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ORIGINAL ARTICLE

# Validation of some engine combustion and emission parameters of a bioethanol fuelled DI diesel engine using theoretical modelling

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**KEYWORDS**

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**Abstract** Earlier reports indicate that ethanol/bioethanol can replace conventional diesel fuel by 15%, when it is emulsified with diesel and used as an alternative fuel in a compression ignition (CI) engine. In this study, initially BMDE15, a bioethanol emulsion containing 15% bioethanol, 84% diesel and 1% surfactant was characterised for its fuel properties and compared with those of diesel fuel properties. The numerical value indicates the percentage of bioethanol in the BMDE15 emulsion. For the investigation, bioethanol was obtained from the Mahua Indica flower which was collected from the Madhuca Indica tree, and it was produced from fermentation process using *Saccharomyces cerevisiae*. Further, the BMDE15 emulsion was tested in a single cylinder, four stroke, air cooled, DI diesel engine developing a power of 4.4 kW at a rated speed of 1500 rpm. Two important combustion parameters: cylinder pressure and ignition delay, and two important emission parameters: nitric oxide (NO) and smoke emissions were determined and compared with those of diesel operation at all loads. The experimental results were validated using mathematical modelling, and the analysis of the results is presented in this paper.


## 1. Introduction

Ethanol is considered to be a potential alternative fuel for transport applications. It can be derived from a variety of sources. Although ethanol has been used in the form of a blend with gasoline, in spark ignition (SI) engines in the last three decades, the use of ethanol in compression ignition (CI) engines is of more interest because of the wider acceptance of CI engines in many applications [1]. Ethanol derived from biomass materials known as bioethanol is paid more attention because it can be derived from a variety of biomass materials which are renewable and abundantly available [2,3]. Numerous research works have been documented to use in the form of blending/emulsion, fumigation, dual injection, surface ignition,

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etc. in CI engines [4]. In recent years the study and control of emissions from internal combustion (IC) engines have been highly concentrated.

Theoretical analysis accomplished by mathematical modelling or numerical solutions using computer program or computational fluid dynamics (CFD) can give more fruitful predictions on the engine parameters [5]. The simulation model by MATLAB program for numerical solution was used to analyse the engine parameters of a single cylinder 3.5 kW rated power diesel engine fuelled with diesel, Palm Oil Methyl Ester and POME-diesel blends [6]. The results reported that, the simulated results on the brake thermal efficiency and in-cylinder pressure were closer by about 2–3% to the experimental results. A single-zone thermodynamic model was developed for a diesel engine fuelled with biodiesel from waste [6]. The single zone model coupled with a triple-Wiebe function was performed to simulate heat release and cylinder pressure. It was reported that, the heat release rate and cylinder pressure predicted were 2.5% and 2.2% closer to the experimental results of the engine. A two dimensional, multi-zone model was developed for a DI diesel engine run with the ethanol–diesel blend [7] and vegetable oil, bio-diesel and diesel [8]. The simulation model was supported by Fortran V language and solved numerically by solution marching technique with a computational step size of 1° crank angle. The heat transfer formulations used in a diesel engine under different operating conditions were computed using computational fluid dynamics (CFD) codes [9] was evaluated and compared with the experimental data. The model predicted more accurately the heat transfer during the compression stroke for motored operation and at the same time the predicted peak heat flux was closer to the experimental results. A quasi-dimensional, multi-zone, direct injection (DI) diesel combustion model has been developed and implemented in a full cycle simulation of a turbocharged engine. Predictions of heat release rate, as well as NO and soot emissions are compared with experimental data obtained from representative heavy-duty, turbocharged diesel engines. It is demonstrated that the model can predict the rate of heat release and engine performance with high fidelity. However, additional effort is required to enhance the fidelity of NO and soot predictions across a wide range of operating conditions [10]. A quasi-dimensional, three-zone combustion model of the diesel engine to calculate performance and emissions using the diesel–ethanol dual fuel was developed by Juntarakod [11]. A study was carried out using multizone modelling to analyse the spray development of a diesel engine run on vegetable oil, and biodiesel diesel blends [12]. It was reported that the prediction of results from modelling was more proximate than the experimental results. The computational time required was not affected in the multi-dimensional modelling. The combustion model of a diesel engine was developed using computational fluid dynamics (CFD) software-AVL Fire, and the performance and emission characteristics for second generation biodiesel were analysed [13]. The simulated results reported that, biodiesel provided better performance and efficiency, and significantly reduced engine emissions. The quasi-dimensional, multi-zone (QDMZ) models [14,15] were formulated by the quasi steady equations which described the individual processes that occur in the engine cylinder such as fuel atomisation, fuel injection, air entertainment, air–fuel mixing, combustion and heat transfer. A combustion model [16,17] was developed for the theoretical DI diesel engine and performance parameters. It was reported that the developed model could be adapted for an alternative fuel in a diesel engine and the performance and cylinder pressure results were closer to the theoretical.

In recent years, the validation of the experimental results from mathematical modelling or simulation through advance software is essential, so that the randomness of the results is minimised. In this study, a mathematical modelling was developed to validate the experimental results obtained from a single cylinder, four stroke, air cooled, DI diesel engine, that was run on the BMDE15 emulsion. A MATLAB program was developed for a two zone model for the validation. One zone consisted of pure air called the non-burning zone, and the other consisted of fuel and combustion products, called the burning zone. In order to obtain the cylinder pressure and temperature by mathematical modelling, the first law of thermodynamics and the equation of state were used for both the zones. The combustion parameters, such as ignition delay and heat release rate the chemical equilibrium composition were calculated theoretically, using the two zone model. As the NO and soot emissions are important in a CI engine, they were calculated using a semi-empirical model. A comparison of the theoretical and experimental results of the BMDE15 emulsion is presented in this paper. A spray profile of diesel and the BMDE15 emulsion is also obtained using a MATLAB program and is presented.

## 2. Materials and method

In this experimental investigation, bioethanol obtained from the Madhuca Indica flower and emulsified with diesel (BMDE15) was used as an alternative fuel in a single cylinder, four stroke, direct injection (DI) diesel engine. Table 2 lists the important properties of diesel and BMDE15. The complete procedure of producing the bioethanol from the Madhuca Indica flower has already been described in [18]. The numeric value after BMDE indicates the percentage of bioethanol in the emulsion. The physicochemical properties of the BMDE15 emulsion are shown in Table 1 in comparison with those of diesel.

The experimental set-up used in this investigation is shown in Fig. 1. A series of tests were carried out on a single cylinder, air cooled, stationary DI diesel engine that has a bore diameter of 87.5 mm and a stroke length of 110 mm and a displacement of 662 cm. The engine had a rated output of 4.4 kW 1500 rpm with a compression ratio 17.5:1. The nozzle opening pressure of the injector was 200 bar and the injection timing was 23 °CA bTDC, set by the manufacturer.

The engine was coupled to an electrical dynamometer to provide the brake load with an electric panel. Diesel and

**Table 1** Properties of diesel and BMDE15.

| Description | Diesel | BMDE15 |
|---|---|---|
| Chemical formula | $C_{16}H_{34}$ | $C_{5.471}H_{6.039}O$ |
| Molecular weight | 170 | 48 |
| Viscosity at 40 °C, cSt | 2.4 | 1.73 |
| Carbon | 86 | 65.65 |
| Hydrogen | 13.60 | 10.21 |
| Nitrogen | 0.18 | 0.14 |
| Sulfur | 0.22 | 0.01 |
| Oxygen by difference | 0 | 24 |