventional diesel fuel, resulting in decrease in pollutants [3]. The most striking features that stands out in favor of using biogas in Compression Ignition (CI) engine is that there is no derating of power which is evident in case of Spark Ignition (SI) engines [4,5]. The reason behind this fact is that SI engines are very sensitive to biogas composition leading to high cycle to cycle variations [6]. Biogas is used in the CI engines in dual fuel mode. In CI engines, the temperature of the air at the end of compression stroke is more than 553 K. The auto ignition temperature of biogas is 1087 K [7]. So, simply compressing the air biogas mixture will not ignite. Hence, a small amount liquid fuel must be supplied along with the gaseous fuel to initiate the combustion process. The liquid fuel is called pilot fuel which acts as a source of ignition for the gaseous fuel. The gaseous fuel is called primary fuel on which the engine mainly runs. A CI engine can be easily modified to a Dual Fuel Diesel Engine (DFDE) by simply connecting a gas mixer in its inlet manifold and installing a fuel control mechanism to limit the supply of pilot fuel. It is seen that in a dual fuel engine, the combustion starts in a similar fashion of a CI engine. However, in the later part of combustion, the flame propagates in a manner similar to the SI engine. The power output of the engine is normally controlled by varying the flow of quantity of biogas. It is possible to achieve a substitution of diesel up to 85% by using biogas [8]. The most exciting feature of DFDE engine is the ability to switch over from dual fuel operation to diesel mode almost instantaneously in case of shortage of primary fuel [9]. The idea of running CI engines on biogas is not of recent origin but the process of refinement is still on. Researchers [2–5,7,8,10–19] have mainly tried to examine the practical utility of biogas in CI engines by using dual fuel technology. Henham and Makkar [2] examined the engine performance by using different quality of simulated biogas. The study indicated the possibility of 60% gas-oil substitution of pilot fuel without knock. Yoon and Lee [3] carried out an experimental investigation to study the combustion and emission characteristics of biogas run DFDE using soybean biodiesel. The study revealed that biogas biodiesel dual fuel combustion exhibited a superior performance in reduction of soot emissions due to absence of aromatic, lower sulphur content and the lower need of air and oxygen content for biodiesel. Walsh et al. [4] carried out a comprehensive study on utilization of biogas in both SI and CI engines. Bari [5] experimentally studied the effect of CO_2 on the performance of a biogas run diesel engine. The study indicated that the presence of CO_2 in biogas up to 40% did not deteriorate the engine performance. He speculatively explained the phenomena of dissociation of carbon dioxide to carbon monoxide and oxygen could improve the performance of the biogas run DFDE. The increased oxygen concentration would reduce Ignition Delay (ID) whereas the carbon monoxide would enhance the flame speed. Sahoo [7] studied the performance and emission characteristics of a biogas run DFDE using diesel and Jatropha biodiesel. The results indicated that the maximum brake thermal efficiency with dual fuel mode was found to be 16.8% and 16.1% for diesel and Jatropha biodiesel, respectively in comparison to 20.9% for diesel mode. Von-Mitzlaff [8] carried out an exhaustive study on modification of diesel engines to run biogas in a dual fuel mode. Cheng-qiu et al. [10] experimentally found that diesel substitution was more in case of low pressure biogas as compared to high pressure biogas in DFDE. Moreover, the study indicated a stronger knocking produced by the high pressure biogas run engine as compared to low pressure biogas run engine.