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Modelling and Simulation of Methanol and Diesel Fuelled HCCI Engine for Improved Performance and Emission Characteristics

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Abstract: ***Alcohol fuels are widely used for HCCI engine. In this study, Methanol is used in single cylinder engine as a premixed fuel with diesel in different compositions. Engine performance will improve in terms of thermal efficiency and emission. Intake charge within temperature range of 120^0-140^{0}c gives good results for combustion, heat release & pressure rise rate. Intake charge temperature and engine speed are dominant parameter which affects the performance and emission of the engine. Higher thermal efficiency & lower emission can be achieved optimizing combustion duration and injection timing of both fuels which is also helpful for extending the operating range of HCCI engine.***

Keywords: HCCI, BSFC, Methanol, Brake thermal efficiency, Emissions

1. Introduction

These days pollution is major issue due to variety of sources where I.C. Engine is the most significant contributor. Extensive uses of conventional fuels are leads to production of very toxic gases & deteriorates environment badly. To overcome this, certain techniques are available called after treatments e.g. catalytic convertor, EGR etc. But it is always better to work at source level. So HCCI engine is one another option which helps to lower down the emission levels. HCCI Engine uses one highly active fuel i.e. methanol and one low reactive fuel i.e. diesel. If methanol and diesel are used in HCCI engine with different compositions at various speed and load conditions, one can identify its effect on thermal efficiency, BSFC & emissions [1].

2. Literature Survey

Homogeneous charge compression ignition engines (HCCI) is a new research area implemented in practice to reduce the exhaust emission and enhancing the thermal efficiency of the engine. The principle of operation of this engine is it inducts the premixed fuel and air through port injector via Intake manifold which is homogeneous charge. Another fuel for e.g. diesel is injected at high pressure through main injector. Hence the combustion takes place spontaneously within shorter duration [2]. This results in to high pressure rise rate as well as heat release rate within combustion chamber. Chunhua zhang et al. (2015) reported that Homogeneous charge compression ignition (HCCI) technology is believed to be a promising one to be applied in both spark ignition (SI) and compression ignition (CI) engines in the near future [3]. However, some researchers such as Dong-bo Yang et al. (2011) were found that some challenges such as compromise combustion phase control, controlled auto-ignition, operating range, homogeneous charge preparation, cold start, emission of unburned hydrocarbon (UHC) and carbon monoxide (CO) need to be overcome for successful operation of HCCI engine. Extensive research on HCCI combustion with a homogeneous fuel–air mixture preparation is going on throughout the world (control strategy) [4].

3. Engine Selection

Diesel engine is suitable to convert in to HCCI engine because it has higher compression ratio and higher efficiency. There are many options available like single cylinder, multi cylinder; vertical, horizontal etc. but we have selected single cylinder four stroke water cooled diesel engine for modification. Table 1 gives the specifications of selected engine which is used for simulation of both the engines (CI as well as HCCI).

Table 1: Engine specification

Type	PPW-5A
No. of cylinder	Single cylinder
Rated output (HP)	5
Rated speed (rpm)	1500
Bore (mm)	87.5
Stroke (mm)	80
Cubic capacity (CC)	481
Compression Ratio	16.7:1
Lubricant oil sump capacity	1.3 Ltr.
Specific fuel consumption (gm/kwhr)	230
Net weight (kg)	80
Method of cooling	Water cooled
Method of starting	Hand starting

Table 2: Fuel Properties [5]

Fuel property	*Methanol*	*Diesel*
Formula	CH_3OH	$C_{12}H_{23}$
Molecular weight	32	180-200
Oxygen content	50%	0
Stoichiometric air/fuel ratio	6.45	14.5
Lower calorific value (MJ/kg)	19.7	42.5
Freezing point(^{0}C)	-98	-1 to -4
Boiling point(^{0}C)	65	175 – 360
Flash point(^{0}C)	11	55
Auto-ignition temperature(^{0}C)	465	220 – 260
Research octane number	108	25
Cetane number	3	40 – 55

4. GT-POWER simulation model

For the simulation of HCCI engine we have used GT-POWER software which is best suitable one. Currently this software is used by almost all engine development industries. This software is useful for all segments of vehicle engines e.g. trucks, buses, cars, two wheelers, locomotives, lawn movers, racing engines, garden equipment etc. With help of this software one can model any advanced concepts with many components. The GT-SUITE environment also provides GT-POWER with a proven set of high-productivity features for pre and post-processing, DOE/optimization, neural networks and control modelling. This is specifically designed for both steady state and transient simulations. GT-POWER has long been recognized for its high degree of accuracy in predicting the behaviour of complex engine related phenomena at its core. The GT-POWER solver is based on the 1D solution fully unsteady nonlinear Navier Stokes equation [6].

5. CI Engine simulation model

The model represents various attributes such as inlet, inrun, inport, injector, cylinder, engine, Exval, Export etc. In this model injector is used for pressurised diesel injection having 6 holes. For connecting two pipes the attribute used is „piperound". Torque attribute is used for applying load on engine. In inlet attribute composition only fresh air is taken. Some of the object/ attribute were considered to be „default" or „ignore" which are not much effective in simulation.

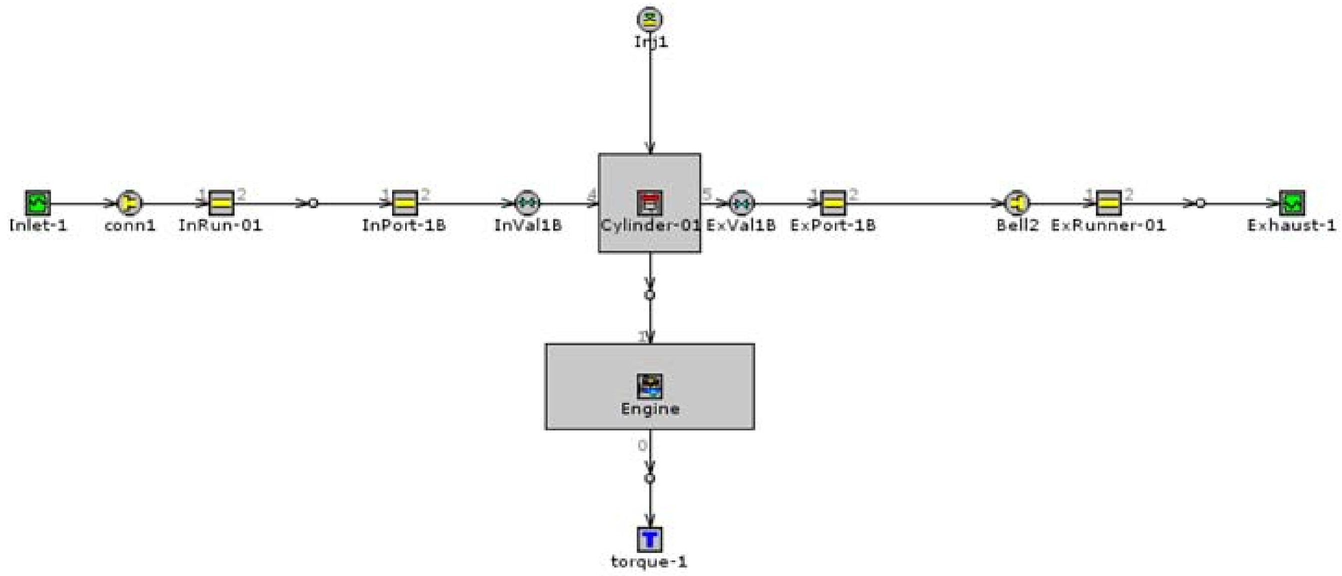

Figure 1: Single cylinder CI engine simulation model in GT-POWER

By using torque attribute engine has been loaded at 5 load intervals for e.g. (20, 40, 60, 80 and 100%). Length of connecting rod of selected engine is 165 mm. Also mass of fuel is varied on the basis of bsfc at all load conditions. BSFC at full load of our engine is 230 gm/kw-hr [6].

6. HCCI Engine Simulation Model

In HCCI simulation model two injectors are used namely Injector1 and Injector2. Injector1 is used for port injection of methanol while Injector2 is used for diesel injection. Injection pressure is set to be 400bar. Injector1 is optimized at 5 to 8 degree crank angle BTDC of suction stroke for methanol injection and Injector2 is optimized to 24 degree BTDC of compression stroke for diesel injection. Other attributes/ objects were kept as same as CI Engine model [6].

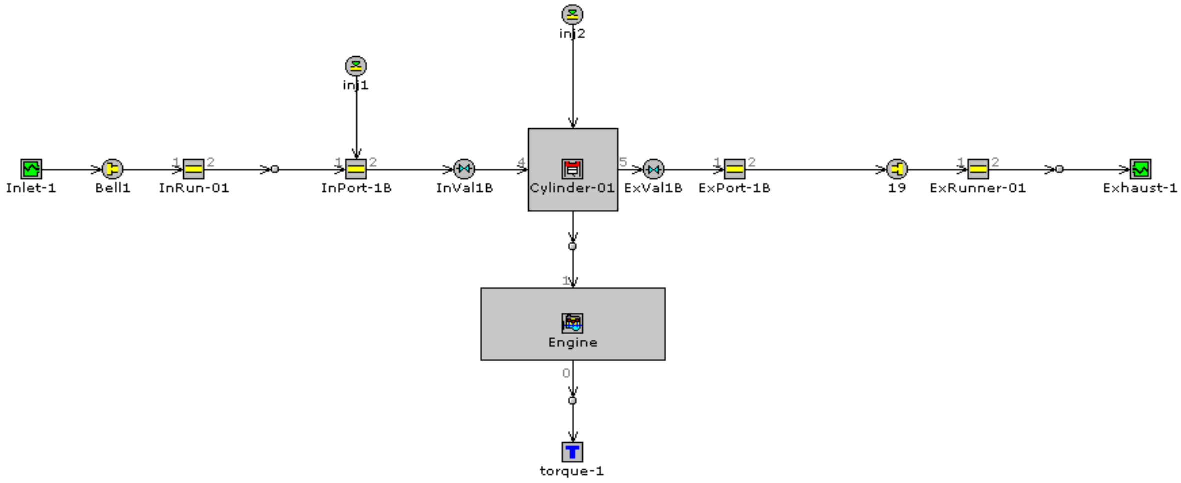

Figure 2: single cylinder HCCI engine simulation model in GT-POWER

7. Results and Discussion

A. Performance plots

Following Graph shown in fig. 3 has compared brake power vs load (%) of both CI and HCCI engine in simulation.

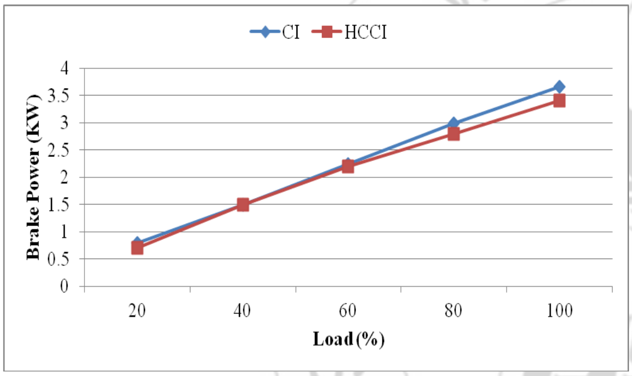

Figure 3: brake power (kW) VS load (%)

From this plot we can conclude that brake power up to 60% load for both engine remains constant but from 60% load HCCI engine power slightly lowers down than CI engine. This is because of less quantity of diesel fuel which is replaced by renewable fuel (methanol).

Figure 4 represents brake thermal efficiency (%) vs load (%) of both CI and HCCI engine. Thermal efficiency of HCCI engine from 40% load gives better results because of increased total fuel consumption comparative to the conventional CI engine. While thermal efficiency of CI engine has gradual increment throughout all loads (21% to 36.5%).

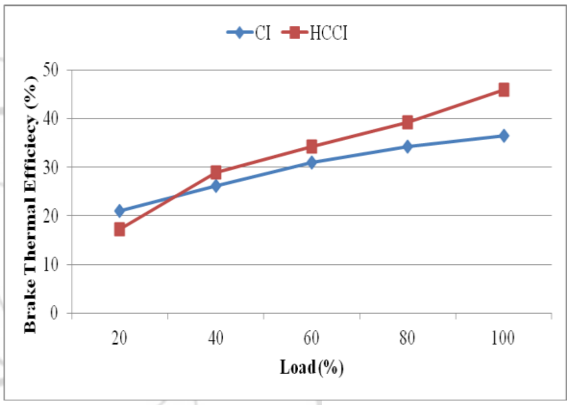

Figure 4: brake thermal efficiency (%) VS load(%)

Graph in fig. 5 shows the BSFC (gm/kwhr) vs load (%) of both engines.

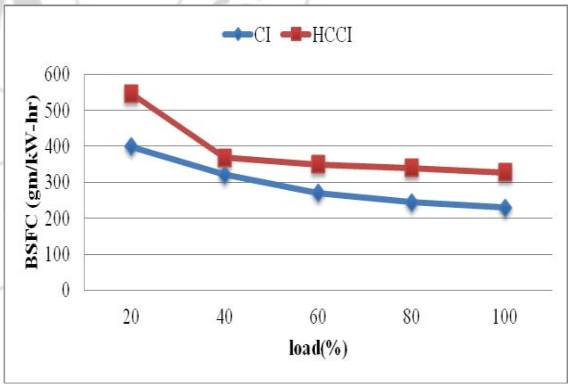

Figure 5: BSFC (gm/kW-hr) VS load (%)

There is gradual decrement in bsfc of CI engine from 20% to 100% load (399.6 to 229.2 gm/kw-hr). But in case of HCCI engine there is sudden drop of bsfc from 20% to 40% further it maintains gradual decrement.

B. Emission plots

Graph in fig. 6 shows the HC emission (ppm) Vs % load of engine.

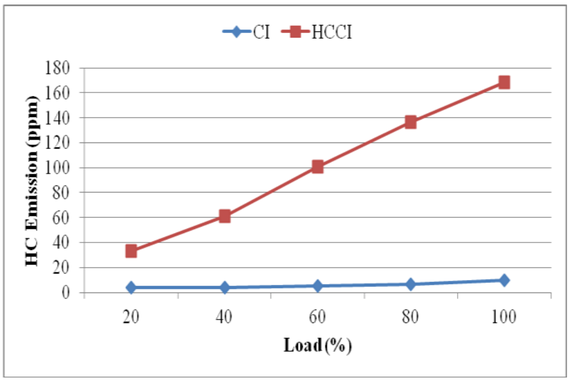

Figure 6: HC emission(ppm) VS load (%)

For HCCI engine HC emission increases linearly with load on the engine increases (33.03ppm to 275.71ppm) while in case of conventional CI engine, it remains constant throughout all loads (3.68 to 9.91ppm).
Graph in fig. 7 shows CO Emission (ppm) Vs Load (%) on engine.

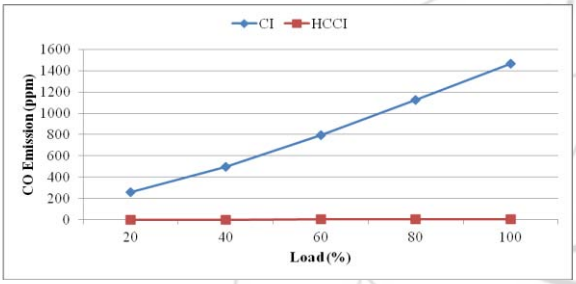

Figure 7: CO emission (ppm) VS load (%)

8. Conclusion

1) Power output is not much affected by engine load in HCCI compare to CI engine.
2) Brake thermal efficiency of HCCI engine from 40% load gives better results than CI engine.
3) BSFC of HCCI engine is always found to be at higher level than conventional CI engine.
4) With increase of engine loads HC emission (ppm) of HCCI engine has increased drastically
5) CO emission (ppm) are quite lower (below 2 ppm).

9. Future Scope

The simulation can be carried out by considering the parameters such as in- cylinder pressure, heat release rate and multiple injection of diesel to improve the performance and emission characteristics of HCCI engine.

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