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Multi objective optimization of performance parameters of a single cylinder diesel engine with hydrogen as a dual fuel using pareto-based genetic algorithm

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ABSTRACT

The present experimental investigation attempts to explore the performance characteristics of an existing single-cylinder four-stroke compression-ignition engine operated in dual-fuel mode with hydrogen as an alternative fuel. Experimental investigation was conceded with the engine being subjected to different loads at a predefined flow rate of hydrogen induction. A Timed Manifold Injection (TMI) system has been developed to vary the injection timing and the durations. The optimized timing for the injection of hydrogen was 10^0 CA after top dead center (ATDC). From the study it was observed that hydrogen with diesel results in increased brake thermal efficiency (BTHE) by 15.7% at 40% full load, volumetric efficiency (Vol. Eff.) by 78.5% at full load condition compared to baseline diesel operation. Hydrogen enrichment registered a maximum reduction of 41.4% in specific fuel consumption (SFC) of diesel at 20% full load. A pareto-optimal front was then obtained using nondominated sorting genetic algorithm (NSGA). Analysis of the front was done to identify the separate regions for Brake specific energy consumption (BSEC), Brake thermal efficiency (BTHE) and Volumetric efficiency (Vol. Eff.). Designed experiments were then conducted in these focused regions to verify the optimization results and to identify the region– specific characteristics of the process.

Introduction

With emission legislations getting more stringent [1] in order to comply with the responsibilities of environmental obligations [2,3], engine manufacturers are turning to explore new avenues [4,5] to meet the paradox of curtailing particulate matter (PM) and NO_x emissions on one hand and maintaining consumer expectations of reduced fuel consumption and increased thermal efficiency on the other. The important motivations for exploring alternative fuel resources are energy security, air pollution, and climate

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Nomenclature

TMI	timed manifold injection
CMI	continuous manifold injection
LPDI	low-pressure direct cylinder injection
HPDI	high-pressure direct cylinder injection
ECU	electronic control unit
GA	genetic algorithm
NSGA	non-dominated sorting genetic algorithm
MOP	multi-objective optimization problem
MOGA	multi-objective genetic algorithm
VEGA	vector evaluated genetic algorithm
PM	particulate matter
DAQ	data acquisition
GUI	graphical user interphase
BP	brake power, kW
BSFC	brake specific fuel consumption, kg/kW-h
BSEC	brake specific energy consumption, kJ/kW-h
EHEPR	effective hydrogen energy participation ratio
Vol. Eff.	volumetric efficiency, %
BTHE	brake thermal efficiency, %
SFC	specific fuel consumption, kg/kW-h
H_2	hydrogen
IC	internal combustion
CI	compression ignition
ATDC	after top- dead- center
TDC	top-dead-center
BDC	bottom-dead-center
DAQ	data acquisition
DI	direct injection
KG	kilogram
DISL	diesel
H1	first injection strategy of hydrogen (@9000 μs)
H2	second injection strategy of hydrogen (@15000 μs)
H3	third injection strategy of hydrogen (@21000 μs)
μs	microseconds
D_i	inlet manifold diameter (INNER), m
Q	heat source, J
Q_w	heat release, J
R	Gas constant, J kg^{-1} K^{-1}
θ	crank angle, degrees
V	volume, m^3
P	pressure, bar
T	temperature, K
W	work done, J
U	internal energy, J kg^{-1}
γ	specific heat capacity ratio
c_v	specific heat at constant volume, J kg^{-1} K^{-1}
m	mass of gas, kg
$\dot{m}_D$	mass flow rate of diesel, kg h^{-1}
$\dot{m}_{AIR}$	mass flow rate of air, kg h^{-1}
$\dot{m}_H$	mass flow rate of hydrogen, kg h^{-1}
BD	baseline diesel operation
DUAL \	dual fuel operation with hydrogen enrichment
LHV_D	lower heating value of diesel
i	test case under consideration
$\O_{OVERALL}$	overall equivalence ratio
$(\O_H)_{ST}$	stochiometric equivalence ratio of hydrogen in air
$(\O_D)_{ST}$	stochiometric equivalence ratio of diesel fuel in air
LHV_H	lower heating value of hydrogen, kJ/kg
m_{HS}	% mass share of inducted hydrogen
$BSFC_{DIESEL}$	brake specific fuel consumption of diesel calculated. As per the actual consumption rate reported by the fuel burette
CA	crank angle, degrees

change, problems that are collectively calling into question the fundamental sustainability of the current energy system. The European Commission‘s White Paper “European transport policy for 2010: time to decide”, natural gas and bio fuels are seen as the most important short-term options for meeting these goals, whereas in the long run, a substantial contribution is expected to be delivered by hydrogen which would facilitate the transition from limited non renewable stocks of fossil fuels to unlimited flows of renewable sources. Hydrogen fueled internal combustion engines with near zero emissions are a potential near-term option and a bridge to hydrogen fuel cell vehicles where fuel cell undergoes developments to make it economically viable. Studies on the application of hydrogen as a dual fuel in diesel engines [6,7] offer the motivation to explore the potential in exploiting the inherent superior combustion characteristics of hydrogen as an in situ dual fuel solution to the emission and performance trade-off challenges of conventional diesel combustion. The efficacy of synergetic hydrogen-diesel dual fuel combustion [Table 1] has been studied to great length in recent times [7–12] where it has been established as a viable alternative to reduce the emission footprint without compromise of the related performance indices of conventional diesel operation.

Motivation of the present study

The results of such hydrogen–diesel dual fuel operation have clearly established that there is an ample scope to peruse an optimization study wherein the various input parameters can be suitably tuned to reap the maximum benefit of hydrogen participation. Real time experimentation dictated by a full factorial approach to unearth a detailed map of the response variables by the variation of control variables is but unviable considering the consequent cost and time resource footprint of the endeavor. Present day recourse to offline computational based exploration techniques provide a suitable opportunity to carryout in depth sensitivity analysis and establish a cost effective investigative platform. IC Engine optimization studies [13–19] have often unraveled multi-objectives that need to be addressed simultaneously. The multi-objectives are often contradictory in that, efforts to optimize one objective would lead naturally to a compromise of the other desired objectives. Thus in contrary to single objective problem multi objective optimization problems provide a challenge to establish a set of solutions that would be acceptable from viewpoint of the contradictory objectives. The present pilot experimental study results identified the importance of accurate tuning of the input parameters to obtain optimal BTHE,