CHAPTER 1

INTRODUCTION

The energy crisis caused by the rapid depletion, rise in prices, uncertain supplies and ever increasing demand for petroleum fuels has triggered an intensive search for either fuel alternatives or means of obtaining more useful work from conventional fossil fuels. In the development of internal combustion engines, there has been a continuous effort to reduce fuel consumption and exhaust emissions. Improved fuel efficiency at constant or even further improved exhaust gas emissions is one of the major challenges that engineers and scientists in the automotive industry and its partners are currently facing. Also in recent years there has been great concern that, the internal combustion engine is predominantly responsible for atmospheric pollution, which is detrimental to human health and environmental damage. Consequently, research engineers have been striving to reduce the quantity of pollutants emitted from exhaust system without sacrificing power and fuel consumption.

The incomplete burning of the air-fuel mixture in the combustion chamber produces pollutants. The major pollutants emitted from the exhaust due to incomplete combustion are, unburnt hydrocarbons (UBHC), oxides of nitrogen (NO\textsubscript{x}) and highly poisonous carbon monoxide (CO). If however combustion is 100 % complete the only products being expelled from the exhaust would be water vapour, which is harmless, and carbon dioxide, which is inert gas and, as such, it is not directly harmful to humans. However such ideal situation is not possible and researchers are constantly trying to optimize
To achieve complete and clean combustion with reduced emissions, the lean burn technology is one of the viable technique for internal combustion engines. Lean burn technology burn the air-fuel mixture completely or almost completely, in an efficient manner, so that fuel consumption is reduced and the level of pollutants are within limits. Hence lean combustion is a preferred concept for reducing exhaust emissions for meeting stringent emission standards. In this work extended expansion concept is applied to lean burn engine to study the effect on performance and emission characteristics.

### 1.1 LEAN BURN COMBUSTION ENGINE

These are engines that use an air to fuel ratio, which is higher than chemically required to burn all the fuel. The lean burn combustion engine is designed to enhance fuel efficiency without sacrificing power or driveability.

In practice use of homogeneous lean burn mixtures pose many problems, such as, lower flame propagation, occurrence of misfire, low mixture distribution quality in multi-cylinder engines and high amount of unburnt HC in the exhaust. But these problems can be overcome to some extent by (Noguchi et al 1976; Geoff J. Germane et al 1983; Aparico J. Gomez and Paul E. Reinke 1988; Dhandapani 1989; Rajashekar Swamy et al 2001).

- **Use of high compression ratio**

  Use of higher compression ratio will lead to increased gas temperature and better combustion characteristics.
• **Use of Higher Energy Ignition System**

Since the minimum energy needed for ignition increases with the air-fuel ratio, specialized high-energy ignition system can be used for ignition of lean mixture.

• **Increasing swirl and turbulence level in combustion chamber**

Enhanced level of swirl and turbulence increases the flame propagation velocity thereby improving characteristics of lean combustion.

• **Use of Catalytic Coating**

The use of catalysts like platinum, palladium, copper, etc on the combustion chamber surface extends the lean misfire limit. Catalysts further accelerate the combustion process and improve the engine efficiency and reduce emissions.

• **Use of additives**

By using few additives which have higher flame velocity than the base fuel, the flame speed of lean mixture can be enhanced leading to improved performance.

• **Adopting low heat loss combustion systems**

Reduction in heat losses increases the gas temperature at the time of ignition and extends the lean limit of operation. It also increases the flame velocity and improves efficiency. Though it has a desirable
effect on HC and CO emissions, it certainly increases the NOx emissions. Heat losses can be reduced by compact combustion chamber design and insulation of chamber walls with ceramic materials also helps in reducing the heat losses.

The classical relationship between emissions, power and fuel consumption as a function of air-fuel ratio is shown in Figure 1.1. The spark-ignition (SI) engine has normally been operated close to stoichiometric, or slightly fuel-rich, to ensure smooth and reliable operation. Fuel consumption decreases as the air-fuel ratio increases from stoichiometric and then increases as incomplete combustion and misfire start to occur. Leaner mixtures give lower emissions until the combustion quality becomes poor, particularly when HC emission raise sharply and engine operation becomes erratic. The shapes of curves shown in Figure 1.1 indicate the complexities of emission control in spark ignition engines.

Lean burn engine has the following advantages:

- Higher thermal efficiency due to

  1. Higher ratio of specific heats as the mixture properties approach that of air when mixture is made leaner
  2. Reduced dissociation losses, as burned gas temperature is lower
  3. Reduced heat transfer losses to the coolant due to lower burned gas temperature
Figure 1.1  Effect of Air-fuel Ratio on Power, Fuel Consumption, and Emissions
• As mixture is made lean, carbon monoxide and oxides of nitrogen are low due to more availability of oxygen and reduced gas temperature

• Reduction in thermal and mechanical loading of engine components.

• Hydrocarbon emission decreases to some extent due to better oxidation, but as the mixture becomes very lean, HC emission may shoot up due to misfiring.

1.2 EXTENDED EXPANSION ENGINE

Two factors limit the efficiency of any conventional engine:

1) **The pumping loss**, which increases with load reduction, constitute a negative force. This loss is a major factor in urban driving cycle which increases the fuel consumption.

2) **The expansion ratio is identical to the compression ratio**: the value of the expansion ratio is not fixed with a view to obtain the highest efficiency. Its value is fixed by the maximum compression ratio permitted by the mixture.

Today many automotive manufacturers have focused their research activities on this problem. The major task is either to eliminate the throttle valve or to use it as open as possible regardless of the load conditions. Practical methods to increase the efficiency at part load are given below as subtitles in Figure 1.2 (Osman Akin Kutlar et al 2005).
Figure 1.2  Practical Methods to Increase the Efficiency of SI Engine at Part Load (Osman Akin Kutlar et al 2005)
For a conventional four stroke Otto cycle engine, in the expansion stroke, the gas pressure within the cylinder at exhaust valve opening is still in the order of three to five atmospheres and is greater than the exhaust pressure. Therefore, a potential for doing additional work during the power stroke is lost when the exhaust valve is opened and the pressure is reduced to atmospheric. However, if the exhaust valve is not opened until the gas in the cylinder is allowed to expand down to atmospheric pressure, the additional expansion would increase the amount of power in the expansion stroke, leading to an increase in engine thermal efficiency (Heywood 1988).

James Atkinson (1846-1914) came out with the Atkinson cycle as an another alternative. The ideal cycle is shown in Figure 1.2. The cycle consists of two reversible adiabatics, a constant volume process and a constant pressure process. Heat is added during the constant volume process 2-3, and the reversible adiabatic expansion process from point 3 is extended right up to the atmospheric pressure at point 4, and is rejected during the constant pressure process 4-1. It may be seen from Figure 1.3 that the expansion process is longer than the compression process.

The cycle conceived by the British engineer James Atkinson offers a solution to this two-fold problem in which the load is controlled without pumping losses, and that the compression ratio is differentiated from the expansion ratio. Based on this principle, for each load level, the combustion chamber volume is designed to maintain the compression ratio at the maximum value below the knock limit, and to obtain the most effective expansion ratio.

In a conventional Spark Ignition (SI) engine, the Compression Ratio (CR) is equal to the Expansion Ratio (ER). Further, the load controls in these engines are performed through throttling, which is mainly responsible
for poor part load efficiency. In these engines, to increase the cycle efficiency, one has to increase either the compression ratio or expansion ratio or both. In SI engines, the compression ratio is restricted by the combustion process, but the expansion ratio can be extended. The engine with higher expansion ratio than compression ratio is referred to as Extended Expansion Engine (EEE).

The principle of extended expansion applied to four stroke SI engine is based on Atkinson cycle which has a larger ER than CR, unlike a conventional Otto-cycle, where CR is equal to ER. By definition ER is the ratio of volume at the end of expansion to the volume at the beginning of expansion. And CR is the ratio of the volume at the beginning of compression to the volume at end of compression. In an Atkinson cycle as shown in Figure 1.3 expansion process is extended until the pressure at the end of expansion is atmospheric. In Figure 1.3 volume $V_4$ is greater than $V_1$ and consequently has higher ER.

Raising the ER unfortunately raises the CR as well. However, by suitably modifying the Intake Valve Closure Timing (IVCT) it is practically possible to increase the ER alone without adversely increasing the effective CR. It is possible to close the intake valve late during the compression process or by early closing intake valve as tried by James H. Tuttle (1980; 1982). Late closing of the intake valve modifies the p-V diagram of Otto cycle into what is known as Otto-Atkinson cycle (David Luria and Yahada 1982) or modified Atkinson cycle (Georege R. Eakin 1988). The modified Otto-Atkinson cycle is shown in Figure 1.4.
Figure 1.3 Atkinson Cycle

Figure 1.4 Modified Otto-Atkinson Cycle
Constant effective compression ratio (in this work called as CR unless otherwise mentioned) can be maintained by suitably varying ICVT and clearance volume. Thus by suitably altering the IVCT and clearance volume ER alone can increased with increasing the CR. This means increasing ER improve the efficiency of conventional engine without adversely increasing CR. Also one of the practical method to increase the efficiency of the engine at part load is by operating the engine on Otto-Atkinson cycle (Osman Akin Kutlar et al 2005).

1.3 PRESENT WORK

Considering the advantages of lean burn engine and extended expansion concept, present work is an attempt to apply extended expansion concept to a four-stroke lean burn engine to study its performance and emission characteristics.

A thermodynamic modeling of extended expansion lean burn has been developed to predict the performance and emission characteristics. A single cylinder four-stroke water cooled diesel engine has been converted to operate as an SI engine. To achieve lean combustion the following modification were done and combustion chamber was modified to enhance swirl and squish and copper as a catalyst was coated on the cylinder head and piston crown, and high energy Transistorized Coil Ignition (TCI) system was used to ignite the lean mixture.

Extended expansion was achieved by varying ER/CR ratio. Experiments were carried out for ER/CR ratio 1, 1.25, 1.5, 1.75 and 2. Effective CR is maintained constant and ER ratio is increased to achieve different ER/CR ratio. By means of late closing of intake valve and adjusting clearance volume of the base engine this was achieved. The top dwell of the
intake cam were increased to delay intake valve closing. Four different top
dwell were formed in the camshaft to achieve the intake valve closing timing
93° 113° 125°, 134° after BDC corresponding to the ER/CR ratio of 1.25, 1.5,
1.75 and 2 respectively. A side draught carburetor was used in the modified
engine. Since delay of IVC increases, the quantity of charge pushed back also
increases, thus lesser amount of charge will be retained inside the engine
cylinder. In order to prevent back flow of charge through the carburetor in to
the surge tank, a suitable reed valve was used. Different parametric studies
were carried out by experiment and simulation. The results obtained using
both methods of study were compared and the simulation code is validated.

1.4 ORGANISATION OF THE THESIS

The work reported in the thesis is organized into 7 chapters. A
detailed introduction of research work is explained in Chapter 1. Also
objective and methodology of research work is presented in this chapter.

In chapter 2 literature which available to support the current work
are discussed. The literature reviews are detailed under three topics;
simulation of spark ignition engine processes, lean burn engines, extended
expansion spark ignition engine and variable valve timing.

In chapter 3 theoretical analysis of extended expansion lean burn
spark ignition engine is discussed. The analysis includes modeling of
compression, combustion, expansion and gas exchange processes. Wiebe
model is used to predict the pressure change during combustion process. Also
emission modeling for Nitric oxides (NOx), Carbon monoxide (CO) and
Unburned Hydrocarbon (UBHC) were discussed. Procedure for estimating
equilibrium concentration for different species is given.
Chapter 4 describes algorithm of “c” program which is developed for the cycle simulation studies.

In chapter 5 experimental methodologies is discussed in detail. In this chapter modification done to convert a single cylinder diesel engine to extended expansion lean burn spark ignition engine is explained in detail. This chapter also covers various instrumentations that are used for experimental investigation in this research work.

Chapter 6 discusses results of different parametric study of this research work in detailed under various headings.

Chapter 7 discusses conclusions arrived based on different parametric studies and indicates scope for future research work.

1.5 OBJECTIVE AND METHODOLOGY

OBJECTIVE

The objective of the present work is

- To develop an extended expansion lean burn spark ignition engine operating with gasoline
- To study the performance and emission characteristics of extended expansion lean burn spark ignition engine both theoretically and experimentally.
- To study the effect of air-fuel ratio, ER /CR ratio, compression ratio, speed and load on performance and emission
characteristics of extended expansion lean burn engine and compare the same with the base engine.

- To validate the mathematical model with experimental data.

**METHODOLOGY**

The methodology that was adopted is outlined below:

- Development of mathematical model for compression, combustion, expansion, gas exchange processes, NO\textsubscript{X} emission, UBHC emission and CO emission to predict performance and emission characteristics of extended expansion lean burn spark ignition engine operating with gasoline.

- Development of an experimental setup by modifying a single cylinder, four-stroke, water-cooled diesel engine to operate as a spark ignited gasoline engine by making changes to compression ratio, by introducing a carburetor, by enhancing swirl and squish in the combustion chamber, providing a high energy spark ignition system, catalytic coating on the cylinder head and piston crown and also varying intake valve closing timing.

- Development of necessary instrumentation facility to study the performance and emission characteristics of extended expansion lean burn spark ignition engine operated on gasoline.
- Investigation of the effect of air-fuel ratio, ER /CR ratio, compression ratio, speed and load on performance and emission characteristics.

- Validation of the developed mathematical model by comparing the simulation results with experimental data.