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A novel emulsion fuel containing aqueous nano cerium oxide additive in diesel–biodiesel blends to improve diesel engines performance and reduce exhaust emissions: Part II – Exergetic analysis

Mortaza Aghbashlo [a,*], Meisam Tabatabaei [b,c,*], Esmail Khalife [c,d], Bahman Najafi [d], Seyed Mostafa Mirsalim [e], Ayat Gharehghani [e], Pouya Mohammadi [c], Ali Dadak [a], Taha Roodbar Shojaei [f], Zahra Khounani [b,c]

[a] *Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran*
[b] *Microbial Biotechnology Department, Agricultural Biotechnology Institute of Iran (ABRII), Agricultural Research, Education, and Extension Organization (AREEO), 31535-1897 Karaj, Iran*
[c] *Biofuel Research Team, Karaj, Iran*
[d] *Department of Biosystems Engineering, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, 56199-11367 Ardabil, Iran*
[e] *Department of Mechanical Engineering, Amirkabir University of Technology, 424 Hafez Avenue, P.O. Box 15875-4413, Tehran, Iran*
[f] *Institute of Advanced Technology (ITMA), Universiti Putra Malaysia, Serdang, Malaysia*

HIGHLIGHTS

- Exergy analysis of a single cylinder DI diesel engine at various engine loads.
- Water/diesel/biodiesel emulsions with cerium oxide nanoparticle as fuel blends.
- Engine load and fuel type profoundly affected sustainability indices of the engine.
- B5 blend with 3 w/w% water and 90 ppm nanoparticles showed the best performance.

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ABSTRACT

This survey was aimed at determining exergy-based sustainability parameters of a single cylinder DI diesel engine in response to various fuel blends and engine loads at a fixed engine speed of 1000 rpm. Engine tests were conducted at four engine loads (25%–100%) using a 95% diesel + 5%biodiesel blend (B5) emulsified with water (3, 5, and 7 w/w%). All the prepared emulsions were stabilized with a 2:1 combination of Span 80 and Tween 80 (overall 7.5 w/w% surfactant). Two levels of cerium oxide nanoparticle concentrations (0 and 90 ppm) were also applied. The results showed that engine load and fuel type profoundly affected the exergy-based sustainability indices of the engine. Generally, increasing engine load steadily decreased exergy efficiency, while normalized exergy destruction declined by up to 75% under full load condition. Among the fuel blends prepared, the B5 blend containing 3 w/w% water and 90 ppm cerium oxide nanoparticles ($B5W3_m$) showed the best exergy-based sustainability parameters at all the studied engine loads as its respective performance approached that of the basal petro-diesel. More specifically, among the fuel blends prepared the highest exergetic efficiency and the lowest normalized exergy destruction at full load condition were achieved using the selected fuel blend at 28.26% and 1.52, respectively. These values stood at 28.36% and 1.69 for neat diesel, respectively. However, the selected emulsified fuel blend represented a remarkably better environmental performance compared with diesel fuel. In conclusion, the $B5W3_m$ fuel blend might be effectively applied as substitute to mineral diesel fuel without any change in the existing engine structure.

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1. Introduction

Diesel engines are superior over gasoline engines from many facets including power efficiency, fuel economy, reliability and

* Corresponding authors at: Biofuel Research Team (BRTeam), Karaj, Iran (M. Tabatabaei).
E-mail addresses: maghbashlo@ut.ac.ir (M. Aghbashlo), meisam_tab@yahoo.com, meisam_tabatabaei@abrii.ac.ir (M. Tabatabaei).

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Nomenclature

C	carbone mass fraction (–)
C_p	specific heat capacity (kJ/kg K)
ex	specific exergy (kJ/kg)
$\dot{E}x$	exergy flow rate (kJ/s)
H	hydrogen mass fraction (–)
i	numerator
LHV	calorific value (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{n}$	molar flow rate (mol/s)
O	oxygen mass fraction (–)
P	pressure (kPa)
$\dot{Q}$	heat transfer rate (kJ/s)
R	gas constant (kJ/kg K)
$\bar{R}$	universal gas constant (kJ/mol K)
S	sulfur mass fraction (–)
SI	exergetic sustainability index (–)
T	temperature (K)
$\dot{W}$	shaft work rate (kJ/s)
x	mass fraction (–)
y	mole fraction (–)

Subscripts

a	air
b	engine body
c	coolant
ch	chemical
des	destruction
f	fuel
g	exhaust hot flue gas
in	inlet
l	loss
out	outlet
ph	physical
ref	reference state
w	work

Greeks

φ	fuel quality factor (–)
ε	specific chemical exergy (kJ/mol)
ω	angular velocity (rad/s)
τ	torque (N m)
η	thermal efficiency (%)
ψ	exergy efficiency (%)
Ψ	normalized exergy destruction (–)

durability, and lower emissions of unburned hydrocarbons (HC), CO, and CO_2 [1]. However, the major drawback of diesel engines is the higher NOx, SO_x, and particulate matter (PM) emissions, portraying them as one of the main culprits of the environmental and human health concerns faced today. On the other hand, the volatile petro-diesel price and its reservoirs depletion have developed the thrust in search of environmentally-clean and economically-viable alternative fuels for diesel engines [2]. To surmount these issues, researches have been directed towards biodiesel in order to find a sustainable and affordable substitute for diesel fuel during the past decade. Despite the fact that biodiesel is renewable, biodegradable, non-toxic, and sulfur-free fuel [3], but it suffers from several deficiencies like lower calorific value, higher viscosity, poorer cold flow properties, higher pour point, lower volatility, and lower oxidation stability compared with mineral diesel.

In general, original vegetable oils, animal fats, non-edible oils, waste vegetable oil, and algae can be used as feedstocks for biodiesel production [4]. However, it is impossible to replace all the diesel fuel demanded worldwide using biodiesel obtained from the above-mentioned feedstocks because of food *vs.* fuel debate, financial and environmental considerations, resources constraints, etc. [4]. In order to offset this defect and to mask the above-mentioned biodiesel disadvantages, partial replacement of petrol-diesel up to 5% by using biodiesel obtained from waste-oriented oils could be put forward as an eco-friendly and cost-effective strategy for the next few decades to achieve a relatively cleaner combustion.

In this regard, a significant amount of research efforts can be found in the literature on the performance assessment and pollutant emission of diesel engine operating on various diesel/biodiesel blends [5–8]. Although biodiesel addition to diesel substantially reduces HC, CO, PM, and smoke emissions, but there is no unanimous agreement on the reduction of NO_x emission [1]. In fact, biodiesel addition into diesel could generally increase NO_x emission due to the higher combustion temperature, prolonged ignition delay, and larger oxygen content. To address the increased NOx emission, various methods like exhaust gas recirculation and engine design alteration have been implemented during the past few decades. Unfortunately, even if these methods decrease NOx emission, they concurrently increase smoke and PM emissions [9].

Another strategy which could to a great extent reduce NOx emission is through introducing water into combustion chamber by different methods, i.e., as an additive through forming water/diesel emulsion in the presence of a stabilizer, spraying water into the cylinder individually, and fumigating water in the inducted air. It is well-documented that the first strategy can effectively reduce the emission of NOx and smoke *via* encapsulating water within the emulsion by using a suitable surfactant. Notably, not only this method does not negatively affect fuel consumption and engine thermal efficiency but also there is no contact between the engine surfaces and the water incorporated [10,11].

In fact, water/diesel emulsion reduces the harmful pollutants and improves the combustion efficiency by 'micro-explosion' phenomena resulted from the varied volatility of the diesel fuel and water. This in turns results in 'secondary atomization' phenomenon by breaking the injected fuel droplets into fine ones, leading to the fast vaporization of fuel and its better mixing with the intake air [10–12]. In spite of its advantages however, unfortunately this technique adversely prolongs ignition delay, leading to high pre-mixed combustion rate, peak pressure, and heat rejection rate as well as harsh engine operation [13]. This problem can be greatly overcome by incorporating a small amount of metallic/non-metallic nanoadditives in order to shorten ignition delay [14–16]. Although promising results have been reported, it is still crucial to scrutinize the potentials of water/diesel/biodiesel emulsion fuel containing nanoadditives from productivity and sustainability perspectives through the application of advanced engineering tools like energy and exergy analyses.

Traditional energy analysis based on the first law of thermodynamics cannot be applied to find the harmony between energy generation/consumption and environmental impacts [17,18]. On the contrary, exergy-based indicators can remediate this shortcoming by providing useful information on the irreversibility aspects (availability losses) of energy conversion systems [19].

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