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An experimental investigation on the potential of hydrogen–biohol synergy in the performance-emission trade-off paradigm of a diesel engine

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ABSTRACT

The global backdrop of energy insecurity and the increasing obligations of complying with the environmental legislations have inspired a distinct shift from the reliance of conventional fossil fuel resources in IC engine paradigms. Existing literature to this end substantiates an extensive effort in rationalizing the usage of biodiesel as a sustainable and renewable alternative fuel in existing diesel power trains without the necessity to adopt radical changes in the existing diesel platforms. In the present study, the synergistic advantage of Mahua (Madhuca Indica) biodiesel and hydrogen application has been investigated in order to establish a definite advantage over diesel operation. As hydrogen application was deemed to accentuate the propensity of biodiesel to NOx emissions, ethanol (20% v/v) has also been investigated in the present study as a viable NOx containment measure owing to its superior miscibility in methyl esters in comparison to conventional diesel. Results at 75% full load indicated that, B100 under hydrogen enrichment registered a consistent increase with a maximum of 13.6% and 15.1% in brake thermal efficiency in comparison to baseline diesel and biodiesel only operations at 42.6% hydrogen energy share. The trend in the gain of brake thermal efficiency was more pronounced at 100% full load operations wherein B100 under hydrogen enrichment registered an increase of 24.2% and 18.4% in brake thermal efficiency in comparison to baseline diesel and biodiesel only operation at 43.4% hydrogen energy share. However, such gains in brake thermal efficiency under hydrogen enrichment were observed to be penalized with a corresponding increase of 24.2% and 45.6% in NOx emissions at 75% full load operation along with 25.2% and 51.9% at 100%load. Application of ethanol as biodiesel blend reduced the corresponding NOx emissions by 9.2% and 3% at the respective load steps in comparison to neat B100 operation at the same rate of hydrogen enrichment without any significant deterrence in the performance characteristics.

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Abbreviations

BSEC	brake specific energy consumption
HC	hydrocarbon
DAQ	data acquisition
TUHC	total unburnt hydrocarbon
μSec	micro second
TSU	total sampling uncertainty
LHV	lower heating value
HES	hydrogen energy share ratio
NOx	oxides of nitrogen
CO	carbon monoxide
NO	nitric oxide
BSFC	brake specific fuel consumption
BSFCeq	equivalent brake specific diesel fuel consumption
BTE	brake thermal efficiency
ppm	parts per million
ECU	engine calibration unit
CA	crank angle
IVC	inlet valve closing
FSN	filter smoke number
IVO	inlet valve opening
RPM	revolutions per minute
TMI	timed manifold hydrogen injection
λ	air fuel ratio
H_1	hydrogen induction strategy with 7000 μSec of duration
H_2	hydrogen induction strategy with 9000 μSec of duration
H_3	hydrogen induction strategy with 11,000 μSec of duration
H_4	hydrogen induction strategy with 13,000 μSec of duration
D100	100% (v/v) diesel
B100	100% (v/v) biodiesel
B x E y	x% (v/v) biodiesel and y% (v/v) ethanol
x % B E y H-z	x% load condition, B-biodiesel E-ethanol; y = % vol; z- H_2 strategy, where x = 75% and 100% load; z = 1,2,3,4
v/v	volume per unit volume
w and w/o	with and without
ϕ	equivalence ratio

Introduction

The gap between the demand and the supply of petroleum derived fuels tends to increase day by day. Moreover, the use of fossil fuel has further threatened the environment in regards of carbon footprint, compelled researcher to go for eco-friendly fuel search which should be economically viable. Eco-friendly alternative fuels as compared to diesel fuel and gasoline fuels are being increasingly explored to meet the energy requirements of IC engines in countries faced with the insecurities of conventional petro fuels. Research [1] has indisputably established that conventional fossil fuels can be reasonably substituted by alternative renewable fuels of the day such as hydrogen and biodiesel [2].

Biodiesel as a potential alternative to diesel fuel has been extensively studied in the works of [3], where it has been shown to have comparable, if not better, performance characteristics to that of baseline diesel fueled operation. From the literature, majority of the studies [4,5], concur that the particulate matter (PM), unburnt total hydrocarbon (TUHC), carbon monoxide (CO) emission from biodiesel are lower than the conventional diesel fuel owing primarily to the oxygenated content as compared to conventional diesel fuel which promote better combustion characteristics [5]. However, operation, with pure biodiesel have been observed to suffer from impaired fuel spray characteristics arising from poor fuel atomization owing to its inferior cold flow properties of high viscosity and pour point. Furthermore, on the emission front, neat biodiesel operation has been observed in principle to be penalized with higher NOx emissions though some studies have reported an opposing trend of reduced NOx footprint than diesel operation [6,7]. Thus, a distinct trade-off is established wherein research studies are motivated to explore potential avenues to simultaneously reduce the NOx footprint of biodiesel operation and retain the incentives of its performance and other emission characteristics.

Research work devoted in mitigating such paradoxical objectives has led to the progress of novel emission reduction systems [8–12], such as Lean NOx trap (LNT), diesel particulate filter (DPF)and Selective catalytic reduction (SCR) after treatment system novel advanced combustion concepts such as HPLI, HCCI, HCLI and DCCS [13–17], to tackle the emission at the source. Though such measures signified with their distinct respective advantages, the penalty of the increase cost of maintenance, complex deployment, lack of adequate control [18,19], deter its immediate deployment on existing diesel power trains. Considering the increasing necessities of infusing the indices of sustainable and renewable energy vectors in the paradigm of viable alternative fuels for existing and future IC engines, the present study advocates the evaluation of ethanol as a promising and viable ready-to-use NOx containment vector in the biodiesel domain of operation without the necessity of incorporating the complexities of after treatment or advanced LTC concepts. To this end, a brief literature survey on the salient effects of ethanol on the baseline performance and emission characteristics of biodiesel/diesel operation is deemed pertinent in cognizance of its relevance in the present objectives of the intended study.

Alcohol in blend with diesel and biodiesel: a brief survey in ICE paradigms

Shi et al, 2006 [20] in their investigation on the emission reduction potential of ethanol–biodiesel in blend (5:20 v/v) with conventional diesel on a Cummins-4B diesel engine reported an average of 30% in PM reduction but with a collateral increase of 5.6–11.4% NO emissions in comparison to baseline diesel operation over the test cases studied. TUHC emissions showed a general trend of decrease with biodiesel–ethanol–diesel operation although aldehyde and acetone emissions were observed to increase. A slight amount of ethanol in the range of 2–12 mg/m^3 was also detected in the exhaust during the investigation. The study concluded that the chosen biodiesel–ethanol–diesel blend