STUDY ON BACKFIRE, PERFORMANCE AND EMISSIONS CHARACTERISTICS OF A HYDROGEN FUELLED SPARK IGNITION ENGINE

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STUDY ON BACKFIRE, PERFORMANCE AND EMISSIONS CHARACTERISTICS OF A HYDROGEN FUELLED SPARK IGNITION ENGINE

by

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Submitted

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CERTIFICATE

The thesis entitled "***Study on Backfire, Performance and Emissions Characteristics of a Hydrogen Fuelled Spark Ignition Engine***" being submitted by **Mr. Bheru Lal Salvi** to the **Indian Institute of Technology Delhi** for the award of **Doctor of Philosophy** is a record of bonafied research work carried out by him. He has worked under my guidance and supervision, and has fulfilled the requirements for the submission of this thesis, which has attained the standard required for a Ph.D. degree of the institute. The results presented in the thesis have not been submitted, in part or full, elsewhere for the award of any degree or diploma.

I certify that he has pursued the prescribed course of research under my supervision.

Place: New Delhi

Date: ……………

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ABSTRACT

This research work was aimed for study of backfire, performance improvement and emissions reduction in a hydrogen fuelled spark ignition engine. For this study, a carburettor based gasoline fuelled spark ignition (SI) engine generator set with rated power output of 2.1 kVA at 50 Hz and 220 V was selected and then converted into hydrogen fuelled generator set using timed manifold injection. The experimental study was carried out at various compression ratios (4.5:1, 6.5:1(base) and 7.2:1), spark timings, delay in start of hydrogen gas injection and exhaust gas recirculation (EGR) up to 25 % by volume. The study at reduced compression ratio of 4.5:1 was also carried out for wide parametric study of backfire occurrence in a hydrogen fuelled SI engine.

Experimental results revealed that hydrogen fuelled SI engine operation at increased compression ratio of 7.2:1 improved the relative brake thermal efficiency (BTE) by 10 % as compared to base compression ratio of 6.5:1 at power output of 1 kW. The highest BTE of 15.3 % was observed at equivalence ratio of 0.5 and it decreased with respect to increase in equivalence ratio, while power output increased. The engine operation at higher equivalence ratio of 0.8 and above was observed with combustion knock and reduced BTE. However, the NO_x emission increased at increased compression ratio of 7.2:1 and also it increased with respect to increase in equivalence ratio.

The spark time variation and EGR were used for NO_x emission reduction at source level. The spark advancing from maximum brake torque (MBT) caused to increase in NO_x emission, while spark retarding up to 2° CA bTDC reduced the NO_x emission marginally, but power output and the thermal efficiency dropped significantly by 6 %. The EGR level up to 24 % by volume significantly reduced the NO_x emission up to 57 %. The spark time retarding is not a suitable option for NO_x emission reduction in hydrogen

fuelled SI engines, whereas the EGR level of 20 % by volume was chosen as optimum where the NO_x emission was reduced by 50 % with marginal effect on power drop as compared to NO_x emission without EGR.

The results of numerical analysis and experimental study on backfire occurrence indicate that backfire is mainly function of residual gas temperature and hot-spots. It was found from the numerical analysis of in-cylinder mixture temperature during suction stroke that delayed gas injection would reduce the probability of backfire occurrence due to cooling of residual gas and hot-spots. In addition to this the backfire occurrence phenomenon was explained using computational fluid dynamics (CFD) and found that backfire occurs due to hot-spot and flame propagate towards upstream of intake manifold. The probability of backfire occurrence reduced with respect to increase in intake charge velocity. The experimental observations for delay in start of injection (SOI) have shown that backfire limiting start of injection (BFL-SOI) reduced with increased compression ratio and the delay in SOI up to 50° CA aTDC eliminated the backfire occurrence and improved the engine performance also. It was found from the experimental results of flame kernel growth rate (FKGR) that higher FKGR for hydrogen with respect to equivalence ratio is responsible for reduced ignition lag and rapid flame propagation, while use of EGR with intake charge reduced the FKGR by charge dilution.

The notable findings emerged from this study are that the hydrogen fuelled SI engine with increased compression ratio of 7.2:1, MBT spark timing of 9° CA bTDC and EGR value of 20 % by volume will give better performance and reduced NO_x emission. The addition of EGR slows down the FKGR and delay in SOI allows to cool down the residual gas; therefore probability of backfire occurrence reduces with EGR and delay in SOI. On the whole, the hydrogen fuelled spark ignition engine with EGR could provide beneficial results of reduced NO_x emission and elimination of backfire.

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NOMENCLATURES

Abbreviations

aBDC = After bottom dead centre
AC = Alternative current
aTDC = After top dead centre
bBDC = Before bottom dead centre
BDC = Bottom dead centre
BMEP = Brake mean effective pressure
BP = Brake power
BSEC = Brake specific energy consumption
BSFC = Brake specific fuel consumption
bTDC = Before top dead centre
BTE = Brake thermal efficiency
CA = Crank angle
CFD = Computational fluid dynamics
CHR = Cumulative heat released
CNG = Compressed natural gas
CR = Compression ratio
CT = Coolant temperature
DOC = Duration of combustion
ECU = Electronic control unit
EGR = Exhaust gas recirculation
EMS = Engine management system
EOC = End of combustion
ER = Equivalence ratio
FKGR = Flame kernel growth rate
HC = Hydrocarbon
HRR = Heat release rate
ICE = Internal combustion engine
IMEP = Indicated mean effective pressure
IPC = Inlet port cooling
IR = Infra-red
ITE = Indicated thermal efficiency
LHV = Lower heating value
MBT = Maximum brake torque
MFI = Manifold fuel injection
NO_x = Nitrogen oxides
NRV = Non-return valve
NTP = Normal temperature and pressure (25° C and 1.013 bar)
PCV = Positive crankcase ventilation
PFI = Port fuel injection
rpm = Revolution per minute
SC = Supercharging
SIE = Spark ignition engine
SOC = Start of combustion
SOI = Start of injection
ST = Spark timing
STA = Spark time advance
STMIS = Sequential timed manifold injection system

TDC	=	Top dead centre
TMI	=	Timed manifold injection
TPS	=	Throttle position sensor
VC	=	Valve close
Vol.Eff.	=	Volumetric efficiency
VOP	=	Valve overlap period
w.r.t	=	With respect to
WI	=	Water injection
WOT	=	Wide open throttle

Symbols

h	=	Enthalpy (J/kg)
m_{mix}	=	Mass of in-cylinder charge
N	=	Engine speed (rpm)
p	=	Pressure (N/m^2)
s	=	Entropy (J/kgK
T	=	Temperature (K)
$\dot{R}_{FKG}$	=	Flame kernel growth rate (m/s)
r_c	=	Compression ratio

Greek symbols

ϕ	=	Fuel-air equivalence ratio
γ	=	Ratio of specific heats
ρ	=	Density (kg/m^3)
η_{ith}	=	Indicated thermal efficiency
θ	=	Crank angle
χ	=	Residual gas fraction