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Design and analysis of inlet manifold of a four stroke petrol engine by increasing tumble flow rate and reducing air pollution using aerofoil plate

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1. Introduction

Motor conveyances emit astronomically immense volume of carbon monoxide CO, hydrocarbons HC nitrogen oxides NOx, carbon-di-oxide CO_2 and toxic substances such as fine particles and lead as well as contributing to secondary by products such as ozone. For spark ignition engine a plausible solution for reducing emissions is by controlling some combustion parameters, in such way engine performance is kept unaltered. The nature of the flows behaviour and combustion in spark ignition engines are important for improving the performance. The flows in internal combustion engines can be achieved by enhancing the tumble motion and swirl movement within the engine cylinder which enhances the mean-flow and turbulence of the mixture. This flow motion has a strong influence on the engine combustion process. Turbulence is practically proved to be a phenomenon that leads to better mixing of air and fuel. It's also leads to increased combustion rate due to increased flame front. The advantages of inducing a tumble inside a cylinder are they increasing to chances of complete combustion of mixing the air and fuel. The turbulence induced by the tumble leads to better heat flow rate to the cylinder walls. This reduces the uneven load on the coolant. The in-cylinder flow motion in spark ignition engines is one of the most important factors controlling the combustion process. The Swirl and tumble motion are well known approaches for in-cylinder flow enhancement. Multidimensional modelling became as an important tool for investigating flow and combustion in reciprocating engines.

Hamai et al. [1] showed that incomplete mixing of fuel/air and residual contribute to cycle to cycle variation in combustion. Also, the increase of residuals resulted in increased cyclic pressure variability. Engine speed also contributes to cycle to cycle variation in combustion, where increasing the engine speed resulted in an increase in flame speeds and cyclic flame speed variations. Increase in turbulence has also been attributed to engine speed and the higher turbulence is the main reason for the increase in flame speed variations. NanthaGopal et al. [2] The exhaust emission levels have been focused on carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). Energy conservation on engine is one of the best ways to deal with these problems since it can improve the energy utilization efficiency of engine and reduces emissions.

Gosman et al. [3] and Yasar et al. [4] to do this, the geometry of the inlet ports was defined utilizing six fundamental parameters. These parameters were culled so that the initial and secondary factors, which define the flow and tumble performance of a port, were included. Sugiura et al. [5], Payri et al. [6] and Abhilash et al. [7] numerically and experimentally studied with laminar and turbulent combustion flow in an axisymmetric reciprocating engine without combustion through a cylinder head port. Calculated and quantified results were in a good accedence. They observed that the mean velocity field was influenced more vigorously by the engine geometry than by the engine speed. In order to simulate the mass flow rate and flow pattern of the induction system in an internal combustion engine. Naitoh et al. [8] Computed velocities and static pressures obtained from simulations were in a good accedence with the experimental data. Computation of the three-dimensional flow in the intake ports of and the cylinders of the authentic engines, including moving valves and piston were carried out by solving the Navier-Stokes equations. Barbouchi and Bessrour [9] and Theodorakakos et al. [10] presented the analysis of the swirl intensity effects on spray formation and obtained plausible accedence with experimental data. However, since the intake process was not included in the calculation, the initial swirl was imposed as a parameter. It can be mentioned that the way to estimate the initial turbulence between these two studies is different. MuraliKrishna and Mallikarjuna [11], Maurice-Kettner et al. [12] and Adomeit et al. [13] have considered the intake valve as a single plate and inflicted the swirl intensity and the intake angle as boundary conditions. The overall in-cylinder tumble flows are much dependent on the crank angle positions irrespective of engine speed. Rajendran and Purushothaman [14] analyzed The result of volumetric efficiency depends upon the position of throttle plate such as double throttle plate angle 60° is identically equal to 66.12%, 75° is identically equal to 71.33% and 76° is equal to 67.76%. Rajendran and Purushothaman. [15] studied the previous research article based on the inlet flow of internal combustion engine.

1.1. Structure of pollutant in carbon monoxide (CO)

The amount of CO configuration increases as the mixture becomes more and richer in fuel. A small amount of Carbon monoxide will emerge from the exhaust even when the mixture is marginally lean in fuel because air/fuel mixture is not homogenous and stability is not conventional when the products pass to the exhaust. At the high temperature developed during the combustion, the products formation are uneven and following reactions take place before the stability is recognized:

$$2C + O_2 = 2CO.$$

1.2. Structure of pollutant in Hydrocarbons (HC)

Hydrocarbons appears in exhaust gas due to local rich mixture pockets at much lower temperature than the combustion chamber and due to flame quenching near the metallic walls. A significant amount of this unburnt HC may burn during expansion and exhaust strokes if oxygen concentration and exhaust temperature is suitable for perfect oxidation.

2. Design and methodology of the aerofoil plate

The experiment facility of the inlet manifold is shown in the (Fig. 1). The most paramount part of our paper is to design the aerofoil plate that involves in reducing the area of the inlet manifold through which the air and fuel mixture enters the cylinder. It has to be designed and mounted in the inlet manifold of most of the subsisting engines. We opted to design an aerofoil plate in such a way that it is hinged at one end and placed in cavity like arrangement in the inlet manifold without making any appreciable changes to it.

Fig. 1 Experiment setup

The second most paramount thing is to design an aerofoil plate in a way that it doesn't act as an obstruction to the airflow. Thus an aerofoil design was achieved to make it feasible to reduce the area as well as be aerodynamically efficient and avails in maintaining the flow pattern of the air/fuel mixture. Hence it's very paramount to actuate and position at point where it doesn't affect the flow. The model of the aerofoil plate design and culled a module that proved to have a very less coefficient of drag from which the Reynold's number could be calculated to determine the nature of the flow of the fluid over the surface. The design we incorporated very well proved to have less co-efficiency of drag and hence the flow over it had a Reynolds number that betokens that the flow around its surface is still identically equal. After the tests we determinately incorporated this aerofoil plate design with a provision for actuating mechanism.

3. Results and discussion

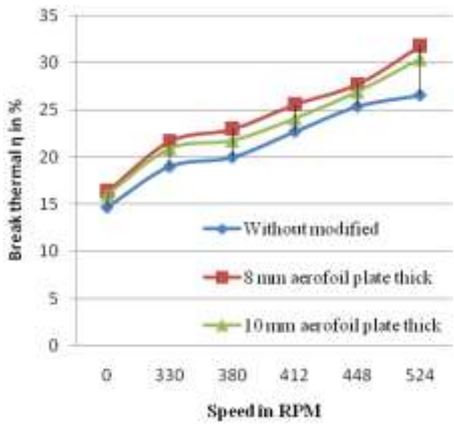
3.1. Experimental evaluation of Brake thermal efficiency, CO, HC and CO_2

The two different types of modified manifold (aerofoil plate) have been analyzed in the flow path of a single cylinder four-stroke naturally air cooled engine. The performance studied has been made for brake thermal efficiency, CO, HC and CO_2 emissions of the modified manifold with standard manifold the experimental analysis of the turbulent flow and combustion in an idealized homogeneous charged engine. Computations are performed for the different engine speeds and load with aerofoil plate. The specification of engine cylinder diameter is 100 mm and stroke is 90 mm.

From this simulation it can be visually perceived that by reducing the area for the flow utilizing the aerofoil plate increases the velocity of the fluid. Thus the incrementation in the velocity stream line that is betokened by the velocity stream line index on the left, we verbalize that it avails the fluid to gain more kinetic energy with which the fluid molecules peregrinate more with more speed, hit the cylinder wall and return towards the piston head which is near BDC at that moment. This action is called tumbling and as verbally expressed earlier the kineticism of the piston towards TDC in fact enhances the indispensable turbulence to be achieved.

(Fig. 2, a) shows that the variation of brake thermal efficiency of two different modified manifolds (aerofoil plate) based on speed. The average brake thermal efficiency obtained by without modified model is 21.37%, with modified 8 mm thick plate is 24.33% and 10 mm thick plate is 23.32% .therefore approximately 2.96% and 1.01% of brake thermal efficiency increased in modified manifold with 8 mm and 10 mm aerofoil plate. (Fig. 2, b) shows that based on speed, the average quantity of CO emissions obtained by without modified model is 0.8515%, with modified 8 mm thick plate is 0.7232% and 10 mm thick plate is 0.8033%. Therefore approximately 0.1283% and 0.0482% of CO decreased in modified manifold with 8 mm and 10 mm thick aerofoil plate. (Fig. 2, c) shows that based on speed, the average quantity of HC ppm in emissions obtained by without modified model is 193.16 pmm, with modified 8 mm thick plate is 72.52 pmm and 10 mm thick plate is 124 pmm. Therefore approximately 120.64 pmm and 69.17 pmm of HC decreased in modified manifold with 8 mm and 10 mm thick plate. (Fig. 2, d) shows that based on speed, the average quantity of CO_2 emissions obtained by without modified model is 5.08%, with modified 8 mm thick plate is 4.53% and 10 mm thick plate is 5.05%. Therefore approximately 0.55% and 0.03% of CO_2 decreased in modified manifold with 8 mm and 10 mm thick plate.

(Fig. 3, a) shows that the variation of brake thermal efficiency of two different modified manifolds (aerofoil plate) based on torque. The average brake thermal efficiency obtained by without modified model is 21.37%, with modified 8 mm thick plate is 24.73% and 10 mm thick plate is 23.70%. Therefore approximately 3.36% and 2.34% of efficiency increased in modified manifold with 8mm and 10mm thick aerofoil plate. (Fig. 3, b) shows that based on torque, the average quantity of CO emissions obtained by without modified model is 0.853%, with modi-



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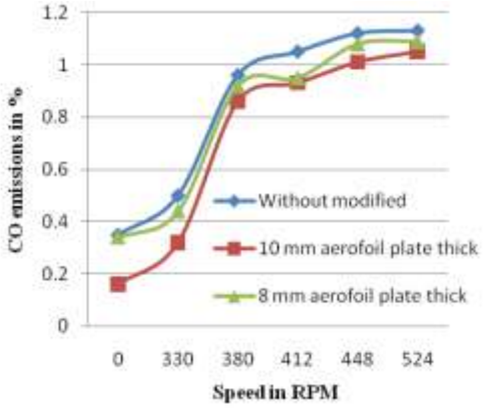

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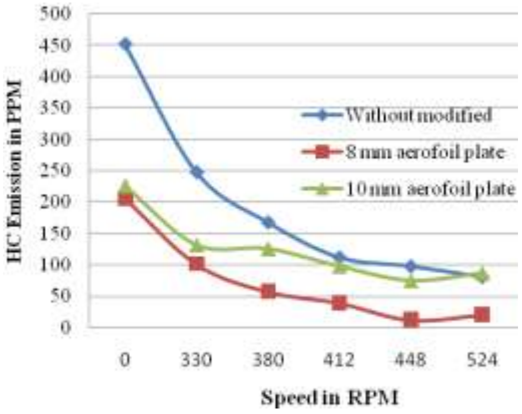

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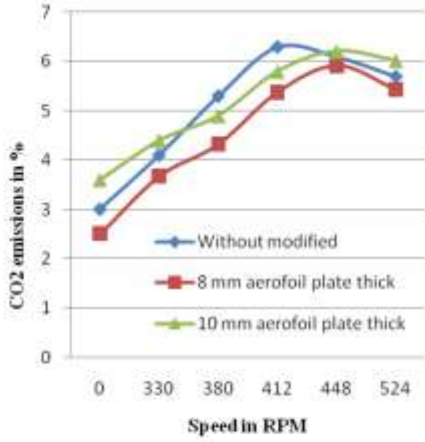

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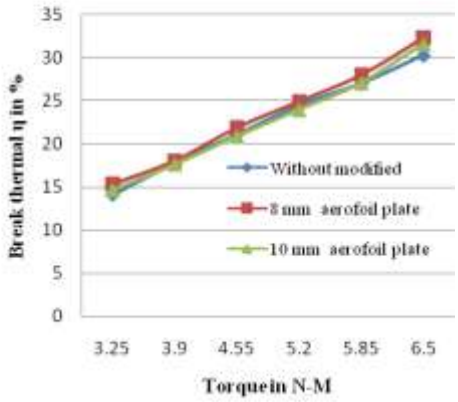
Fig. 2 a) Speed *Vs* Brake Thermal Efficiency; b) Speed *Vs* CO; c) Speed *Vs* HC; d) Speed *Vs* CO_2



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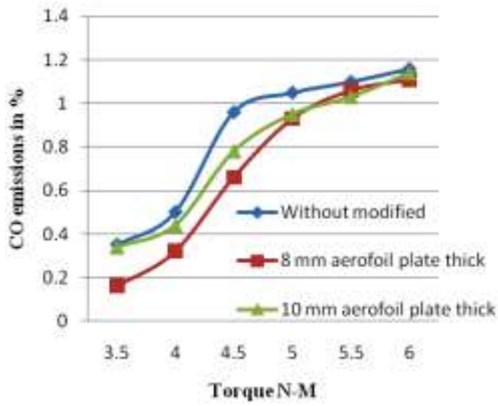

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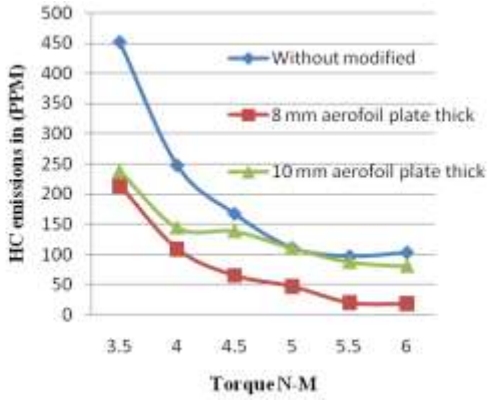

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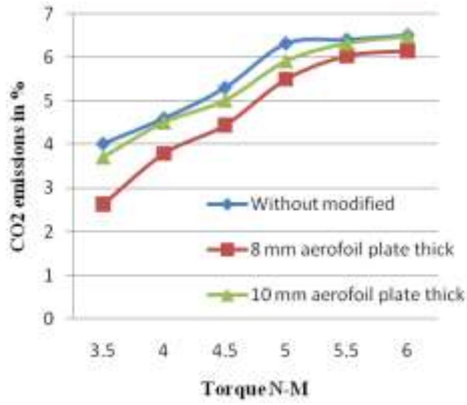

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Fig. 3 a) Torque *Vs* Brake Thermal Efficiency; b) Torque *Vs* CO; c) Torque *Vs* HC; d) Torque *Vs* CO_2

fied 8 mm thick plate is 0.706% and 10 mm thick plate is 0.78%. Therefore approximately 0.147% and 0.073% of CO decreased in modified manifold with 8 mm and 10 mm thick plate. (Fig. 3, c) shows that based on torque, the average quantity of HC ppm in emissions obtained by without modified model is 197 pmm, with modified 8 mm thick plate is 78.8 pmm and 10 mm thick plate is 133.33 pmm. Therefore approximately 118 pmm and 63.67 pmm of HC decreased in modified manifold with 8mm and 10 mm thick plate. (Fig. 3, d) shows that based on torque, the average quantity of CO_2 emissions obtained by without modified model is 5.53%, with modified 8 mm thick plate is 4.75% and 10 mm thick plate is 5.33%. Therefore approximately 0.78% and 0.2% of CO_2 decreased in modified manifold with 8 mm and 10 mm thick plate.

3.2. Effect of pressure drop in inlet manifold

Analysis of friction factor, pressure drop, heat transfer coefficient and heat transfer rate for flow inside a circular tube for laminar flow conditions.

3.2.1. Flow inside a circular tube

The flow condition inside a circular tube depends in the Reynolds number which is defined as

$$Re = \frac{\mu_m D}{\gamma}, \tag{1}$$

when μ_m mean velocity of fluid, D is the inside diameter of the tube and γ is the kinematic viscosity of the fluid. The flow inside the circular tube is laminar up to the Reynolds number is 2300.

3.2.2. Friction factor

To verify the friction factor we consider a small fluid element of thickness dz the pressure force to the shear force of the aerofoil plate:

$$\left(P_A\right)_Z - \left(P_A\right)_{Z+dz} = P\Delta_Z \tau_w, \tag{2}$$

$$\left(P_A\right)_Z + \left(P_A\right)_Z - A\frac{dp}{dz}\Delta_Z = P\Delta_Z \tau_w, \tag{3}$$

$$\frac{dp}{dz} = \frac{P}{A}\tau_w, \tag{4}$$

when P is the perimeter, A is the cross sectional area and τ_w is the aerofoil plate shear stress.

$$\frac{dp}{dz} = \frac{4}{D}\tau_w. \tag{5}$$

Shear stress at the wall is given by:

$$\tau_w = \mu \frac{du}{dy}. \tag{6}$$

The friction factor is defined as:

$$f = -\frac{2d}{\rho\mu m^2}\frac{dp}{dz}. \tag{7}$$

Substituting the Eq. (7) in the friction factor:

$$f = -\frac{(8\mu)}{\left(\rho\mu m^2\right)}\frac{dp}{dr}. \tag{8}$$

The velocity distribution $u(r)$ is required which is obtained by solving the equation of motion. The momentum equation for cylindrical coordinate system is:

r – Momentum

$$\rho\left(v\frac{\partial v}{\partial r} + u\frac{\partial v}{\partial z}\right) = F_r - \frac{\partial p}{\partial r} + \mu\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} - \frac{v}{r^2} + \frac{\partial^2 u}{\partial z^2}\right), \tag{9}$$

z – Momentum

$$\rho\left(v\frac{\partial u}{\partial r} + u\frac{\partial u}{\partial z}\right) = F_r - \frac{\partial p}{\partial r} + \mu\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{\partial^2 u}{\partial z^2}\right). \tag{10}$$

The mean flow velocity is:

$$u_m = \frac{1}{\pi R^2}\int 2\pi r u dr, \tag{11}$$

$$u_m = \frac{4m}{\pi p d^2}. \tag{12}$$

The friction factor:

$$f = \frac{64}{Re}. \tag{13}$$

The pressure drop will be calculated for a given length of tube.

$$\frac{dp}{dz} = f\,\frac{L\rho u^2 m}{2D}, \tag{14}$$

where f *is* the friction factor to be taken from the moody chart. The following equation may also be used to calculate the friction factor of smooth tubes:

$$f = 0.316\,Re^{-0.25} \quad for < 2\times10^4, \tag{15}$$

$$f = 0.184\,Re^{-0.20} \quad for < 2\times10^4 < Re < 3\times10^5. \tag{16}$$

The Air flow rate in the 8 mm aerofoil plate is nearly equal in both Experimental and Analytical methods are shows in the Table 1.

Table 1

Effect of pressure drop in inlet manifold

Torque N-m	TFC	Break power, KW	Velocity of flow, m/s	Reynolds number	friction factor	Pressure drop Δp, N/m^2	Power, KW	Flow rate Q, m/s^2
3.25	0.1080	0.1905	343.95	326172	0.0002	5.8031	0.6267	0.0839
3.9	0.1021	0.2163	325.19	308381	0.0002	5.4866	0.5602	0.0816
4.55	0.1003	0.2429	319.38	302874	0.0002	5.3886	0.5404	0.0808
5.2	0.0921	0.2585	293.20	278048	0.0002	4.9469	0.4554	0.0774
5.85	0.0838	0.2706	266.95	253148	0.0003	4.5039	0.3775	0.0739
6.5	0.0780	0.2925	248.41	235569	0.0003	4.1911	0.3269	0.0713

3.3. Statistical analyses ANOVA using two way method

It is convenient to use the following computational formula for finding the various sums of squares numerically.

Total sum of squares is:

$$SST = \sum_j \sum_i y^2 ji - \text{correction factor}, \quad (17)$$

where correction factor $\frac{c^2}{N}$.

Between treatment sum of squares:

$$R_1 = \sum_J \frac{T_i^2}{r} - \text{correction factor}. \quad (18)$$

Between block sum of squares:

$$R_2 = \sum_J \frac{B_i^2}{K} - \text{correction factor} \quad (19)$$

Error sum of squares $SS_{error} = SST - R_1 - R_2$.

$F_1 < F(5,10)$ reject H_{01} and conclude that there is no significant effect due to difference in speeds. and $F_2 > F(2,10)$ accept H_{02} and conclude that there is no significant effect due to difference in Manifold models shows in the Table 2.

Table 2

ANOVA table

Source of variations	Degrees of freedom	Sum of squares		Mean squares		Variance ratio	
		Speed	Load	Speed	Load	Speed	Load
Speed in RPM	6	738.1594	738.0268	147.6319	147.6054	10.88	12.178
Manifold model	2	63.2359	7.3171	31.6179	3.6586	2.3301	0.3018
Error	10	135.6909	121.2063	13.5691	12.1206	-	-
Total	17	937.0862	866.5502	-	-	-	-

4. Conclusions

The analysis of the air and fuel flows in-cylinder internal combustion engine utilizing different thickness of aerofoil plate, the following conclusions were drawn:

The overall in-cylinder tumble flows are much dependent on the Aerofoil plate thickness with irrespective of engine speed. It is suggested to utilize the aero dynamical Aerofoil plate rather than flat Aerofoil plate as far as tumble flows are concerned. The quantity of molecules entering the in-cylinder is reduced perpetually with incrementing the thickness of Aerofoil plate thick.

This is due to a reduction in the area of the inlet manifold so that, the 8mm thick aerofoil plate, gives the result of drag coefficient as 0.21. This is the best result as compared to the other aerofoil plate. But as the airfoil plate thickness increases above 10mm, it may be blocks the flow of the air fuel mixture.

It is suggested to utilize, the 8mm thickness of aerofoil plate utilized in the inlet manifold, less amount of emission emitted to the atmosphere such that volume of CO and HC (ppm) compared to other thickness of aerofoil plate.

The two different fuel mixture concept (8mm and 10mm aerofoil plate in the inlet modified manifold) results in the brake thermal efficiency incremented by 2.96% and 3.36% in the both condition of speed and load. It is additionally decrease the HC emissions were found and approximately 120.64 – 118 ppm reduction is achieved with the two different fuel mixture concept operations in both speed and loading conditions. A significantly reduction in CO emission is approximately 0.1283%-0.147% and CO_2 emissions were observed in the two different fuel mixture concept is 0.55 -0.78% with an incrimination in engine performance without increase in emissions.

In future, introducing the modified aerofoil plate at inlet flow is possible to increment turbulence kineticism, so that it increments the efficiency and reduces the emission due to congruous commixing of flow.

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DESIGN AND ANALYSIS OF INLET MANIFOLD OF A FOUR STROKE PETROL ENGINE BY INCREASING TUMBLE FLOW RATE AND REDUCING AIR POLLUTION USING AEROFOIL PLATE

S u m m a r y

This research targets the moment of tumble and swirl function of air flow in cylinder. It is explained by introducing aerodynamically efficient aerofoil plate in the path of inlet stream of air with fuel mixture. In normal level, Engine have cylinder and inlet manifold geometry that lead to tumble motion and better mixture of air and fuel. The motion of tumble is entirely different than traditional method. The new level research carries the manifold with 8mm and 10 mm aerofoil plate for the amalgamation of fuel and air. By the low level speed in any prevailing engines the movement of tumble is practiced. To have a complete combustion stimulated by the process of mixing air and fuel molecules with the observation at lower engine speed and better mixing is the Moto of research. The performance of the engine increase and complete combustion leads to reduced emission (CO, HC, and CO_2) and small change in volumetric efficiency. It is also proved that, increased tumble movement introduces aerofoil plate that helps the flame spread which used into constant heat transfer rate. This suggests to a new combustion technique that should be developed to yield improved primary combustion processes in-side the engine with slightly increase in the break thermal efficiency.

Keywords: Aerofoil plate, Swirl motion, Tumble motion, HC and CO_2.

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