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Performance and emission assessment of diesel–biodiesel–ethanol/bioethanol blend as a fuel in diesel engines: A review

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A B S T R A C T

The aim of this review is to study the opportunities and prospects of introducing diesel–biodiesel–ethanol/bioethanol blend as fuel in the existing diesel engines. The study is based on the engine emissions and its performance. The energy policies and the ever growing energy demand of the world, require an alternative to fossil fuels. In this quest, the diesel–ethanol blend or the diesohol blend might be a good option. But this blend possesses stability problem as well as inferior physicochemical properties when compared to diesel fuel and needs additives to remain stable. When biodiesel is used as an additive in this diesohol blend, it improves the physicochemical properties of the ternary blend, engine performance and also increases the renewable portion of the blend. First the engine performance and emissions data found by using diesel–biodiesel–ethanol/bioethanol ternary blends are accumulated. Then the results of the scientists and investigators are discussed to evaluate its potential as an alternative to fossil diesel fuel. The physicochemical properties of ternary blends are found to be almost similar to the diesel fuel. These ternary blends significantly reduce the PM (particulate matter) emissions from the diesel engine but the emissions of NO_x (nitrogen oxides), soot and smoke, HC (hydrocarbon), CO (carbon monoxide), CO_2 (carbon dioxide) and the carbonyl compounds depend on the operating conditions of the engine and remain almost similar to the diesel fuel exhaust.

Contents

Abbreviations: CI, compression ignition; EtOH, ethanol; BD, biodiesel; SBD, soybean biodiesel; B10E5, ternary blend of 85% diesel, 10% biodiesel and 5% ethanol; B10E10, ternary blend of 80% diesel, 10% biodiesel and 5% ethanol; B10E15, ternary blend of 75% diesel, 10% biodiesel and 15% ethanol; B10, blend of 90% diesel and 10% biodiesel; CA50, crank angle 50°; BTDC, bottom top dead center; RPM, rotation per minute; EGR, exhaust gas re-circulation; HC, hydrocarbon; PM, particulate matter; SFC, specific fuel consumption

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1. Introduction

The rapid industrialization has increased the demand of fossil fuels more than ever. But fossil fuels reserves are depleting at an alarming rate around the globe. The new reserves found using the state of the art technologies are not enough to meet their increasing demand. Therefore, there is need to find alternative resources. On the other hand, the fuels used in transportation are subjected to increasingly stringent emission regulations. In this pursuit it is urgently needed to replace fossil fuels along with keeping the environment clean. Research efforts have been directed towards finding alternative economical fuel sources and thus reducing the dependency on fossil fuels. These researches have led us to alternative and economically viable fuels which are also environment friendly. Among the proposed alternative fuels for diesel engines, the biodiesel and diesel–ethanol/bioethanol blend has gained much attention in recent years. This attention is due to the fact that both of these are renewable energy carriers and can be produced domestically. Moreover, studies have shown that reduction in CO, unburned hydrocarbon and PM emissions from diesel engines can be achieved using these renewable fuels [1–4].

Biodiesel is mainly methyl ester of triglycerides prepared from animal fat and virgin or used vegetable oils (both non-edible and edible) [5]. It can be used in diesel engines as a single fuel or as a diesel–biodiesel blend. These require little or no engine modifications [5,6]. Ethanol is also an attractive renewable fuel. But it cannot be used as a single fuel in diesel engines thus it is blended with diesel which results in an oxygenated fuel. This blend of ethanol and diesel is also known as diesohol/e-diesel. Diesohol has a number of advantages [7,8]. It is already known that adding ethanol/bioethanol to the fossil diesel fuel increases the ignition delay, increases the rate of premixed combustion, increases the thermal efficiency and reduces the smoke exhaust. The solubility of ethanol/bioethanol in the diesel fuel is mainly affected by hydrocarbon composition of diesel, temperature and water content of the blend [9–11]. However, there are some technical barriers in the direct use of diesel–ethanol blends in the CI engine. Many researchers have tested these blends with different additives (emulsifiers) but all of the blends contained small quantity of ethanol as the additives can only improve the solubility but other properties of the blend are not affected [12–16]. The low flash point of this blend without biodiesel, is another critical problem, which hinders the application of this blend in the CI engine and studies have shown no effect of emulsifiers on this property [17]. When biodiesel is added to this diesel–ethanol blend then the solubility of ethanol in the diesel fuel increases over a wide range of temperature along with improving the blend's physicochemical properties [8,18]. This blend is stable well below under sub-zero temperature [8,19] and have equal or superior properties to fossil diesel fuel [8,20]. Studies have shown that the diesel–biodiesel–ethanol/bioethanol blend has improved physicochemical properties compare to diesel–biodiesel or diesel–ethanol/bioethanol blends separately [8,21]. This blend has better water tolerance and stability than the diesel–ethanol blend [2]. Some researchers have studied this blend with hydrous ethanol ($\geq 95\%$ EtOH+ $\leq 5\%$ water) [20] while some of them used anhydrous ethanol ($\geq 99\%$ EtOH+ $\leq 1\%$ water) [18,22–24]. From previous studies it is obvious that for better physicochemical properties, anhydrous ethanol must be used in ternary blends [8] but the quantity of ethanol in ternary blends to demonstrate best performance needs to be determined. Researchers have used up to 40% ethanol in a single ternary blend with 10% biodiesel and 50% diesel [25] while some of them used maximum 80% biodiesel in a single ternary blend with 10% ethanol and 10% diesel [26]. Their results showed very good performance of this ternary blend. Although many researchers have reported good performance of this blend, there are also many of them who reported very high BSFC and emissions from this blend. So there is need to evaluate research works done on this blend to conclude about its performance. The present study reviews the literature on evaluating power, torque, fuel consumption, efficiency and emissions (soot, smoke, NO_x, CO, CO_2, HC, PM, unregulated emission, sulfur dioxide and exhaust gas temperature) of this ternary blend found by many researchers around the globe.

In this review, the data from research studies conducted for evaluating diesel–biodiesel–ethanol/bioethanol blends are collected, summarized and compared to highlight potential of this blend as an alternative to diesel fuel.

2. Performance

2.1. Power and torque

Diesel–biodiesel–ethanol blends reduces engine power and torque output as the portion of oxygenated compounds (biodiesel and ethanol/bioethanol) in the blends increases [27]. This is due to the low cetane number and calorific value and higher ignition delay of the blends, compared to diesel fuel [15]. Cheenkachorn and Fungtammasan [22] found approximately 4.4–8.7% reduction in maximum power output by using diesel–biodiesel–ethanol blends compared to fossil diesel fuel.

Thus, using these blends without any additives reduce engine power and torque output. These reduced torque and power can be improved and the combustion characteristics can also be optimized by using additives with these blends [24]. If no additives are used, then the portion of the ethanol/bioethanol should be kept as low as possible.

2.2. Brake specific fuel consumption (BSFC)

The BSFC of a fuel blend reflects some of the physicochemical properties like the calorific value and the density of the blend. Theoretically, BSFC of a fuel blend increases (compared to diesel fuel), as the energy content of the blend decreases. Due to the low heating value of ethanol and biodiesel, the heating value of the blend consists of these three constituents is little low compared to diesel fuel. This low heating value of the diesel–biodiesel–ethanol/bioethanol blends increase the BSFC. This increase in BSFC depends on the biofuel (ethanol and biodiesel) content of the blends. As the portion of biofuel in the blends increases, the BSFC also increases [25–31]. But there are some researchers who investigated reduced BSFC initially but again found it increasing with increasing speeds [27]. The difference between BSFC of diesel and diesel–biodiesel–ethanol blends is maximum when the load is small/low [28] and high [26] on the engine. At low load condition, Barabás et al. [18,28] found this increase to be maximum 32.4% with a 30% biofuel content. And at high load condition, Subbaiah et al. [26] found maximum 40% increase but overall they encountered 26.97%, 31.33% and 35.33% increase in BSFC for B10E5,