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# Experimental evaluation of a rice bran biodiesel – biogas run dual fuel diesel engine at varying compression ratios

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ABSTRACT

The present work attempts to unfold the effect of compression ratio on performance, combustion and emission characteristics of a rice bran biodiesel-biogas run dual fuel diesel engine. For experimentation, a single cylinder, direct injection (DI), natural aspirated (NA), water cooled, variable compression ratio (VCR) diesel engine is converted into a biogas run dual fuel diesel engine. Experiments were conducted at three different compression ratios (CRs) of 18, 17.5 and 17, and at a fixed injection timing of 23° bottom top dead centre (BTDC) under different loading conditions. At full load, the maximum brake thermal efficiencies (BTEs) under dual fuel mode (DFM) are found to be 20.27%, 19.97% and 18.39% for CRs of 18, 17.5 and 17, respectively. For same loading condition, the maximum liquid fuel replacement (LFR) is found to be 80%, 79% and 78.2% for CRs of 18, 17.5 and 17, respectively. On an average, there is a reduction in carbon monoxide and hydrocarbon emissions by 17.67% and 17.18% when CR is increased from 17 to 18. However, for the same setting of CRs, there is an increase of oxides of nitrogen as well as carbon dioxide emissions by 42.85% and 14.13%, respectively.



## 1. Introduction

Diesel engines are commonly used in power generation, automobiles, and countless industrial applications. As a whole, diesel engines may be considered as building blocks of the contemporary human civilization. The uses of liquid and gaseous biofuels in diesel engines have become received much attention because of their environmental benefits and direct replacement for diesel fuel. In this perspective, biogas along with biodiesel seems to be one of the emerging future fuels for diesel engines.

Biogas mainly contains methane and carbon dioxide, produced from anaerobic digestion of organic materials [1,2]. Biogas is known as mash gas, fuel gas, swamp gas, sewer gas, wet gas and gobar gas. A period of 15 days enables anaerobic bacteria to convert organic matter to biogas.

Biodiesel is an environment friendly alternative liquid fuel that can be used in any diesel engine without any modification [3]. It can be blended with diesel or be used directly in diesel engines [4]. Biodiesel, a fuel comprised of mono-alkyl esters of long fatty acids, is produced by transesterification [5]. It is characterized by its higher flash point, lubricity, Cetane number, biodegradability, non-toxicity, minimal sulphur and aromatic content [6]. Biodiesel offers great reduction in wear of engine components due to its improved lubricity over low-sulphur petro-diesels [7]. The recent review work [8–12] on biodiesel operated diesel engines highlight two key findings. Firstly, they exhibit a great reduction in aromatic compounds, particulate matter, carbon monoxide (CO) and hydrocarbon (HC) emissions. Secondly, they also show a marginal power loss, and an increase of both fuel consumption and oxides of Nitrogen ($NO_X$).

Gaseous fuels having low cetane number can be used in diesel engines through dual fuel technology, where the engines can operate on both liquid and gaseous fuels simultaneously. The reason behind using liquid fuel is that the temperature attained at the end of the compression stroke in a Compression Ignition (CI) engine is lower than the self-ignition temperature of gaseous fuel. Hence, a liquid fuel having high Cetane number is fired in the air-gas fuel mixture at the end of compression stroke which initiates the ignition process of the gaseous fuel. The liquid fuel, known as the pilot fuel, acts as a source of ignition. The gaseous fuel is called the primary fuel on which the engine mainly runs. The versatility of the dual fuel diesel engines can be realised from the research carried out on different types of primary fuel like hydrogen [13], ethanol [14], Liquefied petroleum gas [15], methane [15], natural gas [15,16], producer gas [17], syngas [18] and biogas [18–39].

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Of these, biogas is an attractive option for power production through dual fuel technology particularly in rural areas. The high octane number of biogas makes it suitable for engines with high CR in order to maximize thermal efficiency [19]. Besides, the carbon content in biogas is relatively low compared to that of the conventional diesel fuel, resulting in a diminution in pollutants [20]. The most attractive feature of using biogas in CI engine is that there is no derating of power as observed in case of biogas run SI engine [21,22]. Research investigations on biogas run dual diesel engines have advanced significantly during last two decades. Studies were carried out to understand the effect of load [18,20,37,38], variation of quantity of carbon dioxide ($CO_2$) in biogas [22,30], design of biogas-air mixing system [23,27], compression ratio [34,35], injection timing (IT) [35,39], raw biogas [28,21,25,26,32–39], simulated biogas [19,20,22,24,27–31], oxygen riched air [29], biogas inlet pressure to the engine [24], exhaust gas recirculation [31], quantity of pilot fuel [27] and different types of pilot fuel [18,20,27,28,33,35,36,38].

There have been several studies to understand the effect of operating parameter, compression ratio, on the performance and emissions of CI engines with different types of fuel. Raheman and Ghadge [40] found that the BTE increased by more than 33% when CR was increased from 18 to 20 for diesel engine using Mahua oil and its blend with diesel. Jindal et al. [41] studied the effect of CR in a DI diesel engine running on Jatropha methyl ester. The test indicated that the combination of CR 18 with injection pressure 250 bar resulted an increase of BTE by 8.2% as compared to standard setting of CR 17.5 with injection pressure 210 bar at full load. Muralidharan and Vasudevan [42] investigated the influence of CR on the performance of a VCR engine running with waste cooking oil and its diesel blends. The results indicated a superior performance of B40 blend in comparison to standard diesel at CR 21. EL_Kassaby and Nemit_allah [43] found an increase of BTE with an increase of CR for waste cooking oil blend with diesel. The change of CR from 14 to 18 resulted in an increase of BTE by 27.48% for B20 blend. Sayin and Gumus [44] studied the effect of CR on the performance and emission parameters of a DI diesel engine fuelled with biodiesel blended diesel fuel. For this purpose, CR of 19, 18 and 17 were considered. The study suggested that brake specific energy consumption (BSEC) were found to improve with the increase of CR as opposed to the original CR of 18. On the part of emission, CO and HC were found to diminish with the increase of CR. Hirkude and Padalkar [45] found that the brake specific fuel consumption reduces as opposed to increase in exhaust gas temperature (EGT) with the increase of CR for waste fried oil methyl ester blend operated diesel engine. Gnanamoorthi and Devaradjane [46] used higher CR along with ethanol blended diesel fuel to improve the performance of a diesel engine. Sharma and Murugan [47] studied the effects of varying the CR on the behaviour of a diesel engine by using a blend of 80% biodiesel and 20% oil obtained from pyrolysis of waste tyres. At CR of 18.5, the maximum BTE is found higher by about 8% than that of the original CR of 17.5.

There has been a considerable amount of work done at IIT Guwahati, India on renewable fuels such as syngas [18], pongamia biodiesel [36], rice bran biodiesel (RBB) [36], palm biodiesel [36,48], emulsified fuel [33,35,49] and biogas [33–46]. Debnath et al. [48,49] adjusted the operating parameters of a diesel engine for palm biodiesel and emulsified palm biodiesel. The test indicated that the BTE for palm biodiesel run diesel engine increased by 7% when CR was increased from 16 to 18 at IT = 23° BTDC. However, for a change of CR from 17 to 18 at IT = 23° BTDC, the BTE was found to increase by 8.2% for emulsified palm biodiesel run diesel engine. Bora et al. [34] studied the effect of CR on performance and emission characteristic of a raw biogas run dual fuel diesel engine. The study indicated a reduction of BSEC by 19.38% as CR was increased from 16 to 18 at 100% load. Recently, Bora and Saha [35] demonstrated that the use of emulsified RBB as pilot fuel at high CR of 18 can bring about a significant improvement in the performance for a biogas powered dual fuel diesel engine.

### 1.1. Present objective

The use of biodiesel along with biogas in dual fuel diesel engine seems to be an interesting prospect for power production in rural areas. Several studies have been carried out on biogas run dual fuel diesel engine using different types of biodiesel [18,20,27,28,33,38]. Recent investigations [35,36] on RBB as pilot fuel for biogas run dual fuel engine have identified it as one of the potent replacements of diesel fuel. However, more intensive research needs to be done to make RBB-biogas run dual fuel diesel engine more energy efficient through suitable adjustments of operating parameters viz. compression ratio, injection timing and injection pressure. Keeping this into view, the objective of the present study is to unravel the effect of CR on the performance, combustion and emission characteristic of a RBB-biogas run dual fuel diesel engine. In order to carry out this investigation, a 3.5 kW single cylinder, DI, NA, water cooled, VCR diesel engine is converted into biogas run dual fuel diesel engine. Experiments have been conducted at different loading conditions (20%, 40%, 60%, 80% and 100%) at the IT of 23° BTDC for three CRs of 18, 17.5 and 17 respectively.

## 2. Material and methods

### 2.1. Test set-up

The test set-up is a single cylinder, four stroke, DI, NA, water-cooled, 3.5 kW VCR diesel engine as shown in Fig. 1. The detailed specification of the set-up has already been reported [33–36]. For experimentation under DFM, the existing diesel engine is modified by connecting a venturi gas mixer in the inlet manifold. The venturi gas mixer is fabricated based on a recent design [50]. The pilot fuel supply under DFM is limited by installing a fuel control mechanism (FCM). The FCM consists of a spindle, shaft and control lever connected to fuel shut off valve of the fuel pump. This control lever marginally pushes the fuel shut off valve on the rotation of the spindle to limit the supply of fuel. The biogas flow rate (BFR) is measured by a biogas flow metre. The biogas used for this investigation is procured from a fixed dome type biogas digester, which uses cowdung as feedstock. The pressure of the biogas at the outlet of the digester is found to be 1.062 bar. The composition of biogas used for this work is determined through gas chromatography. The properties of the fuel are given in Table 1.

### 2.2. Test procedure

The diesel engine is tested initially with diesel for baseline data at standard IT of 23° BTDC and CR of 17.5. The brake mean effective pressure (BMEP) corresponding to percentage loading conditions is given in Table 2. The details of both baseline and dual fuel tests are reported earlier [33–36]. The same procedure is followed for all the test cases as given in Table 2.

### 2.3. Emission measurement

The emission analysis is carried out by using a Testo flue gas analyser. The analyser uses ASTM-D6522 standard for emission measurement. The resolution, accuracy and range of these emission parameters can be found in our work reported earlier [33–36].