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Research Paper

Optimized ANN-GA and experimental analysis of the performance and combustion characteristics of HCCI engine

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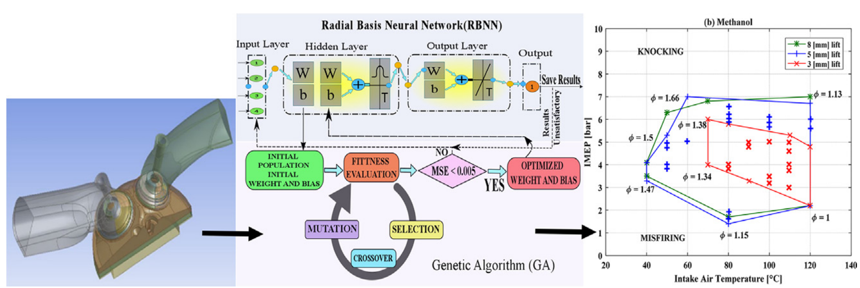
HIGHLIGHTS

- CFD analysis on HCCI combustion with trapped residual gas is performed.
- Key challenges are addressed, cyclic variation, operating region and combustion phasing control.
- Methanol extended the operating range by 12%, reduced cyclic variation by 15%.
- Ultra-low emissions of NO_x was obtained with reduced valve lifts.
- Good agreement amongst the CFD, ANN GA and experimental results is observed.

GRAPHICAL ABSTRACT



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ABSTRACT

HCCI (Homogeneous Charge Compression Ignition) engine has the benefit of operating at high thermal efficiency and low emissions of NOx and soot. However, it has challenges of complex combustion phase controlling and low operating range. This research work investigated the performance and combustion characteristics of HCCI engine with numerical simulations on ANSYS FLUENT and neural network models. The numerical and neural network results were validated by experimental observations with different fuel properties and reduced valve lifts for trapping of the exhaust gases. Experiments were performed on a SMART engine for different speeds and inlet air temperature, with various reference fuels (PRF30, PRF50, PRF70) and methanol to validate the CFD and ANN-GA observations. The engine performance was analyzed for IMEP, ISFC and thermal efficiency, which were found to be 8.2 bar, 205 g/kWh and 44.5% respectively as the optimum performance with PRF-70 fuel. The trapping of the residual gases was performed with various fuel blends in order to overcome the cyclic variations and to improve the operating zones near the knock boundary. The heat release rate was significantly reduced with trapped exhaust gases, and operating region was improved with the use of methanol fuel. Overall the trapping of the hot residual gases resulted in the maximum increase in the operating region by 12% and reduced cyclic variations by 15% for methanol fuel. The exhaust emissions were analyzed and ultra-low emissions of NO_x at lean operating conditions were observed with the reduced valve lifts. The study results indicated thermal NO emissions on an average were decreased by 7.8%, CO emissions reduced by 6% and HC emissions increased by 9%. Methanol had ultra-low emissions of HC and CO, but higher emissions of NO and PRF30 had lower emissions of NO. However, ANN-GA model gave satisfactory combustion characteristics and emissions with respect to experimental results. Thus, CFD simulations, Neural Network methods and

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Nomenclature

Greek letters

k	turbulence kinetic energy
ω	specific dissipation
k	ratio of specific heats
$d\theta$	variation in crank angle
dV	variation in cylinder volume
dP	variation in in-cylinder pressure
$k-\omega$	k-omega turbulence model
$k-\in$	k-epsilon turbulence model

Subscripts

ϕ_u	unburnt scalars
ϕ_b	burnt scalars
f_{mean}	mean of the turbulence function
f_{var}	variance of the turbulence function
P_{max} [bar]	maximum Pressure
S_L	laminar flame speed
S_T	turbulent flame speed
τ_t	turbulent time scale
τ_c	chemical time scale

Abbreviation name

3D	three dimensional
aTDC [°CA]	after top dead center
ANN	artificial neural network
bTDC [°CA]	before top dead center
CA [–]	crank angle
CA50 [°CA]	crank angle at 50% completion of combustion
CAI	controlled auto ignition
CFD	computational fluid dynamics network
CI	compression ignition
CO	carbon monoxide
COV	coefficient of variation
DPM	discrete phase modelling
EVC	exhaust valve closed
EVO	exhaust valve open
GA	genetic algorithm
HC	hydrocarbons
HCCI	homogeneous charge compression ignition
HRR [J/deg]	heat release rate
IMEP [bar]	indicated mean effective pressure
ISFC [g/kWh]	indicated specific fuel consumption
IVC	intake valve closed
IVO	intake valve open
MBF	mass burn fraction
NOx	oxides of nitrogen
PPC	partially remixed combustion
PRF	primary reference fuels
PRR [bar/deg]	pressure rise rate
RANS	Reynolds-averaged navier-stokes
RBNN	radial bias neural network
rpm	revolutions per minute
SDR	specific dissipation rate
SI	spark ignition
SOC	start of combustion
SST	shear stress transport
STD	standard deviation
TKE	Turbulent Kinetic Energy
TDC	Top Dead Center
RBFNN	Radial Basis Function Neural

experimental study gave valuable thoughts of trapped residual gases approach on performance, combustion and emission characteristics of HCCI with PRF's and methanol fuel.

1. Introduction

The contemporary world is facing problems due to environmental pollution more than ever as a result of which there are stricter emissions and better fuel economy regulations in place. This requires the introduction of the novel and alternative mode of engine combustion, Homogenous Charge Compression Ignition (HCCI) to the automotive market, due to its ability to reduce emissions and operate at an increased thermal efficiency simultaneously [1–3]. HCCI combustion occurs with a homogenous mixture of air, fuel and the residual gases which are compressed until auto ignition occurs at sites distributed throughout the combustion chamber. Therefore, in a way, it combines the advantages of the spark ignition combustion engine (gasoline engines), and compression ignition engine (diesel engine). The diesel dilemma of NOx and soot [4] is addressed to an extent with this mode of combustion, as a result of the low local combustion temperature due to its operation at lean premixed air-fuel mixture in the combustion chamber. Moreover, the performance benefits in terms of increased thermal efficiency for the HCCI engine were associated with the features of compression ignition and reduced throttling losses during the intake process. The HCCI engine suffers from direct combustion phasing control due to lack of spark plug for ignition like a gasoline engine, and direct fuel injection similar to a diesel engine. The chemical kinetic reactions of the air-fuel mixture were solely responsible for the ignition timing in an HCCI engine [5,6], which in turn makes the inlet temperature of the mixture important. The effect of the intake air temperature on a hydrogen HCCI engine was investigated by Ibrahim et. al. [7] and found that significant increase in the combustion phasing advancement with an increase in the intake temperature. Furthermore, the composition of the fuel used in the HCCI engine is an important contributing factor for the chemical kinetics of the HCCI combustion taking place in the chamber and control effects in terms of the fuel variation has been a major topic of discussion and the limelight of research in the engine combustion arena. HCCI engine displays a strong compatibility of operation in terms of different fuel types, as can be observed from the various fuels investigated such as natural gas, gasoline, diesel [8–10], pure hydrocarbon fuels, n-heptane, iso-octane, hydrogen, and acetylene [11–13], however, different combustion and emission properties were observed with different fuels. Two stage reactions were observed using heavy hydrocarbons, and their sensitivity with regard to the octane number of the fuels was investigated by Tanaka et. al. [14]. The HCCI engine also suffers from cycle to cycle variations, which could be improved by reducing the octane number of the fuel according to