Performance of a Stratified Charge Spark Ignition Engine with an Injection of Different Fuels

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ABSTRACT

The purpose of this paper is to contribute to knowledge of the behavior of the stratified charge spark ignition engine by the injection of different fuels (gasoline and propane) in the pre-chamber followed by an injection of oxygen with each type of the used fuel. Therefore, the study was focused on the effects of the degree of stratification, the pre-chamber volume, and the time of fuel and oxygen injection upon the engine performance and combustion characteristics at different compression ratios and engine speeds. These parameters have more or less significant influence on the engine output, fuel consumption, and exhaust emission. Combustion pressure traces were recorded simultaneously. These records were analyzed to obtain the required engine performance data and to compare with a conventional spark ignition engine.

1. INTRODUCTION

The conventional four stroke cycle spark ignition engine continues to be used extensively in many fields and is expected to serve as a power source in automobiles for many years to come. Engine fuel contemplation as well as environmental pollution, fuel consumption and exhaust emission are very important factors in engine performance. As well established, the keys for enhancing thermal efficiency are to operate engines at higher compression ratios and weaker mixtures especially at part loads. The technical problems with the former are these avoiding "Knock" at high compression ratios. A number of concepts for the operation of lean burning engines, such as torch ignition and stratified charge combustion, have been proposed. In such a stratified charge engine, arrangements are made for the generation of a slightly fuel rich region mixture in the vicinity of the spark plug, whilst the overall air-fuel ratio is maintained lean. Direct torches deeply into the main-chamber are recommended by Gussak [1]. Consideration development work on 3-valve stratified charge was done at the Honda company in Japan [2] and [3]. Pr-chamber injected type of divided chamber engine has been studied by Pischinger and Klocker [4]. Nakazono [5] also Nakazono and Natsumi [6], investigated the effect of dimensions of pre-chamber on lean burn gas engine. They concluded that, it is necessary to control A/F ratio more finely and optimize the shape of main-chamber and the hole dimensions in order to improve the thermal efficiency while decreasing NOx emission.

2. EXPERIMENTAL APPARATUS

Tests were run on a modified Ferryman A30 marine single cylinder, variable compression ratio, water-cooled engine with cylinder bore and stroke of 95 and 82 mm, respectively. The engine used was prepared with different facilities to obtain maximum possible flexibility both in the range over which engine operation and design parameters. These facilities give variable pre-chamber volume, variable ignition timing, variable pr-chamber injection timing and different fuel type injection in the pre-chamber. A schematic diagram of the experimental apparatus and the stratified charge divided-chamber are shown in Figs. 1 and 2, respectively. Engine out put power was measured with an electric dynamometer. Pressures were recorded by AVL and E32 piezoelectric pressure pickup units located in the pre-chamber and main-chamber, respectively and a degree marker system was used to record the crank-angle degrees. Gasoline, propane and oxygen were injected separately in the pre-chamber. Gasoline was injected by an injection pump through an injector, propane was injected by a gas compressor through a nozzle, and oxygen was injected directly from an oxygen bottle through a nozzle into the pre-chamber. Each injection system was equipped with a control system for injection pressure and timing, and a device for measuring fuel or oxygen consumption. The main-chamber and pre-chamber fuel consumptions (liquid fuel) determined by measuring the time for the engine consume a given volume of fuel. Flow rate of air and gas fuel are measured by using calibrated viscous flow meters. Oxygen consumption was measured by weighing its bottle before and after a certain consumption period. Pollutant concentrations in the exhaust gas were measured by a combustion analyzer ENERAC model 2000 and BECKMAN analyzer model 590 NIDR.

3. RESULTS AND DISCUSSION

Obtained experimental results were classified in order to study effects of pre-chamber volume to the total clearance volume which defined as volume ratio (VR), timing of fuel injected in the pre-chamber, the ratio of the pre-chamber
propane at two degrees of stratification is shown in Fig. 3. Generally, volume ratio affects engine brake specific fuel consumption for all considered speeds and degrees of stratification. Values of brake specific fuel consumption decrease with increasing volume ratio until about 10%. This is may be, due to the incomplete oxidation of the fuel in the rich region of the charge with subsequent loss in the mean effective pressure.

![Graph showing effect of volume ratio on BSFC](image)

Fig. 3 Effect of volume ratio on brake specific fuel consumption for different speeds and injection fuels at different degree of stratification.

3.1 Effect of Volume Ratio

Effect of volume ratio on brake specific fuel consumption for different speeds and injection of gasoline and equivalence to the main-chamber equivalence ratio at the time of ignition which defined as degree of stratification (S) and compression ratio (CR). Also, comparison between results of standard engine and stratified charge engine has been carried out.

![Diagram showing stratified charge divided chamber](image)

Fig. 2 Schematic diagram of the stratified charge divided chamber.

1. Pressure transducer 2. Injector 3. The pre-chamber
4. Spark plug with transducer 5. The main-chamber

![Diagram showing schematic of the experimental apparatus](image)

Fig. 1 Schematic diagram of the experimental apparatus.
Effect of the volume ratio on the emission of nitric oxide and unburned hydrocarbon is shown in Figs. 4 and 5, respectively. As shown in Fig. 4, the brake specific nitric oxide (BSNO) decreases as volume ratio increased initially and goes through a minimum at VR ~ 8 - 10%. Also, the same trend of the effect of volume ratio on brake specific unburned hydrocarbon (BSHC) can be shown in Fig. 5. However, the BSHC remarkably increased for volume ratio larger than 10%. This leads to lower adiabatic flame temperature in the main-chamber than that in the pre-chamber.

3.2 Effect of Injection Time

The effect of start injection of fuel in the pre-chamber on the thermal efficiency is shown in Fig. 6. From this figure it can be seen that the start of fuel injection in the pre-chamber has an influence on the engine performance. The optimum start of fuel injection is varied from 40 ~ 60 degrees BTDC for all ranges of the equivalence ratio.

3.3 Effect of Degree of Stratification

Effects of the degree of stratification on engine performance and emission characteristics for different equivalence ratios, and two engine speeds at optimum value of compression ratio, volume ratio and MBT ignition timing are shown in Figs. 7 - 9.

From Fig. 7, it can be seen that the brake power is increased with stratification degree until S = 1.2 to 1.4, and then tends to decrease. The rate of increasing of brake power for propane fuel injection is higher than for gasoline injection due to the higher heat of reaction for propane than gasoline.

As indicated in Fig. 8, the BSFC values for stratified operation are decrease until S = 1.2 to 1.4, then tend to increase for lean mixtures operations. BSFC shows lower values compared with rich mixture operation.

The effect of the degree of stratification on BSNO emissions level is shown in Fig. 9. BSNO emission curves show lower values for any increase in degree of stratification. Also, it is found that the effect of stratification on BSNO level is remarkably dependent on the overall equivalence ratio. The lower BSNO values were obtained with leaner mixtures. It is useful for understanding the dependence of NO formation upon stratification to review the kinetic theory of NO formation and the trials made to extend it to accounts for charge stratification, [7].

3.4 Effect of Compression Ratio

The effect of compression ratio on brake mean effective pressure is shown in Fig. 10. For stratified charge engine, the BMEP increases as the compression ratio is increased. However, for divided chamber without stratification (S = 1.0), it can be seen that the brake mean effective pressure increases with increasing the compression ratio up to the knock limit, after which it drops with any further increase in compression ratio.

3.5 Comparison between Standard Engine and Stratified Charge Engine

Comparison of BSFC of the stratified charge test engine and the standard engine operating homogeneously before modification is shown in Fig. 11. Six engine operating cases have been shown in the illustrated figure as follows:
Case 1- Single chamber-homogeneous (standard).
Case 2- Divided chamber-homogeneous (non-stratified, S = 1.0).
Case 3- Divided chamber-stratified charge with gasoline injection (S = 1.2).
Fig. 6 Thermal efficiency versus start of fuel injection for different degrees of stratification.

Case 4- Divided chamber-stratified charge with propane injection (S = 1.2).
Case 5- Divided chamber-stratified charge with gasoline and oxygen injection (S = 1.2).
Case 6- Divided chamber-stratified charge with propane and oxygen injection (S = 1.2).

As shown in Fig. 11 there is a decrease in the specific fuel consumption associated with the presence of divided chamber in the region which overall equivalence ratio less than stoichiometric. With increase of oxygen concentration (α) to 30% in the used air there is a decrease in the specific fuel consumption for all range of overall equivalence ratio. This is may be due to that oxygen injection enhancing the combustion characteristics and reducing the residual gases in the pre-chamber.

Comparison of lean misfire limit (LML) for different engine conditions is shown in Fig. 12. The lean misfire limit is defined eventually as the point reached where engine operation becomes rough and unstable, and hydrocarbon emissions increases rapidly. The figure indicates that the stratified charge engine was found to have the ability to operate leaner than the standard engine. The turbulence at the active products emerging from the pre-chamber serves as a more effective ignition source for the main-chamber mixture.

Fig. 7 Effect of degree of stratification on brake mean effective pressure for different equivalence ratios.
4. CONCLUSIONS

Based on the obtained results, the following conclusions may be drawn:

1. Generally, the brake power of the engine is gradually increased with stratification until $S=1.2-1.4$ and then decreased.
2. The optimum volume ratio is in the range of 10%.
3. Fuel injection not start too early during compression and should not terminate too close to the end of compression. From the results an optimum values were found between 40 and 60 degrees BTDC.

4. The BSFC was decreased with stratified engine in the lean region than standard engine, and the decreasing rate is higher for all overall equivalence ratio with propane injection.
5. Charge stratification yields reduction in NO emissions in the range of overall equivalence ratios.
6. Injection of oxygen in the beginning of compression stroke enhances the engine performance and combustion characteristics.
7. Stratified charge engines can be operated by injecting different fuels at high compression ratios without
combustion problems which in turn leads to increasing the thermal efficiency.

8. Stratified charge engines can be operated at lean mixture until an equivalence ratio of 0.55, which couldn’t be achieved with the conventional engines. The operation with lean mixture leads to the decrease of NO concentration emitted with the exhaust products.

APPENDIX : Calculation of Degree of Stratification (S)

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\frac{F}{A}_P = \frac{\dot{m}_B + VR \cdot \dot{m}_B}{\dot{m}_B \cdot \dot{m}_a}, \quad \frac{F}{A}_M = \frac{\dot{m}_B}{\dot{m}_a},
\]

and, \( \phi = \frac{\text{actual fuel to air ratio}}{\text{theoretical fuel to air ratio}} \)

\[
S = \frac{\phi_P}{\phi_M}
\]

Where: \( p, m, \phi \) and VR are the pre-chamber, main-chamber, the equivalence ratio and the volume ratio respectively.