CHAPTER -6

CONCLUSIONS

From the present investigation it is found that HCCI engine giving encouraging results as far as NOx and smoke emissions are concerned. The brake thermal efficiency of HCCI engine is being dropped slightly and with marginal increase in CO and HC emissions.

6.1 HCCI ENGINE USING DIESEL FUEL

The following are the important conclusions drawn from the experimental results before optimizing the injection timing and fuel injection pressure of HCCI engine using diesel. The results are compared between HCCI engine operating at injection timing $60^\circ$ bTDC & compression ratio 14 and base engine diesel (BED) at 60% of full load condition (BMEP 3.1 bar).

- It is noticed from the results that HCCI engine using diesel has difficulty in operating at higher loads due to instantaneous combustion.
- The brake thermal efficiency is decreased by 12.63 % for HCCI engine when compared with base engine diesel.
- The CO emissions are increased by 70 % for HCCI engine when compared with base engine diesel.
- It is noticed from the experimental results that 21.68% decrease in CO$_2$ emissions when compared with base engine diesel.
- It is observed that the HC emissions are increased by 28.15 % for HCCI engine when compared with base engine diesel.
\begin{itemize}
\item The NOx emissions are reduced by 41.35\% for HCCI engine when compared with base engine diesel.
\item The smoke density is decreased by 26.92\% for HCCI engine when compared with base engine diesel.
\item The heat release rate is instantaneous for HCCI engine when compared with base engine diesel.
\end{itemize}

From the above results, it is noted that there is a scope to improve HCCI engine by improving homogeneity of air fuel mixture in the engine cylinder.

\section*{6.2 HCCI ENGINE USING DIESEL AT OPTIMUM CONDITIONS}

To improve the performance of HCCI engine, the injection timing, compression ratio and fuel injection pressure are to be optimized. From the experimental results it is found that the optimum operating conditions for HCCI engine are injection timing 80^{\circ}\text{bTDC}, compression ratio 14 and fuel injection pressure 190 bar.

The experimental results are compared between HCCI engine operating at optimum conditions using diesel and base engine diesel at 60 \% of full load condition (BMEP 3.1 bar) and following conclusions are drawn.

\begin{itemize}
\item The brake thermal efficiency is decreased by 8.42\% for HCCI engine when compared with base engine diesel.
\item It is noticed that 12.59\% decrease in exhaust gas temperature for HCCI engine when compared with base engine diesel.
\item It is observed that 50 \% increase in CO emissions for HCCI engine when compared with base engine diesel.
\end{itemize}
• It is noticed from the experimental results that 14.45% decrease in CO$_2$ emissions when compared with base engine diesel.

• The HC emissions are increased by 12.62% for HCCI engine when compared with base engine diesel.

• The NOx emissions are decreased by 48.31% for HCCI engine when compared with base engine diesel.

• It is noted from the results that the smoke density is decreased by 42.3% for HCCI engine when compared with base engine diesel.

From the above results it can be concluded that operating HCCI engine at optimum conditions improve the brake thermal efficiency and decrease the CO, HC, NOx and smoke emissions when compared with HCCI engine before optimization. But the HCCI engine using diesel has a difficulty to operate at high loads (beyond 60% of full load condition) due to instantaneous combustion leads to knocking.

6.3 HCCI ENGINE USING BLENDS OF DIESEL AND ETHANOL AS FUEL

The experimental investigation has been carried out on HCCI engine using blends of diesel and ethanol to avoid instantaneous combustion and to improve the loading range of the HCCI engine. The fuel used is blends of diesel and ethanol both are having different auto-ignition temperatures to spread the combustion event. As ethanol and diesel are immiscible , an emulsifier 1-hexanol is added .The diesel fuel having low auto-ignition temperature burns first and latter ethanol burns so that the combustion event will spread and rate of pressure rise will be within the limits and increase the loading range of the HCCI engine.
The experimental results of HCCI engine are compared between the blends E0 (pure diesel) and E30 (30% ethanol, 65% diesel and 5% 1-hexanol) at 60% of full load condition.

- It is observed from the results that the brake thermal efficiency is increased by 3.06% for blend E30 when compared with pure diesel (E0).
- The CO emissions are reduced by 13.33% for E30 when compared with E0.
- It is noticed from the experimental results that 9.85% decrease in CO$_2$ emissions for E30 when compared with E0.
- The HC emissions are increased by 7.2% for E30 when compared with E0.
- The NOx emissions are reduced by 7.3% for E30 when compared with E0.
- The smoke density is decreased by 16.66% for E30 when compared with E0.
- Heat release rate is elongated due to the addition of ethanol to the diesel. The loading range is improved to 95% of rated load (BMEP 4.9 bar) for HCCI engine using blend E30.

From the above results it can be concluded that the blend E30 is suitable for HCCI operation and loading range is improved up to 95% of full load condition.

6.4 COMPARISON OF HCCI ENGINE USING BLEND E30 AND BASE ENGINE DIESEL
The experimental results are compared between HCCI engine using blend E30 (30% ethanol, 65% diesel and 5% 1-hexanol) and base engine diesel at 95% of full load condition (BMEP 4.9 bar) and following important conclusions are drawn.

- The brake thermal efficiency is decreased by 4.9% for HCCI engine when compared with base engine diesel.
- It is observed that the exhaust gas temperature is decreased by 13.23% for HCCI engine when compared with base engine diesel.
- It is noticed that the CO emissions are increased by 21.05% for HCCI engine when compared with base engine diesel.
- It is observed from the experimental results that the CO$_2$ emissions are decreased by 6.12% when compared with base engine diesel.
- The HC emissions are increased by 8.1% for HCCI engine when compared with base engine diesel.
- It is noticed that the NOx emissions are decreased by 50.13% for HCCI engine when compared with base engine diesel.
- It is observed that smoke density is decreased by 51.38% for HCCI engine when compared with base engine diesel.

6.5 **COMPARISON OF HCCI ENGINE USING BLEND E30D3 AND BASE ENGINE DIESEL**

The experimental results are compared between HCCI engine using E30D3 (30% ethanol, 62% diesel, 5% 1-hexanol and 3% DTBP) and base
engine at full load condition (BMEP 5.25 bar) and following important conclusions are drawn.

- The brake thermal efficiency is decreased by 3.92% for HCCI engine using E30D3 when compared with base engine diesel.
- It is observed that the exhaust gas temperature is decreased by 11.17% for HCCI engine when compared with base engine diesel.
- It is noticed that the CO emissions are increased by 6.97% for HCCI engine when compared with base engine diesel.
- It is observed from the experimental results that the CO$_2$ emissions are decreased by 4.85% when compared with base engine diesel.
- The HC emissions are increased by 4.5% for HCCI engine when compared with base engine diesel.
- It is noticed that the NOx emissions are decreased by 50.31% for HCCI engine when compared with base engine diesel.
- It is observed that smoke density is decreased by 55.26% for HCCI engine when compared with base engine diesel.
6.6 COMPARISON OF HCCI ENGINE USING BLEND E30DEE6 AND BASE ENGINE DIESEL

The experimental results are compared between HCCI engine using E30DEE6 (30% ethanol, 59% diesel, 5% 1-hexanol &6% DEE) and base engine at full load condition (BMEP 5.25 bar) and following important conclusions are drawn.

- The brake thermal efficiency is decreased by 2.94% for HCCI engine using E30DEE6 when compared with base engine diesel.
- It is observed that the exhaust gas temperature is decreased by 12.35% for HCCI engine when compared with base engine diesel.
- It is noticed that the CO emissions are increased by 4.65% for HCCI engine when compared with base engine diesel.
- It is observed from the experimental results that the CO\textsubscript{2} emissions are decreased by 3.88% when compared with base engine diesel.
- The HC emissions are increased by 3.22% for HCCI engine when compared with base engine diesel.
- It is noticed that the NO\textsubscript{x} emissions are decreased by 50.56% for HCCI engine when compared with base engine diesel.
- It is observed that smoke density is decreased by 56.57% for HCCI engine when compared with base engine diesel.

6.7 SUMMARY

From the experimental results, it can be concluded that that the HCCI engine can be operated up to 60% of full load condition using diesel. The loading range of the
HCCI engine is improved from 60% of full load condition to 95% of full load condition by using blend E30. The loading range is further improved to rated load using ignition improvers. The instantaneous combustion in HCCI engine can be avoided by blending diesel and ethanol. The blend E30 is more suitable fuel to improve performance and to extend the combustion event in HCCI engine to avoid instantaneous combustion. It is observed that there is an increase in brake thermal efficiency by 3.06% for HCCI engine using blend E30 when compared with HCCI diesel. The reason is addition of 1-hexanol to the blend of diesel and ethanol which is acting as an ignition improver. It is clear from the results that there is a decrease in NOx emissions by 50.13% for HCCI engine using blend E30 when compared with base engine diesel. It is also observed from the results that there is a decrease in smoke density by 51.38% for HCCI engine using blend E30 when compared with base engine diesel at 95% of full load condition.

However, from the experimental results it is found that an increase of 21.05% CO emissions and 8.1% HC emissions for HCCI engine using blend E30 when compared with base engine diesel due to low temperature combustion. The CO and HC emissions are reduced by using ignition improvers.

By modifying the operating parameters and fuel the HCCI engine is operated up to full load condition. It is noticed that the NOx emissions are decreased by 50.56% and smoke emissions decreased by 56.57% for HCCI engine using blend E30DEE6 when compared with base engine diesel. It is also noticed from the results that an increase of 4.65% CO emissions and 3.22% HC emissions for HCCI engine using blend E30DEE6 when compared with base engine diesel at full load condition. The carbon monoxide and hydrocarbon emissions can be reduced easily by using catalytic
converters. Hence, the objective of present research work is achieved by adopting HCCI combustion in a diesel engine.

Due to diminishing fossil fuel reserves, alternative energy sources need to be renewable, sustainable, efficient, cost effective and convenient and safe. Ethanol being renewable energy source is one of the alternative fuel to reduce the stress on fossil fuel consumption.

Hence, from the above results it can be concluded that the HCCI engine is successfully operated up to full load condition by optimizing operating parameters and fuel modification. The HCCI engine is operated successfully up to full load condition using diesel-ethanol blend E30DEE6 and found that significant reduction in NOx and smoke emissions.

6.8 SCOPE OF FUTURE WORK

The Oxides of Nitrogen (NOx) and smoke emissions are reduced in HCCI engine. But the CO and HC emissions are marginally high when compared with base engine. So, efforts are required to reduce CO and HC emissions. Combustion chamber geometry will benefit the atomization of fuel which leads to better HCCI combustion. The flow characteristics should be studied and the engine geometry should be designed for further improvement in HCCI combustion. It is felt that there is a requirement to investigate and analyze the flow characteristics either by using multi-dimensional models theoretically or Laser Doppler Anemometry (LDA) experimentally. This is going to be very helpful for the development of future HCCI engine.