ENERGY, EXERGY AND EMISSION PERFORMANCE OF DIESEL ENGINE WITH WATER EMULSIFIED BASED NANO FUELS

Thesis Submitted in Partial Fulfillment

For the Award of Degree

DOCTOR OF PHILOSOPHY

By

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I, **Ranjeet Kumar Rai,** certify that the work embodied in this thesis is my own bona fide work carried out by me under the supervision of **Dr. R.R. Sahoo** for a period of 4 years 9 months from December 2017 to September 2022 at IIT (BHU) Varanasi. The material contained in this thesis has not been submitted for the award of any other degree. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any others' work, paragraphs, text, data, results etc. reported in journals, books, magazines, reports, dissertations, theses, etc. or available at websites and have not included them in this thesis and have i
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Nomenclatures

Al_2O_3	Aluminum oxide
bTDC	Before top dead center
BTE	Brake thermal efficiency
BP	Brake power
BSFC	Brake specific fuel consumption
BSCO	Brake specific corbon monoxide
BSNOx	Brake specific oxides of nitrogen
CeO_2	Cerium dioxide
C_p	Isobaric specific heat
CO	Carbon monoxide
CO_2	Carbon dioxide
CNT	Carbon nano tube
CuO	Copper oxide
CV	Calorific Value
D_o	Deviation sequence
$\dot{E}_x$	Exergy rate
FeO_2	Iron dioxide
GRC	Grey relational coefficient
GRD	Grey relational grade
HC	Hydrocarbon
$\dot{m}$	Mass flow rate (kg/s)
MgO	Magnesium oxide
MnO	Manganese oxide

N	Engine speed
NO_x	Oxide of nitrogen
$\dot{n}$	Number of moles
OPB10	10% orange peel biodiesel-diesel blend
OPB20	20% orange peel biodiesel-diesel blend
OPB30	30% orange peel biodiesel-diesel blend
P	Pressure (bar)
R	Gas constant
$\dot{S}$	Entropy generation rate
SOB10	10% sal oil biodiesel-diesel blend
SOB20	20% sal oil biodiesel-diesel blend
SOB30	30% sal oil biodiesel-diesel blend
T	Temperature (^oC)
WiDE5	5% water emulsified diesel
WiDE10	10% water emulsified diesel
WiDE15	15% water emulsified diesel
Y	Mole fraction
ZnO	Zinc oxide

Subscript

a	Air
c	Coolant
des	Destruction
f	Fuel
l	Loss
g	Exhaust gas

gen	Generation
ref	Dead state
w	Shaft power

Superscript

Ph	Physical
Ch	Chemical

Greek symbols

η_{ex}	Exergy efficiency
η_{en}	Energy efficiency

μ	Dynamic viscosity (N/s-m^2)
ρ	Density (kg/m^3)
υ	Specific volume (m^3/kg)
ϕ	Chemical exergy factor

Abbreviations

EE	Exergy efficiency
EDR	Exergy destruction rate
EE	Exergy efficiency
EF	Fuel Exergy rate
EGR	Entropy generation rate
ES	Exergy sustainability
Ew	Coolant exergy rate
GE	Exhaust exergy rate
OPB	Orange peel biodiesel
ppm	Parts per million
rpm	Revolution per minute
S/N ratio	Signal to noise ratio
SOB	Sal oil biodiesel
v/v	Volume to volume ratio
WiDE	Water in diesel emulsion

ABSTRACT

Now a day, depleting fossil fuel resources and environmental issues are the major area of interest for researchers. To overcome the above issues, in this research work, orange peel biodiesel (OPB) and sal oil biodiesel (SOB) were prepared, and investigations on diesel engine performance and emission parameters were performed with 10%, 20%, and 30% (v/v) of biodiesel blending. The blending of biodiesel in diesel fuel led to reduction in HC, CO, and smoke emissions, and a slight increase in NO emissions. The limitation of biodiesel blending, i.e., NO emissions growth, is reduced by using water in diesel emulsion (WiDE) fuel. In this research work, WiDE fuels were prepared by emulsifying 5%, 10%, and 15% (v/v) water in diesel fuel, and investigations were performed. The incorporation of nano additive further reduces the NO emissions as well as the smoke and CO emissions. The engine performance and emissions analysis were also performed by incorporating Al_2O_3, and CNT nano additive with water-emulsified biodiesel blended fuel. The engine performance and emission parameters optimization was also performed using the Taguchi-Grey relational method for each set of experiments. The Taguchi method was used for experimental design and optimizing individual performance and emission parameters through the signal-to-noise ratio analysis. The Grey optimization techniques were used to convert the multi optimum response into a single optimum response.

This experimental investigation analysed the impact of engine power, engine speed, and percentage blends on exergy, energy, and emission parameters for the variable speed engines. The energy parameters like brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), exhaust gas temperature (EGT), exergy parameters, i.e., exergy efficiency, engine sustainability, exergy destruction rate (EDR), entropy generation rate, and emission parameters,

i.e., HC, NO, CO, CO_2, and smoke emissions were investigated for percentage of orange peel biodiesel and sal seed biodiesel fuel blends. Experimental results revealed that the BTE and exergy efficiency of the engine with biodiesel- diesel blend fuels are lower than diesel fuel at each engine power and speed condition. The HC, CO, and smoke emission were observed reduced, and NO, and CO_2 emission enhanced with biodiesel-diesel blends fuel at each engine power and speed. The signal-to-noise ratio (S/N) curve of grey relational grade (GRG) for SOB and OPB blended fuel declared that the engine load was the most affecting parameter, with a contributing factor of more than 45% for each performance parameter. The performance and emission parameters with OPB20 and SOB20 fuels were comparable with diesel fuel.

In this research work, the impact of percentage emulsification for water in diesel fuel on exergy, energy, and emission parameters for diesel-based samples (5–15% v/v.) water emulsification were also analysed on variable speed engines. The engine BSFC and CO_2 emissions were observed enhanced with water-emulsified fuel compared to diesel fuel. The engine BTE, exergy efficiency, and sustainability index were observed to enhance up to 5% of water emulsification in water emulsified fuel. The engine HC, CO, NO, and smoke emissions were reduced with water-emulsified fuel at each engine power and speed. The S/N curve of GRG of water emulsified fuel declared that the performance and emission parameters with WiDE fuels were better than diesel fuel and the engine load was the most affecting parameter, with a contributing factor of more than 50% for each performance parameter.

Finally, the investigation was performed by incorporating Al_2O_3, and CNT nano additive in the optimum water-emulsified biodiesel blended fuel level. The engine BSFC and EGT were observed to be reduced, and BTE, exergy efficiency, EDR, sustainability index, and entropy generation rate were observed to be enhanced with the

incorporation of Al_2O_3 and CNT nano additive. The effect of incorporation of CNT nano additive on engine exergy and energy performances has been observed to be higher than Al_2O_3 nano additive. The engine CO_2 was enhanced, and HC, CO, NO, and smoke emissions were reduced by incorporating Al_2O_3 and CNT nano additive. The S/N curve analysis of GRG revealed that the result obtained with CNT nano additive incorporated water emulsified biodiesel blended fuel was comparable to diesel fuel.

The optimization of engine performance and emission parameters was also performed with SOB-based CNT fuel and OPB-based CNT fuel using the mixed level of Taguchi experimental design method. The S/N curve of GRG of CNT incorporated 5% water emulsified OPB20, and SOB20 fuel revealed that 14 N-m engine torque, 1400 rpm engine speed, and CNT incorporated 5% water emulsified SOB20 fuel was optimum engine setting for overall optimum performance and emission parameters. The engine load was observed most affecting input parameters with more than 45% contribution factor for each output response except smoke emission. For smoke emission, the fuel type was observed most concerning input parameters.

Furthermore, with an engine load of 14 N-m, 1400 rpm engine speed, and with CNT incorporated 5% water emulsified SOB20 fuel, the engine BTE, exergy efficiency, EDR, EGT, entropy generation rate, NO, and CO_2 emission have been observed with 1.66%, 1.30%, 7.50%, 1.0%, 7.54%, 4.26%, and 27% higher than the diesel fuel. However, BSFC, CO, HC, and smoke emissions have been observed at 1.81%, 1.05%, 67.64%, and 50% lower than diesel fuel. The experimental result revealed that CNT incorporated 5% water emulsified SOB20 can be used as a fuel for diesel engines for better engine performance and emission characteristics without any engine modifications.

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