ISSN No:-2456-2165

Experimental Investigation on Performance of Pre-Mixed Charge Compression Ignition Engine

[1]Sanjay Singh
Research Scholar
Department of Mechanical Engineering
Vinayaka Mission's Kirupananda Variyar Engineering College, Salem
Vinayaka Mission's Research Foundation, Deemed to be University, Salem, Tamil Nadu, India.

Abstract:- Over the period of time, emission standards have become stricter and stricter. The adverse effect of greenhouse gases generated by not only industries but also automobiles have become a major concern for addressing as it produces ill health to all human beings. The tremendous growth in the automobiles and related industries have reached to an alarming level and necessitates engineers to work harder and harder to devise systems which can reduce harmful emissions to an acceptable level. Pre-Mixed Charge compression ignition (PCCI) is one of the technological methods of achieving complete combustion in an internal combustion engine which contribute further in reducing emissions. PCCI engine has been proved as a better choice in the present scenario where emission standards are degrading day by day making the environment dangerous for sustenance of life.

***Keywords**:- Homogenous charge, Compression, Auto-ignition, Emissions, Lean mixture, Stoichiometric etc.*

I. INTRODUCTION

An intensive research is performed in older days and still continuing for optimizing the performance of IC (Internal Combustion) engines in achieving complete combustion with low temperature and low CO_2 and NO_x emissions. In order to achieve acceptable standards of emissions and reduce green house gases, CO_2 and NO_x, the concept of homogenous charge compression ignition engine is introduced which works on the concept of controlled auto-ignition. The low combustion temperature leads to low emissions of CO_2 and NO_x and are much lower than the emissions produced by conventional SI and CI engines. The emission of CO2 affects vegetation adversely and thereby change in Global climate occurs It affects the climate in many ways like change in temperature, humidity and even absorption of solar radiation (1). Greenhouse gases emissions creates temperature rise above the normal variability level and have become potentially dangerous for sustenance of life (2). Many names have been given to this auto-ignition of lean homogeneous charge like Premixed Lean Diesel Combustion (PREDIC), Premixed Charge Compression Ignition (PCCI), Active Thermo Atmosphere Combustion (ATAC), Active Radical Combustion (ARC), Controlled Auto-ignition (CAI) etc. The combustion in HCCI engines are controlled by chemical kinetics of fuel and not by any physical means like spark plugs, ignitors etc. The temperature generated in a PCCI engines are much lower than the conventional engines and high temperature is also one of the factors which affect emissions of greenhouse gases (4). Application of a PCCI engine is not limited and is applicable for both light and heavy engines. (6). Also the engine can be operated over a range of loads and speeds. PCCI Engines are capable in exceeding the efficiency of normal conventional engines. An PCCI engine generally behaves like a hybrid between spark ignition and compression ignition engine. Mixing of the characteristics of these two engines offers high efficiency as in diesel engine and reduces particulate emissions to a considerable level and well within the limits of emission standards.

II. BASICS OF AN INTERNAL COMBUSTION ENGINE

An Internal Combustion (IC) engine is the engine in which power is produced in the same place where combustion occurs. An IC engine consists of components like crankcase, cylinder, connecting rod, crank shaft, inlet valve, exhaust valve, spark plug in Spark Ignition (SI) engines, gears and bearings etc. Fig. 1 and 2 provides the details of accessories and components used in an internal combustion engine. The engine is further classified as two stroke and four stroke engines on the basis of number of power strokes in revolutions of crankshaft. In two stroke engine, the engine produces power in each complete revolution of crankshaft i.e. 360^0 crank angle whereas four stroke produces power once in two complete revolutions of crankshaft i.e. 720^0 crank angle. All the four strokes namely induction, compression, power and exhaust are completed in two revolutions of crankshaft in four stroke engine. Ignition which is provided with the use of spark plug at the completion of compression stroke is an event and not to be considered as a stroke.

The engines are also classified on the basis of use of fuel like petrol and diesel engines. Engines using gasoline as a fuel are spark ignition (SI) engines and diesel as a fuel are compression ignition (CI) engine. The air fuel mixture is supplied to the cylinder through intake valve either through carburetor in SI engine or directly injected to the cylinder in case of CI engines. Presently, direct injection engines are used almost in all applications.

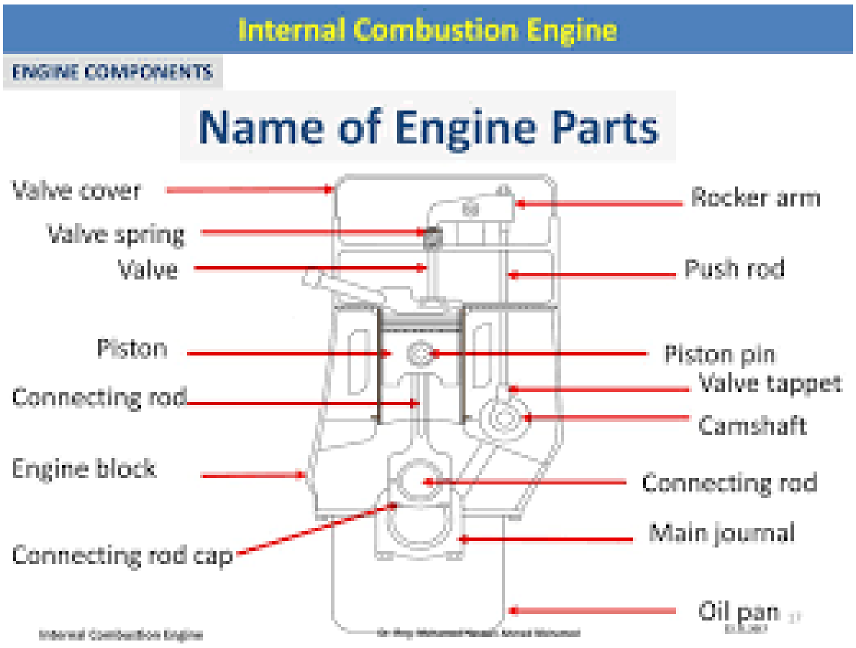

Fig. 1:- Components of an internal combustion engine

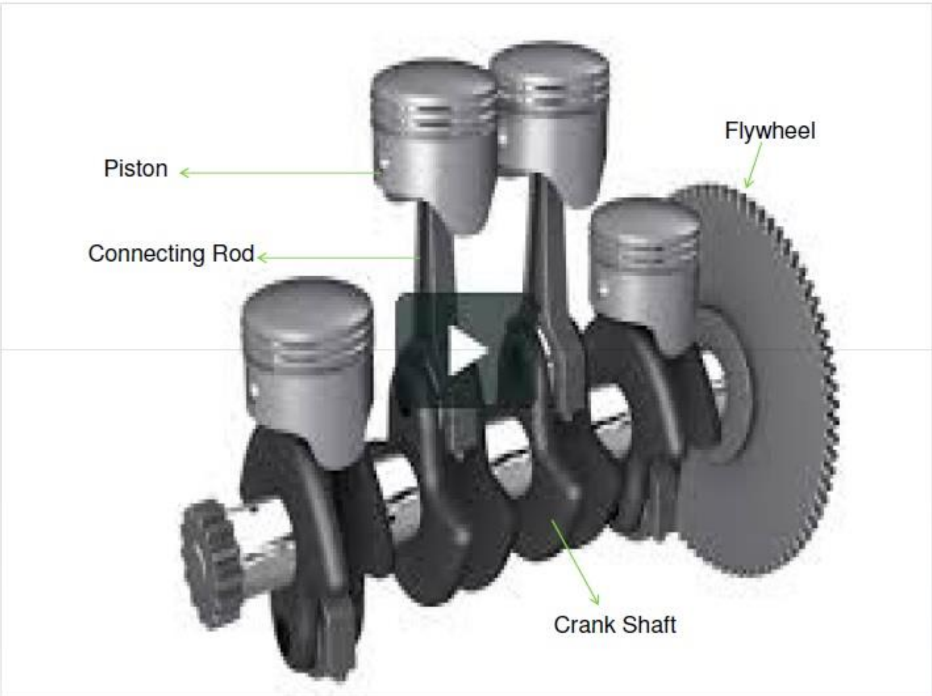

Fig. 2:- Piston, Crankshaft and Flywheel of an internal combustion engine

Internal combustion engines used in aircrafts are similar to the ones used in automobiles with respect to its operation except some differences in accessories and components for some specific operation. In addition to reciprocating engines (Piston and Cylinder type), gas turbine engines are used mostly in present days aerospace applications for advancement in altitude and speed. One such engine is shown in Fig. 3 in which compressor and turbines are used for compression of air and expansion of gases (extraction of work) respectively. Combustion chambers are used for addition of kinetic energy in high pressure air coming from compressor by injecting and burning fuel. Hot gases with high pressure and energy move rearward and after expansion in the turbine is further expanded to atmospheric pressure in convergent or convergent-divergent nozzle to achieve high velocity. This high velocity exhaust gases in turn produces thrust which is the force responsible to move the aircraft forward.

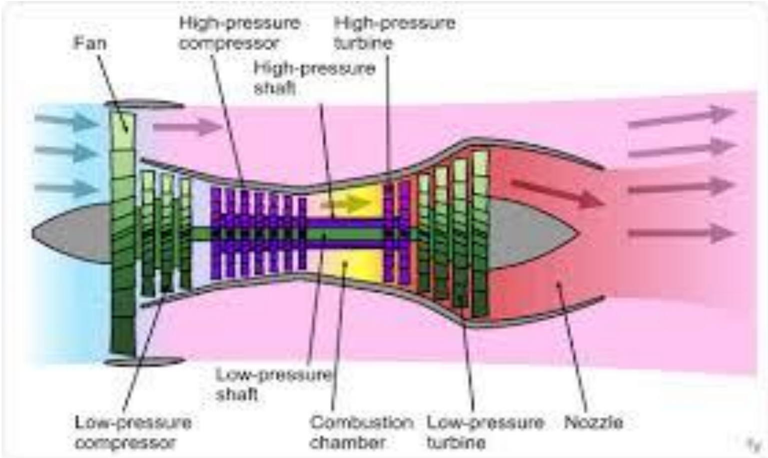

Fig. 3:- Gas Turbine Turbofan Engine used in a transport aircraft.

III. PRE-MIXED CHARGE COMPRESSION IGNITION (PCCI) - WORKING PRINCIPLE

In this type of combustion, very lean homogenous mixture of fuel is made to auto-ignite by retaining some portion of hot exhaust gases containing partially oxidized hydrocarbons and chemical species in the cylinder. The process will lead to low temperature requirement for combustion of the fuel injected in the cylinder. As the concept is not meant for spark ignition engine, temperature of the resulting mixture will not increase. Due to compression of the mixture of gases and freshly injected fuel, the mixture will attain temperature sufficient enough for combustion and low temperature combustion takes place. This low temperature combustion will not involve nitrogen gas present in air to participate in combustion and thereby emission of NO_x is greatly reduced. Also the low temperature combustion will enable the fuel to have complete combustion and emissions of green house gases are also considerably reduced. The engine which is shown in Fig.4 doesn't look differently than a diesel engine except the injection process which differs from a conventional diesel engine. This engine requires low pressure injection and a pre-mixing process and combustion at lower temperature whereas a conventional diesel engine is provided with high pressure injection for a thorough and complete atomization, vortex formation and combustion takes place at higher temperature.

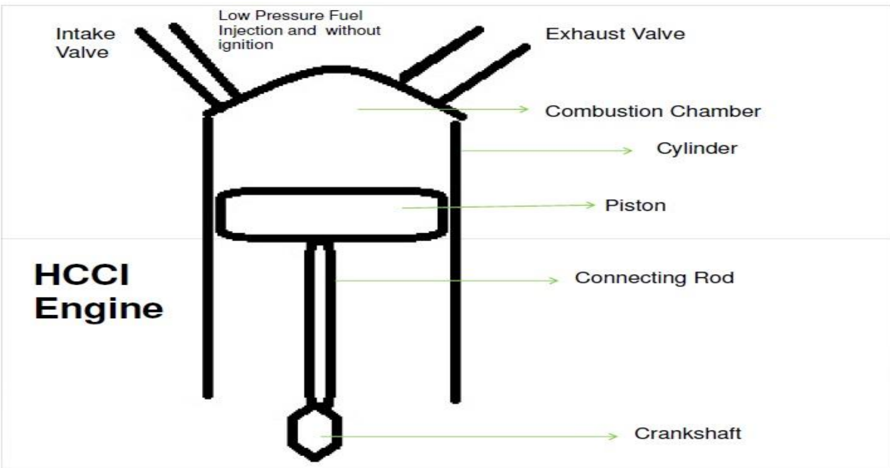

Fig. 4:- A Schematic of a Pre-Mixed Charge Compression Ignition (PCCI) Engine

IV. ADVANTAGES

The concept of Pre-Mixed Charge Compression Ignition Engine (PCCI) has many advantages. Some of them are as mentioned below.

- Low temperature combustion reduces harmful emissions of CO_2 and NO_x thereby keeping the environment clean and healthy.
- Low temperature combustion provides a complete combustion and thereby formation of soots is greatly reduced.
- The efficiencies of the engines are higher and similar to direct injection diesel engines.
- The process requires a little modification in the engine.
- Approximately 30% improvement in fuel economy 50% reduction in hydrocarbon.
- Faster Combustion.

V. APPLICATION OF CONTROLLED AUTO IGNITION IN GASOLINE ENGINES

The process of combustion in Pre-Mixed Charge Compression Ignition Engine (PCCI) needs two important steps to be accomplished for its completion and achievement of objectives.

- Pre-mixing of fuel and the hot residual gases for preparing a homogenous lean mixture.
- Compression of the homogenous lean mixture and its auto-ignition.

The main important point of concern in using gasoline as fuel in homogenous charge in controlled auto-ignition is to obtain high fuel efficiency, reduce emissions of nitrogen oxides and to have high rate of combustion. Emissions of particulate matters are not of much concern while using gasoline as fuel. The combustion process is almost similar to constant volume combustion. The charge to be combusted is kept for high duration at a temperature sufficient enough for burning to ensure acceptable rate of combustion and reduced nitrogen oxides emission.

VI. PARAMETERS AFFECTING HOMOGENOUS COMBUSTION

In order to obtain the required temperature and pressure, the parameters to be maintained and monitored for efficient combustion are as follows.

A. Compression Ratio

The ratio of cylinder volume and clearance volume is called compression ratio. For SI Engines, compression ratio ranges from 10-12 and for CI engines, it ranges between 16 to 20.

B. Residual Gas Content Or Exhaust Gas Recirculation (EGR)

Pre-mixed condition of mixture is very important to achieve the objectives of PCCI engines. Therefore, residual gas in the cylinder plays an important role in preparation of a homogenous mixture. The same can be achieved through recirculation of a specified proportion of exhaust gas through the cylinder.

C. Intake Mixture Temperature

PCCI engines require the mixture temperature to be low in the cylinder for proper combustion and thereby reduce NOx levels. The combustion properties of hydrocarbons greatly depend on the temperature and performance of the PCCI engines also depend on the intake mixture temperature. High temperature more than the specified limit will not be allowing for complete combustion and thereby reduce the efficiency of the engine.

D. Intake Mixture Pressure

A specified pressure is required for the mixture which is entering in the cylinder for atomization of the fuel and thereby producing a completely mixed homogenous air fuel mixture along with residual gases in the cylinder for raising the temperature for initiation of auto ignition.

E. Fuel-Air Ratio

The fuel air mixture injected in the cylinder makes a lean mixture after mixing with a portion of exhaust gases which contains partially unburned hydrocarbons in it. This will produce low temperature in the cylinder and thereby reduce emission of harmful gases like carbon dioxides and nitrous oxides.

F. Temperature of Coolant

In an engine which produces high temperature during combustion needs to be cooled to a suitable temperature for Pre-Mixed Charge Compression and further combustion. High temperature is detrimental to the health of the engine which may lead to failure of components if operation is continued for a longer time above than the limit specified. The engine works efficiently when the temperature is maintained within specified temperature limits which can be achieved by using suitable coolant. High temperature of coolant does not cool engine efficiently and produce conditions which are adversely affecting homogenous charge compression. Hence, monitoring and maintaining the specified temperature of the coolant is one of the major requirements for a PCCI engine in its efficient working.

G. Injection Timing

The HCCI engine utilises the principle of mixing of air fuel mixture with a specified portion of exhaust gases during the completion of the exhaust stroke in the cylinder and commencement of induction stroke. It is therefore, injection timing of the fuel especially in direct injection engine has to be specified and to be properly followed in sequence of events occurring in PCCI engine. The combustion process with an early injection in the cylinder during completion of exhaust stroke, i.e. when piston is little away from TDC is found to be useful in reducing NOx and particulate emissions.

H. Operation of Controlled Auto Ignition / Spark Ignition Engine – Modification In Engine

The engines which are in use today need to be operated in dual mode for efficient use of homogenous charge compression and ignition. In order to have auto ignition, the charge need s to be compressed to high compression ratio, approximately 18-20 which further require robust engine components and high size cylinder to withstand such a high pressure which can generate temperature enough for auto ignition. With an increase in size of components and further increase in the frontal area of the engine, the weight of the engine also increases which will be a disadvantage for engine design. If in a small engine, homogenous charge compression and ignition is desired, it needs to be operated in the mode of Spark Ignition first for first few cycles. In second phase or change in the mode of combustion by shifting from spark ignition to compression ignition, and immediately after the engine starts working in a normal manner, the injection timing and method of injection may be adjusted in such a way that some dilution of charge takes place before the piston reaches top dead centre (TDC) in exhaust stroke. This dilution of charge with a portion of exhaust gases increases the temperature of the charge to auto ignition temperature.

Spark is not required for initiating the combustion. This modification of the engine avoids increasing of size of the cylinder for high compression ratio. The engine will work smoothly with reduced size and a considerable reduction in emissions can be obtained.

I. Reduced Nitrous Oxides and Carbon Monoxide Emissions by a Pcci Engine

The emissions through Spark Ignition engine is compared with the emissions through PCCI engine. PCCI engine demands the closing of exhaust valve little earlier and keeping the inlet valve open for more time in comparison to normal SI engine. The valve overlap may be between 140^0 - 200^0 crank angles for efficient combustion with controlled auto ignition. The premixing of the charge with exhaust gases makes the charge as lean mixture. The fraction of the exhaust gases mixing with the charge varies approximately from 30% to 70%. It is found that the NOx emissions are very low in PCCI engine when the conditions specified above is maintained meticulously. In contradiction to our expected results, it is observed that the hydrocarbon emissions (HC) are higher. The reason may be due to partial burning of the charge which results in HC emissions. Also Carbon Monoxide emissions have reduced considerably approximately to 75%. PCCI engine have proved a better option for improvement in fuel efficiency as approximately 15% of the total fuel consumption has been reduced in comparison to conventional SI and CI engines.

VII. CONCLUSION AND FUTURE SCOPE

The emissions of harmful gases through industries and automobiles have become a major source of pollution of atmosphere. These gases not only pollutes atmosphere but also increase the concentration of Green House gases to an alarming level contributing severely for global warming which lead to melting of glaciers and thereby raising the water level. The adverse effects of Global warming include devastating effect on life of human beings and further depletion of atmospheric ozone due to which harmful rays from sun penetrates earth atmosphere and produces several skin diseases in addition to sinking of land portions and expansion of water bodies. Scientists in global level are worried and working together to reduce these harmful emissions by designing new engines with modifications in phases of combustion. Pre-Mixed Charge Compression and Ignition (PCCI) is one of the methodology by which a considerable reduction in emissions of Nitrous Oxides and Carbon Monoxide is achieved by using pre-mixed and leaner combustion. This method of combustion requires modification in engines to work in dual mode of combustion. Shifting of engine working from SI engine mode to CI engine mode is still a challenge and needs to be further investigated in future by researchers.

ACKNOWLEDGEMENTS

I sincerely acknowledge the support and guidance provided to me by my guide in doing my research work in the field of using different fuel combinations for complete combustion with reduced emissions of nitrous oxides and also particulate emissions leading to considerable reduction in pollution level. I also acknowledge the support provided to me by my superiors, seniors and colleagues in their critical analysis of my research work and their further suggestions for successful completion of research work.

REFERENCES

[1]. Graham RL, Turner MG, Dale VH. How increasing CO_2 and climate change affect forests - Bio Science. 1990:575-87.

[2]. Jonathan P. Responses to questions on the design elements of a mandatory market-based greenhouse gas regulatory system. World Resources Institute, Washington, 2006.

[3]. Aziz Hairuddin A, Wandel AP, Yusaf T. Effect of different heat transfer models on a diesel homogeneous charge compression ignition engine. International Journal of Automotive and Mechanical Engineering. 2013:8:1292-304.

[4]. Mohanamurugan S, Sendilvelan S. Emission and combustion characteristics of different fuel In a HCCI engine. International Journal of Automotive and Mechanical Engineering. 2011:3:279-92.

[5]. Gharehghani A, Hosseini R, Yusaf T. Investigation of the effect of additives to natural gas on heavy-duty SI engine combustion characteristics. Journal of Mechanical Engineering and Sciences. 2013:5:677-87.

[6]. Venkataramana P, Homogeneous Charge Compression Ignition (HCCI) Engine, International Journal of Engineering Research and Technology, 2013.

[7]. Flynn P. et al., "Premixed Charge Compression Ignition Engine with Optimal Combustion Control," International Patent WO9942718, World Intellectual Property Organization.

[8]. Iida, N., "Alternative Fuels and Homogeneous Charge Compression Ignition Combustion Technology," SAE paper 972071, 1997.

[9]. Web Resources - Alexandros G. Charalambides, “Homogenous Charge Compression Ignition (HCCI) Engines, Text Book Chapter 4, http://dx.doi.org/10.5772/55807.

[10]. Web Resources - Advanced Combustion Systems and Alternative Powerplants, www.nptel.ac.in.