Experimental investigation and simulation of fuel blends and exhaust gas recirculation (EGR) in CI engine

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Abstract: Investigating the Emission Mitigation Potential of Nitromethane as an Additive in a 20% n-Butanol-Diesel Blend with Exhaust Gas Recirculation (EGR) in a Diesel Engine. The utilization of biofuels and additives has shown promise in curbing exhaust emissions from internal combustion (IC) engines. This study delves into the feasibility of incorporating Nitromethane (NM) as an additive in a 20% n-butanol-diesel (BU20) blend, in conjunction with the application of Exhaust Gas Recirculation (EGR), to mitigate smoke and NOx emissions from a diesel engine. The primary objectives of this investigation are to determine the optimal NM-to-BU20 ratio and EGR flow rate for enhancing engine performance while reducing emissions.

The experimental evaluation was conducted on a vertical, single-cylinder, four-stroke, constant-speed, water-cooled, direct-injection (DI) diesel engine. A range of NM-BU20 blends, spanning NM concentrations from 1% to 3%, and EGR rates from 10% to 30%, were meticulously prepared. Experimental tests were carried out based on a design matrix generated using Design Expert software. A comprehensive comparison of various fuel and EGR combinations was performed to identify the most effective blend of NM-BU20 and EGR for achieving emission reduction while maintaining reasonable engine performance.

Keywords: Diesel engine, Additives, Performance, Emissions, Exhaust gas recirculation

1. Introduction

Environmental pollution has become an issue as a result of the growing global population and accompanying growth in energy consumption. On the other hand, it is clear that the availability of fossil fuels as a long-lasting energy source is limited. The fastest-growing developing economies account for all regional growth in energy consumption, with China and India leading the way. By 2050, oil will continue to play a significant role in the world's energy consumption [1]. As a result of globalization, demand for oil-based fuels has significantly increased [2]. Currently, 12.2 x 109 tonnes of the yearly global energy consumption are provided by crude oil. This energy use will have grown to 1.75 x 109 tonnes of crude oil by 2035 [3]. The world may soon experience a petroleum shortage due to the depletion of fuel reserves. Diesel engines are preferred over SI engines due to their better fuel efficiency and lower carbon monoxide and hydrocarbon (HC) emissions. However, compared to spark ignition engines, compression ignition (CI) engines produce more nitrogen oxides (NOx) and smoke [4]. Biofuels will play an important role in meeting the shortfall in the demand for crude oil. The production of biofuels may roughly triple by 2050 to around 10 EJ, with most of these fuels being used in the transportation sector [5]. Biofuels greatly help in reducing the dependence on crude oil as well as reduce engine tailpipe emissions [6].

Use of biofuels/additives:

Good physicochemical characteristics of biofuels/additives have the greatest potential to reduce dependence on crude oil and also reduce emissions from the engine tailpipe. Numerous organic substances can be added to diesel to enhance the fuel's combustion and emission characteristics [7, 8]. As a result of having more oxygen in their molecular structures, which improves combustion, oxygenated compounds are more prevalent among all readily available additives. It was shown that using 10–20% of oxygenated additives with diesel fuel can lower exhaust emissions [9].

n-Butanol: The use of additives in diesel engines is being encouraged at the moment. Higher alcohols like n-butanol are thought to be preferable than methanol and ethanol for blending with diesel [10]. Because n-butanol is totally miscible with diesel and doesn't require any surface reactants, a number of research investigations [11–13] have shown that it may be able to mitigate the negative effects associated with the mixing of ethanol and methanol in diesel. The butanol gives an opportunity for researchers to study its performance in IC engines due to its high cetane number, high oxygen to carbon and oxygen to hydrogen ratios, and high heat capacity. With no adverse effects on the engine's power output, these characteristics will help reduce exhaust emissions.

Nitromethane (NM): The chemical name for nitromethane organic additives is CH3NO2. NM is a highly polar liquid with a viscosity that is just somewhat greater than that of diesel. Nitromethane is commonly used in a wide range of industrial applications as an extraction solvent, reaction medium, and cleaning solvent. For I.C. engines and drag racing cars, NM is widely utilized as a racing fuel. The creation of explosives, medicines, fibres, insecticides, and coatings are some of NM's additional uses [14].

2. Methods and Materials

The engine used for this test is a single-cylinder, four-stroke, DI water-cooled, compression ignition engine. The engine may be manually or self-starting, and it is usually equipped with a centrifugal speed controller. Specifications for the engine are shown in reference table 3.

Table 1- Engine setup's specifications

Equipment	**Specification**
Engine	4-stroke, single cylinder, water cooled, steady 1500 RPM Diesel Engine, 3.75 kW, 660 CC
Load Capacity(Nm)	Load cell Transducer, Torque Reso. : 0.01 kg–m, Range: 0- 6.00 kgm , radius: 0.16 m
Dynamometer	RPM: 1500 rpm - 2200 rpm, 3.75 kW Rating of torque
Measurement of Temp (Five channel indicator)	RTD Sensor (Pt 100), Reso. : 0.1°C ,Range: 0–400°C
Exhaust Gas analyzer	AVL-DIGAS-444N, NOx gas-Electrochemical, Range 0-5000 PPM , Resolution 1PPM
Smoke Analyzer	AVL-437C, Range 0-99.99 m-1, Resolution 0.01
Fuel flow rate calculation	Range: 0–5 kg, Weighing Reso. :- 1g, fuel flow range: 0–10kg/h, Reso. :- 0.06 kg/h, Measuring the Fuel rate By weight loss
Control Panel Connectivity	Connected by Comm 1 port with computer, RS232-RS485 Transformer
Water Flow Measurement	Turbine flow transducer, Reso. :- 0.1 cc/s, Range: 0–99.9 cc/s

The fuel-blends combination needed to be prepared before the experiment could begin. Three diesel, n-butanol, and nitromethane combinations were created on a volume basis. The n-butanol was added while the mixture was being constantly stirred with a magnetic stirrer after the pure diesel fuel had first been metered out into glass containers in accordance with the blending ratio. After combining n-butanol with pure diesel, nitromethane was added in a similar manner, according to the blending ratio. All of the aforementioned steps were repeated for different fuel blends. The consistency of fuel blends was also checked prior to experimenting, and no settling was seen.

3. Results and Discussion

This discussion will delve into the details of diesel engine Brake specific fuel consumption (BSFC): The greater percentage of NM in blends and with higher rates of EGR the BSFC increases. It is noted that the rate of increment of BSFC with EGR variation is higher than that of increment of BSFC with NM variation. The most probable reason of higher BSFC with NM blending is higher rate of burning and less time-duration available for heat conversion into mechanical work.

BTE variations with different NM blends and different rates of EGR. It can be seen from the figure that the BTE increased with higher ratio of NM and decreased at increased rate of EGR. The fast burning quality of NM improves the efficiency. The dilution of charge has needed more supply of fuel quantity for the same amount of power and results in lower efficiency at higher EGR rates.

Considerable drop in smoke emission was observed for NMBU-diesel blends. For NMBU blends smoke emission decreased by 28.8% as compared to emission at BU20 at rated load condition. Two factors were affected the smoke emission: (i) the higher oxygen (52.4%) in structure of nitromethane. Premixed combustion reactions are not able to break bond between O_2 and carbon atom; thus carbon atom are not available for taking part in combustion process which in turns creates soot & smoke. (ii) The another factor is the high latent heat of vaporization for NM-diesel blends which affect the smoke formation. To attain auto-ignition temperature of fuel-air mixture extra warm air is supplied to vaporize the fuel, this reduces the equivalence ratio (thus forms leaner mixture). Both aspects (oxygen enhancement and high latent heat for vaporization) hinder the smoke production in premixed-combustion and overall emission of smoke is decreased for NMBU blends. However, the use of EGR lead to increase in smoke emission due to dilution of charge.

The increased peak temperature during combustion because of enhanced combustion with NM leads to increase NOx generation (this is also reflected by improved BTE). The amplified NOx is basically due to thermally produced NOx, and not because of the nitrogen present in NM [20]. The fast burning property of NM augmented maximum temperature. Variation of NO and NO2 in total NOx may be another potential reason of total NOx increment. The NOx is reducing with higher proportion of EGR. Due to dilution of charge the maximum temperature during the combustion is declined this in turns reduces the generation of NOx. Also the rate of declination of NOx is greater at higher loads. It can be seen that the rate of reduction of NOx due to EGR is also higher than rate of increment of NOx due to blending of Nitromethane. The net effect of NM and EGR is reduced NOx by 15.7% at 3% NM and 30% EGR as compared to 1% NM and 10% EGR.

4. Conclusion and Future Directions

The conclusions reported in past studies presented in literature review and the results obtained in the present study are consistent. The closeness of experimental results and predicted data from the generated mathematical models is exhibited by confirmation test. It can be stated that the developed models are fairly dependable and can be applied for guessing outputs of similar type of cases without conduction of experiments. Following conclusions were drawn from current study:

1. With NM2BU20EGR15 (2% NM blending in 20% butanol-diesel blend with 15% EGR rate) BSFC is increased by 10.5% and 8.4% as compared to diesel and BU20 respectively.
2. The thermal efficiency of NM2BU20EGR15 is increased by 14.7% as compared to diesel and decreased by2.22% as compared to BU20 respectively.
3. The reduction in smoke with NM2BU20EGR15 is 64.45% as compared to diesel and 32.14% as compared to BU20 respectively on the optimum load conditions. The NOx is decreased by 25% and 17.18% for NM2BU20EGR15 as compared to diesel and BU20 respectively.
4. On the basis of above results it can be stated that the use of NM2BU20EGR15 is useful to control smoke and NOx simultaneously with a tolerable change in performance.

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