CHAPTER 6: CONCLUSION AND FUTURE WORK

The results of Physico-chemical analysis of the test fuels and combustion, emissions and performance are summarized as under.

(i) When PCCI combustion is applied to the diesel engine without EGR, the BTE is reduced at BMEP of 2.1 bar (50% load) under all operating conditions. So it can be concluded at this load there is poor utilization of ethanol. However, at BMEP of 3.1 bar (75% load) while operating with PFR18EGR0, BTE increased by 4.48% compared to pure diesel. Several researchers (Cheng and Cheung 2008; Cheung C S and Zhang Z H 2009; Tsang and Zhang 2010) also concluded that at low engine load premixed alcohol produce negative effect whereas at high engine load it reversed the trend. The BSFC increases with the percentage of premixed ethanol at all engine loads, which is a consequence of the lower calorific value of ethanol. Nevertheless, percentage increase in BSFC was higher at BMEP of 2.1 and 3.1 bar engine loads compared to BMEP of 4.2 bar.

(ii) When PCCI combustion is applied to the diesel engine with EGR, the BTE is reduced at BMEP of 2.1 bar and 3.1 bar but at 4.2 bar (100 % load) there is slight positive effect was evident when premixed ethanol is used along with 10% and 20% of EGR. Thus, at BMEP of 4.2 bar the in-cylinder gas temperature is higher and there is more ethanol in the air/fuel charge, which tends to reduce the adverse effect on BTE. Results showed that in case of PFR20EGR10 and PFR20EGR20, BTE is increased by 2 and 1.67% respectively compared to pure diesel fuel. The BSFC increases with the percentage of premixed ethanol at all engine loads, which is a consequence of the lower calorific value of ethanol. Nevertheless, percentage increase in BSFC was higher at low and
medium engine loads and small reduction is recorded with EGR at high engine load.

(iii) When PCCI combustion is applied to the diesel engine without EGR at BMEP of 4.2 bar, there is small increase in peak in-cylinder pressure, higher heat release rate, and an increase in ignition delay arising from the cooling effect of ethanol. However at BMEP of 2.1 bar and 3.1 bar, with and without EGR in-cylinder pressure decreases with premixed fuel ratio.

(iv) In case of PCCI combustion mode, there is an increase in fuel burnt in the premixed mode and subsequently it results into reduction of fuel burnt in the diffusion mode. Thus, it is one of cause of reduction in soot under premixed ethanol at all engine loads. Also, diesel has higher polyaromatic compounds compared to ethanol which results in higher smoke emission from pure diesel combustion.

(v) In case of PCCI combustion mode, there is an increase in UHC and CO emissions. At BMEP of 2.1 bar, UHC emission increases dramatically, however rate of increase is decreases with increase in engine loads. Moreover, combined effect of PFR and EGR lead to significantly increase in emissions.

- At BMEP of 2.1 bar, PFR18EGR20, UHC and CO emissions is increased by 6 and 10 times respectively compared to PFR0EGR0
- At BMEP of 3.1 bar, PFR15EGR20, UHC and CO emissions is increased by 7.6 and 4.7 times respectively compared to PFR0EGR0
- At BMEP of 4.2 bar, PFR20EGR20, UHC and CO emissions is increased by 4.85 and 2.25 times respectively compared to PFR0EGR0

(vi) In the PCCI combustion mode, there is a decrease in NOx emission arising from the cooling effect of ethanol and EGR, nevertheless EGR alone effectively reduce NOx significantly. Simultaneous reduction of NOx and smoke is evident at BMEP of 3.1 and 4.2 bar.

- At BMEP of 2.1 bar up to 89% of NOx reduction is achieved by using 20% EGR without premixed ethanol, however, combined application of
premixed ethanol and EGR increases it to 95%. And using 18% of premixed ethanol without EGR leads to reduce NO\textsubscript{x} emission by 50% compared to pure diesel. Hayes et al. and Ishida et al. (Hayes and Savage 1988; Ishida and Shohei Ueki 2010) also observed similar trends.

- At BMEP of 3.1 bar up to 92% of NO\textsubscript{x} emission could be achieved by using 20% EGR without premixed ethanol (PFR0EGR20), however, combined application of premixed ethanol and EGR increases it to 95%. And using 15% of premixed ethanol without EGR (PFR15EGR0) lead to reduce NO\textsubscript{x} emission by 33% compared to pure diesel. This is due to at high engine loads cooling effect produce by ethanol is weakened leading to lower reduction in NO\textsubscript{x} emission.

- At BMEP of 4.2 bar up to 88% of NO\textsubscript{x} emission could be reduced by using 20% EGR without premixed ethanol (PFR0EGR20), however, combined effect of premixed ethanol and EGR increases it to 92%. And maximum reduction of 16% is recorded using 20% premixed ethanol without EGR (PFR20EGR0).

(vii) At BMEP of 3.1 and 4.2 bar premixed ethanol can effectively reduce smoke as compared to diesel fuel. However, at relatively low load (BMEP of 2.1 bar) this could not happened.

- At BMEP of 2.1 bar smoke opacity increases with EGR as well with premixed ethanol. Low in-cylinder temperature reduces rate of oxidation and hence smoke. However only marginal variation is recoded.

- At BMEP of 3.1 bar smoke opacity increases with EGR but premixed ethanol lead to reduce it. In case of PFR15EGR0 smoke opacity is decreased by 20% compared to PFR0EGR0. However, other mixture composition did not show any significant reduction.

- At BMEP of 4.2 bar, smoke opacity corresponds to PFR13EGR10 and PFR20EGR10 decreased by 45% and 56% respectively compared to
PFR0EGR0. Also, at PFR20EGR0 about 34% reduction in smoke was found as compared PFR0EGR0. Therefore simultaneous reduction of NO\textsubscript{x} and smoke was observed.

(viii) Ignition delay period decreases with increase in engine load, however PFR and EGR both lead to increase it at any load. Thus, increase in ignition delay period provides more time for fuel evaporation and reduces in-homogeneities in the reactant mixture, thus reducing NO\textsubscript{x} formation from local temperature spikes and soot formation from locally rich mixtures.

(ix) It can be concluded that the application of PCCI combustion could lead to pave the way to achieve simultaneous reduction of smoke and NO\textsubscript{x} emissions, while there is an increase in CO and UHC. Moreover, there could be a slight reduction in BTE at medium load but it increases at BMEP of 3.1 bar and 4.2 bar corresponds to different intake mixture composition.

6.1 SCOPE OF FUTURE WORK

Toroidal combustion geometry improves mixing under high engine loads and results did not provide any exact correlation of other parameters. Therefore, more detailed analysis is required to understand effect of increasing swirl ratio without changing compression ratio.

Since the experimental test-rig available does not provide flexibility to change the premixed ethanol in any proportion as per demand, therefore controller needs to be upgraded to change the injection duration in fraction of milliseconds. It gives greater range of premixed fuel ratio within the maximum limit. So that even at low engine loads, it will possible to obtain more numbers of different premixed fuel ratios.

As discussed compression ratio have significant effect on combustion kinetics, therefore PCCI combustion fueled with ethanol and diesel should be studied at variable compression ratio.
To reduce unburned hydrocarbons (UHC) and carbon monoxide (CO) emissions further enhancement of combustion geometry is required. Also, further study needs to be done to analyze effect of diesel oxidation catalyst. Moreover, with the help of advanced experimental facility one could see particulate mass concentration, particle number concentration and size distribution.