A New Strategy to Achieve Radical Combustion Through Exhaust Port Throttling for Two Stroke Engine

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Abstract

Radical combustion is a critical condition behind control. In two stroke engine, a condition of radical combustion could be achieved through control of the trapped exhaust gases at a certain condition, might include, the engine load, speed, concentration of the unburned hydrocarbons, their temperature and other operational parameters.

An earlier work was conducted towards the achievement of the radical combustion. The mechanism was made to throttle the opening of the exhaust port at a range of 1% to 8 % [1]. However, several difficulties were faced, mainly with the control mechanism of throttling. In addition there is a complexity in identifying the critical conditions at which the radical combustion could be achieved.

In this paper, a new strategy was used to control the exhaust port throttling in a way to manage the amount of exhaust gases trapped and avoiding the drawbacks of the throttling mechanism in the earlier work. Three trial plates were used, one-sixth closed, one-third closed and half closed to throttle the exhaust gases leaving the combustion chamber.

Results reveal the possibility of achieving radical combustion, when using the one-sixth closed plate under relatively higher load. Therefore, partial trapping of the exhaust gases should be carried, through the restriction of the opening of the exhaust port not to exceed 15% of the port exit area. However, it is more interesting, that throttling of the exhaust gases of the two stroke engine have clear influence on the quality and stability of the combustion and hence its direct effect on the fuel consumption and the rate of pollutants expelled to the environment.

Keywords: Spark Ignition Combustion, Radical Combustion, Exhaust Port Throttling, Two Stroke Engine, Trial Plates for Throttling Control,

1. INTRODUCTION

The combustion is a chemical reaction in which certain elements of the fuel (i.e. hydrogen and carbon) combined with oxygen liberating heat energy and causing an increase in temperature of the gases. The conditions necessary for combustion are the presence of a combustible mixture and some means of initiating the process (electric spark). Generally, the chemical reaction occurs more rapidly as the temperature increase. Chain reactions are the most common type of chemical reactions occurs in internal combustion engines. They consist of a series of consecutive, competitive and opposing reaction steps with different reaction rate constants [2, 3, 4]. These complex chemical reactions occur in all combustion processes. For many combustion processes, the specific rate constant for separate reaction steps either are not known or have been approximated roughly [5, 6, 7]. In this reaction process, the most active species are called free radicals. In chemical terminology, free radicals are known as unpaired electrons or “bond-paired” electrons. The hydrogen atom is a free radical, as is illustrated below, where the dots symbolize electrons.

$$\mathbf{H:H} \Rightarrow \qquad \mathbf{H\bullet + H\bullet}$$

If one hydrogen atom **H** is taken away from $\mathbf{CH_4}$, two radicals are formed;

$$\begin{array}{ccccc} & \mathbf{H} & & \mathbf{H} & \\ & \mathbf{..} & & \mathbf{..} & \\ \mathbf{H:} & \mathbf{C:\ H} & \Rightarrow & \mathbf{H\ :C^{\cdot}} & \mathbf{+\ ^{\cdot}H} \\ & \mathbf{..} & & \mathbf{..} & \\ & \mathbf{H} & & \mathbf{H} & \end{array}$$

Elementary reactions are called chain initiating or chain-terminating reactions, according as they produce or destroy free radicals. Also, with regard to the ratio of the number of free radicals in the products to that in the reactant, elementary reactions are called chain-propagating reactions if the ratio is equal to 1, and bring chain-branching reactions if the ratio is greater than 1. Some elementary reactions and their denominations are given below.

$\mathbf{A_2 \Rightarrow 2A}$ **chain initiating** (A_2 has low dissociation energy)

$$\left.\begin{array}{lcl} \mathbf{A + B_2} & \Rightarrow & \mathbf{AB + B} \\ \mathbf{B + A_2} & \Rightarrow & \mathbf{AB + A} \\ \mathbf{A + AB} & \Rightarrow & \mathbf{A_2 + B} \\ \mathbf{B + AB} & \Rightarrow & \mathbf{B_2 + A} \end{array}\right\} \text{chain propagating (very fast rate)}$$

$$\left.\begin{array}{lcl} \mathbf{M + 2A} & \Rightarrow & \mathbf{A_2 + M} \\ \mathbf{M + 2B} & \Rightarrow & \mathbf{B_2 + M} \end{array}\right\} \text{chain termination}$$

A and B are called chain carriers or free radicals and seldom build up in high concentrations. The elementary reaction

$$\mathbf{H + O_2 \Rightarrow OH + O}$$

Is a chain branching reaction, since the number of chain carriers formed is more than a number of chain carriers used up in the reaction [8, 9, 10].

In this combustion reaction, the element that involved must have energy supply from outside of the system. The molecules will not react unless heat is produced to some extent from outside. From the analysis, the combustion not only needs the high temperature but also by fuel concentration and pressure. Below this temperature, the chain reaction does not take place because of the few molecules acquire the activation of the combustion reaction have not enough energy[11, 12, 13].

The most important elements of the fuel are carbon and hydrogen with a small amount of sulphur, oxygen, water vapour, nitrogen and ash. The fuel elements are bonded to one and another. The bonding systems have their own energy and are difficult to break. To make sure this hydrocarbon reacts, the energy must be added to break these bonds. Though there are many kinds of fuel as well as very complicated combustion mechanisms, fuels usually decompose before the combustion starts and the oxidation occurs through some basic form. The main substances are hydrogen, carbon monoxide, gaseous hydrocarbons and solid carbon [14, 15].

2. ACTIVATED RADICAL COMBUSTION THEORY

When the spark plug fires and ignites the fuel mixture, some of the fuel is isolated from the resulting flame by the exhaust constituents remained in the cylinder from the previous cycle and does not burn. Activated radical combustion process will burn all the fuel inside the combustion chamber by using the active radical molecules that are formed in the exhaust gas. When hot exhaust gases remain in the cylinder, it contains a small percentage of active radical molecules; when these are combined with the incoming fuel charge, the resulting mixture begins to auto-ignite at a lower temperature in comparison to that of a pure gasoline/air mixture [14, 17, 18, 19].

3. ACHIEVEMENT OF RADICAL COMBUSTION

Radical combustion is a critical condition behind control. The condition of the radical combustion is affected by the amount of exhaust gases trapped in the combustion chamber at certain critical conditions, including the engine load, engine speed, concentration of unburned hydrocarbons presence in the trapped part of exhaust and its temperature [1, 20, 21].

The earlier work was carried for the achievement of the radical combustion. A control of the amount of exhaust gasses flow out from combustion space, will lead to trap small amount of exhaust gasses and kept to the next cycle inside the combustion chamber. Trapping of such part of exhaust gases may assure the existence of radical agents as OH and H. The exhaust port throttling mechanism to control the amount of the exhaust gases flow out from the combustion chamber has been designed and fabricated. A sliding plate has been fabricated to slide within the machined slot in the cylinder block. Figure 1. illustrates the exhaust throttling mechanism and the slot machined through the cylinder head and the cylinder block.

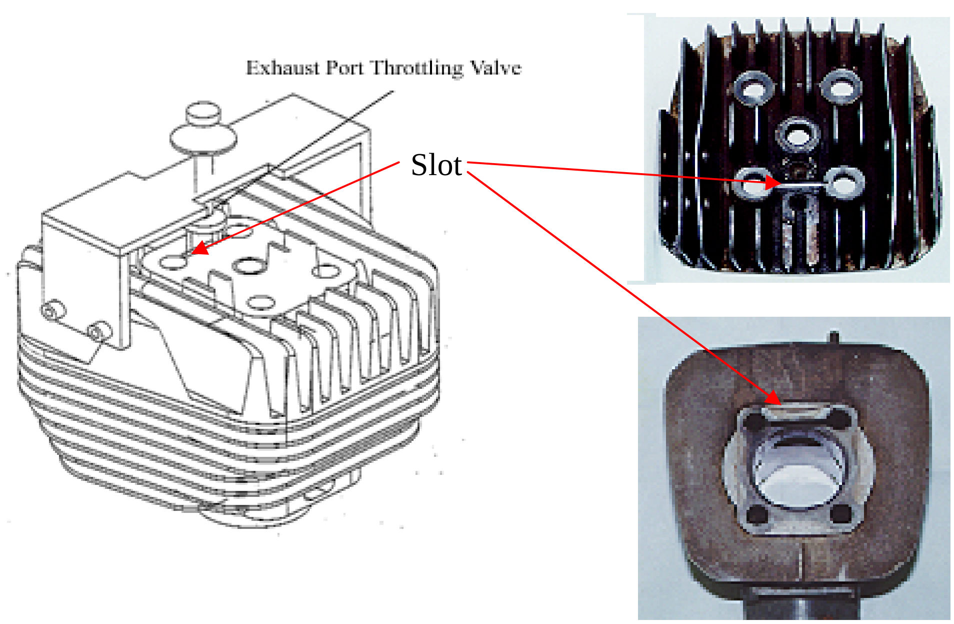


FIGURE 1: Illustration of the Throttling Valve Mechanism.

A very close tolerance slot was machined through the cylinder head and the cylinder block, in which the control blade move in and out to control the opening of the exhaust port. The machining process was carried out by Electrical Discharge Machining (EDM). The control blade was made of stainless steel and machined with very close tolerance with the slot using CNC machine. The control blade and its slot must have close tolerance to avoid any leakage. A spring is used to make sure that the control blade can move up or down, to increase or decrease the exhaust port opening. In this operation, the spring was in turn act to reduce vibration effect of the blade.

In this throttling process, the amounts of exhaust gases flow out can be reduced, hence a part of it will be kept inside the combustion chamber. Applying this type of throttling process, the occur of radical combustion was investigated. The engine is tested under different operating condition at which the exhaust port throttling was set at a range of 2 to 16 mm (exhaust port area of 1 to 8%). It was proved that radical combustion took place at an engine speed of 3000 to 4000 rpm while the engine load was in the range of 1 to 2.5 N.m. Specification of the classical two-stroke engine used in the test, condition of testing and the detailed results of the work were introduced [22, 23]. It was found that when the engine running under radical combustion, assures almost complete stable combustion. In addition the engine could run under lower temperature and with minimum emission as it is proved that contents of exhaust gases have much less CO and minimum Nitrogen Oxides NO_x. A typical results of the previous study are illustrated in figures 2 and 3. It is clear that, lower Specific Fuel Consumption (SFC)) of the engine under radical combustion could be achieved. This indicate better fuel economy. Figure 3 shows a good indication of relative increase of the carbon dioxide CO_2 under radical combustion which lead to tendency of complete combustion.

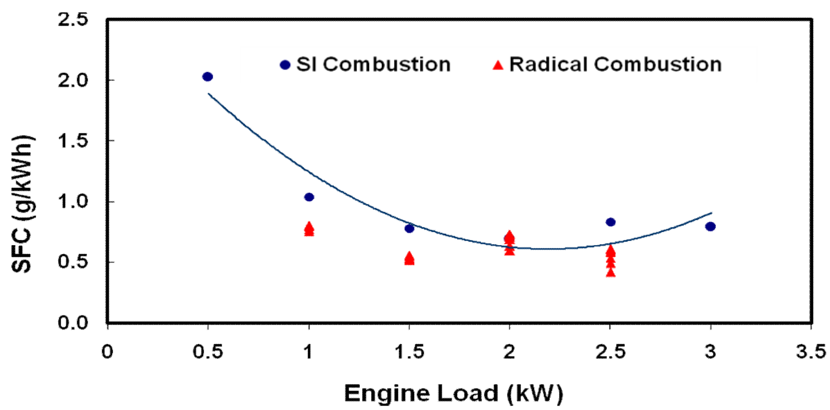
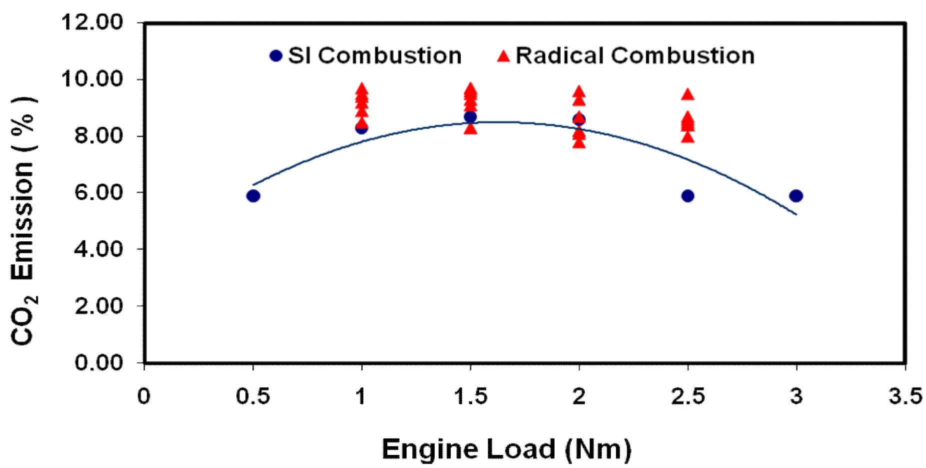


FIGURE 2: Specific Fuel Consumption (SFC) For SI Combustion and Radical Combustion (Engine Speed 4000)



FGURE 3: CO_2 Emission for SI Combustion and Radical Combustion (Speed N=4000 rpm)

Although the above-mentioned method achieve radical combustion, but there are several difficulties faced with such mechanism of the exhaust port throttling, and summarized as follows:

1. Accumulation of carbon deposits on the moving blade as it is exposed to the combustion products. In the other hand, the high temperature reached, lead to affect the sliding mechanism and hence influence the accuracy of the throttling control.

2. As the slot is machined within a narrow space just at a side of the liner on the cylinder block, which make sealing is difficult as the gasket at that part is thin and might lead to a serious leakage, which in turn affect the engine performance.

3. This throttling mechanism was relatively costly, as highly sophisticated machines was used for the machining and producing its components.

4. Manual control of the throttling mechanism will be difficult and not reliable.

The above mentioned difficulties, made such type of throttling control was not successful.

4. A NEW STRATEGY FOR EXHAUST PORT THROTTLING:

In this paper, a new strategy is followed to overcome the above difficulties. The same classical two stroke engine was used. No modification this time is carried on the cylinder head or the cylinder block. The throttling control is placed, just at the point where, the exhaust manifold is connected to the cylinder block. Figure 4: shows clearly the position where to place the throttling control of a partially closed plate. The throttling process, is carried by means of a partially closed plate, at the exit of the exhaust port, to restrict and control of the amount of exhaust gases come out from the combustion chamber.

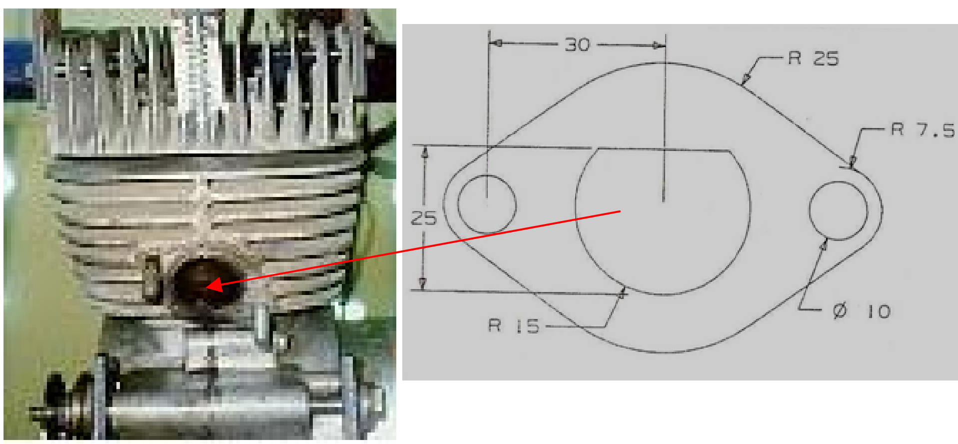


FIGURE 4: A Partially Closed Plate, To Be Fitted To Control The Flow Of The Exhaust Gases Come Out Of The Engine.

In this method of the exhaust port throttling, assuring the simplicity of control of the flow of exhaust gases. Thus displacing the gate of the throttling at the outer side of the cylinder block overcoming the drawback of the earlier work mechanism.

In this case the throttling process was carried out using three different trial plates of different opening size, one-sixth closed, one-third closed and half open, to throttle the exhaust gases leaving the combustion chamber. The configuration of those plates is illustrated in figure 5. The plates was designed and fabricated to fit easily at the exit of the exhaust port where the neck of the exhaust pipe (exhaust manifold) is to be fitted.

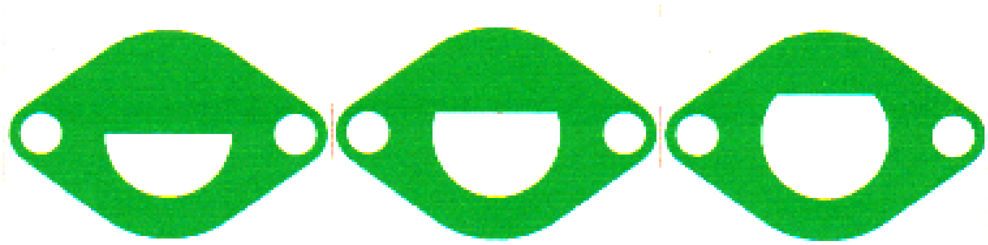


FIGURE 5. Different Trial Plates of Different Opening.

4.1 Engine Testing

A single cylinder, 100 cc direct scavenging, air cooled two-stroke SI engine was employed in the present investigation. This engine was coupled to water dynamometer for torque measurements. A computer exhaust gas analyzer was used to measure the unburned hydrocarbon (UHC), Nitrogen oxides (NO_x) as a part per million (ppm), carbon monoxide (CO), carbon dioxide (CO_2) and Oxygen (O_2) as a percentage emission levels in the engine exhaust. Calibrated standard instrumentation was used for air and fuel flow rates, and exhaust temperature measurement. Experiments were conducted with ignition system using a normal spark plug, without any restriction on the exhaust gases, hence the engine was run as a normal spark ignition combustion. The engine was tested under different engine speed, ranges from 2000 rpm to 4000 rpm.

4.2 Engine Run to Achieve Radical Combustion:

In this stage the engine was run to achieve radical combustion, using the new strategy of control illustrated above. The partially closed plates are fitted alternatively to investigate the achievement of the radical combustion. The plate will act to restrict the flow of exhaust gases come out of the engine, thus lead to trap apart of the exhaust in the combustion space to the next cycle. The exhaust port opening area is 560 mm^2, if the plate is fully open. So with fitting of the different opening plates, the exhaust gases flow could be controlled. Therefore, the trap of a part of exhaust gases rich with free radicals, might lead to the achievement of radical combustion.

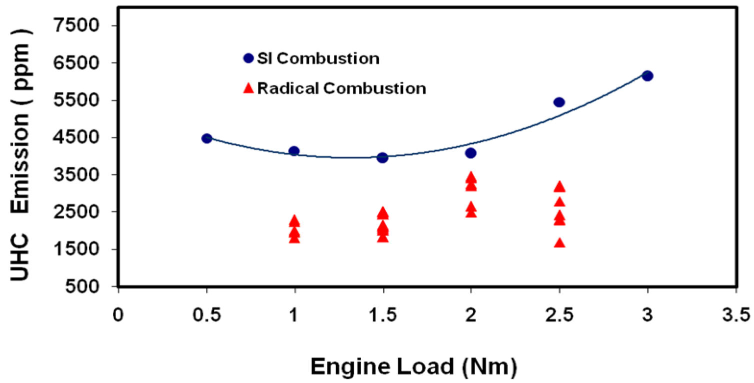
5. RESULTS AND DISCUSSION

The main goal of this paper is to investigate the criticality of radical combustion and its achievement using a simple method to throttle the engine exhaust gases. Different partially closed plates were used in the experiment, to trap a part of the exhaust gases likely rich with free radicals to the next cycle. Once, the new charge introduced to the engine combustion chamber will be mixed with the trapped exhaust gases carry radical, lead to achieve radical combustion.

The engine test results was recorded at speed range from 2000 to 4000 rpm, with spark ignition combustion (SI combustion, normal run). For the same range of speed, the engine results, for the condition with the exhaust throttle also recorded. The engine different parameters as UHC, SFC, NO_x, CO_2 and others are traced at different operating conditions under varying engine load. Results reveal the difficulty to achieve radical combustion, except with presence of plate one-sixth closed and at a higher speed. The other trial plates (one-third closed and half open), made the engine to run with less stable running condition, cause more interrupted running of the engine. More restriction of the exhaust gases will act to dilute the charge and lead to retard the combustion.

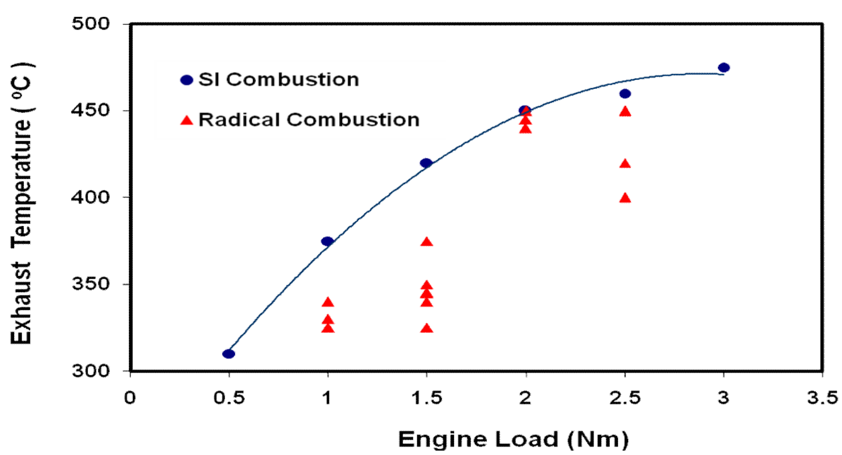
However, with the one-sixth closed trial plate, after several runs it was found that radical combustion could be achieved, under specific operating conditions. A sample of some of the results are introduced to indicate the difference of the condition of normal run (SI combustion) and radical combustion.

Figure 6; presents the measured unburned hydrocarbon UHC emission versus engine load at 4000 rpm. Restriction and control of the exhaust port opening acts to achieve the radical combustion. Therefore, more stable combustion consumes most of the hydrocarbons of the fuel in an efficient way. This clearly indicate the reduction of the UHC emission levels. A noticeable decrease in the level of UHC ensure better combustion compared to the case of normal run (SI combustion) of a classical two stroke engine where UHC emission levels is normally higher. It is found that, there is a good agreement of this result with that obtain in an exhaust gas recycle (EGR), in which, slow down the speed of chemical reactions. This is favorable at higher speed, for two stroke engine as it give more chance for complete combustion, thus reduction in fuel consumption and exhaust emissions [24, 25].



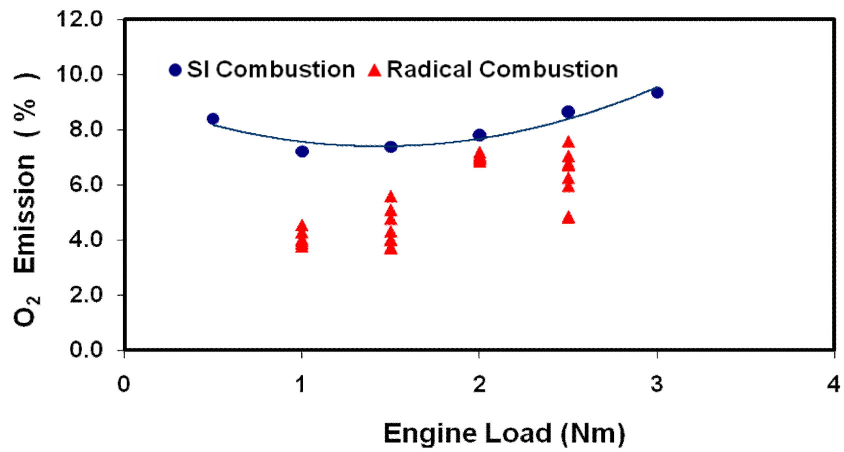
FGURE 6: UHC Emission for SI Combustion and Radical Combustion (Speed N=4000 rpm)

Figure 7; indicate the clear difference of the temperatures of the exhaust gases at normal running condition (spark ignition SI combustion) and radical combustion running condition. It is observed that when engine is running on radical combustion the exhaust gases temperature is lower over the entire load range. The reduction in the exhaust temperature is due to the trap of exhaust gases in the combustion space by restriction of their flow and mixed with new charge, acting to dilute the mixture. This might deplete the reaction and lead to noticeable decrease of the exhaust gas temperature under radical combustion. In addition, the radical combustion is sensitive to the condition of the exhaust trapped, in particular its temperature, and pressure [26].



FGURE 7: Exhaust Temperature for SI Combustion and Radical Combustion (Speed N=4000 rpm)

The O_2 emission under SI ignition and radical combustion is investigated. Figure 8; shows the clear reduction of Oxygen percentage compared to that under SI combustion at 4000 rpm, in particular under moderate load. At higher engine speed the oxygen reacted with the hydrocarbon to form CO. With the restriction of the exhaust flow, the residence time is increases, which will further convert the CO to CO_2 and to the oxides of nitrogen, leading consume more oxygen. It is an evident that under radical combustion where auto-ignition is predominant more stable combustion is recorded with less exhaust emissions [27, 28]



FGURE 8: O_2 Emission for SI Combustion and Radical Combustion (Speed N=4000 rpm)

Investigating of the engine running, incorporated with this new strategy of exhaust port throttling (throttling control at the exit of the exhaust port) leads to several interesting results about the criticality and conditions at which radial combustion is occurring.

1. The throttling controller should be placed adjacent to the exit from the combustion chamber. Displacement of the location of the controller as conducted in this run of experiment, made it hardly to achieve the radical combustion. It is believed that displacement of the throttling control will sweep some of the radical agents to the extra volume formed by the passage (between the port exit and manifold neck). Therefore considerable amount of those active radical will leave the combustion chamber hence reduce the activity of the mixture to achieve radical combustion.

2. Partial trapping of the exhaust gases should be carried through throttling of the exhaust port with a limit not to exceed 15 % of the exit area. Increase of the amount exhaust gases trapped lead to dilute the mixture inside the combustion chamber and hence affect the rate of combustion.

3. As the piston descends and the exhaust port starts to open, most of the unburned hydrocarbon (UBH) leave with first lot hence, presence of this extra volume due displacing of the controller will contribute in trapping less active exhaust gases.

4. As the amount of the exhaust gases trapped increase, it was found that radical combustion is taking place at relatively higher speed and load. Therefore, the volume and state of the trapped exhaust gases are very critical to achieve radical conditions.

5. Results reveal the importance of the shape and direction of opening of the exhaust port. Occurring of the radical combustion is strongly affected by the condition inside the combustion chamber, and the amount of exhaust gases trapped and their content of active radical.

However, it is more interesting, that throttling of the exhaust for two stroke engines have clear effect on the quality and stability of the combustion and hence its direct effect on the fuel consumption and the rate of pollutants expelled to the environment.

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