Experimental and Theoretical Study to Improve the Spark Ignition Engine Performance

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Abstract. One of the most important components affecting performance in internal combustion engines(ICE) is the intake manifold. The present work presents an improvement of Spark Ignition (SI) engine performance by adding a swirl generator (mixer) within the inlet port. Experiments were applied on a single-cylinder, four-stroke, GREEN CUT AV3500 gasoline engine. Exhaust emissions compositions and fuel consumption are recorded. To understand the behaviour of airflow through the intake port with and without the swirl generator, a 3D model was analysed using Computing Fluid Dynamic (CFD) by ANSYS Fluent 2020 R1. Results show an enhancement of engine performance especially fuel consumption by 24%, and the concentration of CO in exhaust emissions by 67%. As well as, computationally, pressure drop improved with intake port equipped with the mixer.

Keywords: Internal Combustion Engine, Intake Manifold, CFD simulation, Swirl Motion, Experiment.

1 Introduction

Improving performance (power and torque),fuel-saving, and reducing pollutant emissions have intensified efforts to gain better design of an internal combustion engine manufacturing field [1]. One of the most crucial factors in achieving this is the optimization of the intake manifold design [2]. the inlet manifold is responsible for uniform air distribution inside the runner and preparing a homogeneous air-fuel mixture [3] inlet manifold geometry plays an important role in air motion phenomenon inside the intake manifold, which governs the engine performance of spark ignition engines [4] Generally, In a typical intake manifold, airflow is laminar during the induction stroke, resulting in weak homogeneity of fuel atomization. Meanwhile, creating turbulent flow decreases pressure drop through the intake port which increases air density to get better air-fuel mixing and complete combustion [5],[6]. Since the intake manifold plays an important role in engine performance, different techniques were studies to improve engine performance. J.Bayas, et.al. [7] conducted a study of the effect of intake manifold length on internal combustion engine performance. A single-cylinder, four-stroke intake manifold with various intake lengths mounted on the engine has been tested Length of the intake manifold is changed for a speed range of 1200-2000 rpm and the other parameters are kept constant. The first test was carried out with the typical intake manifold length of the engine under study 250mm and 45mm diameter, then the intake manifold length was changed

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as per the calculations done by using empirical relationships and the data were recorded. Results show that the volumetric efficiency, toque, and brake power can be improved by varying the intake manifold length. The optimum engine performance was achieved when the length of the intake manifold decreased at high engine speeds. Och et. al. [8] investigates the effect of the intake manifold length on engine performance. The study is carried out on a single-cylinder diesel engine. The authors applied the stochastic optimization technique called Differential Evolution to find optimal duct lengths to optimize the engine performance. Results showed that the length of the intake manifold plays a role key in the engine outputs. Mohammed K. et al. [9] experimentally and numerically investigates the effect of the curvature of the inlet port on the engine performance. Various angles(0º,90º,180º,180º NP,135º NE) of curved intake port are applied on a single-cylinder four-stroke gasoline engine, the analysis of data shows the optimal angle of curvature is 135º, at which air velocity and pressure are improved resulting in enhancement of air/fuel ratio, the mass of fuel consumed and the emissions of exhaust gases. D.Ramasamy et. al.(10)conducted a study of performance improvement in Air Intake System (AIS) of 1.6L Engine by adding guide vane in the inlet plenum of the air filter, It was found that the pressure drop improved by 12.01% for the rpm speed of 1000 to 7000 With Guide Vanes, this results in air-fuel mixing and fuel combustion process to improvement in airflow behaviour. Sunaryo et. al. [6] presents a CFD analysis of adding a gasket mixer shaped between the carburettor and intake manifold in order to optimize the airflow behavers, researchers found that Adding an insulator mixer inside the air duct can improve the airflow characteristics, such as pressure and turbulence intensity, resulting in increased volumetric efficiency. In the same context, S.L.V. Prasad et.al. [11] Reported that The effect of air swirl created by directing airflow in the intake manifold on the engine outputs. Turbulence is created in the inlet manifold by grooving it with a helical groove that is 1 mm wide and 2 mm deep with different pitches to guide the airflow. Experiments are carried out on a single-cylinder, light-duty, direct injection diesel engine. As a result, the brake thermal efficiency was increased with an increase in brake power and specific fuel consumption and soot emission level were reduced. moreover, A.K. Mohiuddin [12] investigates the swirl effect on engine performance by inserting a swirl adapter. The experiment has been carried out on the protons CAMPRO engine model of 1.6 litters. In swirl device adapter blade angle is maintained at 30º placed in the intake port. The GT-SUITE software was used which has a standard swirl flow embedded in it. It is found that a swirl factor is an important tool in the reduction of fuel consumption and influences volumetric efficiency improvement. In this study, a swirl generator is applied in the intake port in order to improve the airflow characteristic

2 Materials and Methods

Figs 1 and 2 show the Schematic diagram and photographic experimental setup used for the investigations. A four-stroke, single-cylinder, SI engine is coupled to a dynamometer for measuring brake power. Fuel consumption of the engine is measured with the burette method, Engine speeds are measured with a tachometer, while exhaust gases are analysed by INFRARED 4 GAS ANALYZER model: FLUX-2000-4. A pipe of 90cm long is cut into 9 parts connected to the inlet port of the carburettor. At the beginning of the experiments, the engine was run at full load at 2760 rpm. When the engine reached the steady-state conditions, the first experiment was conducted to locate the best position for fixing the swirl generator. Then tests were carried out with various engine speeds and loads, with and without swirl generator.

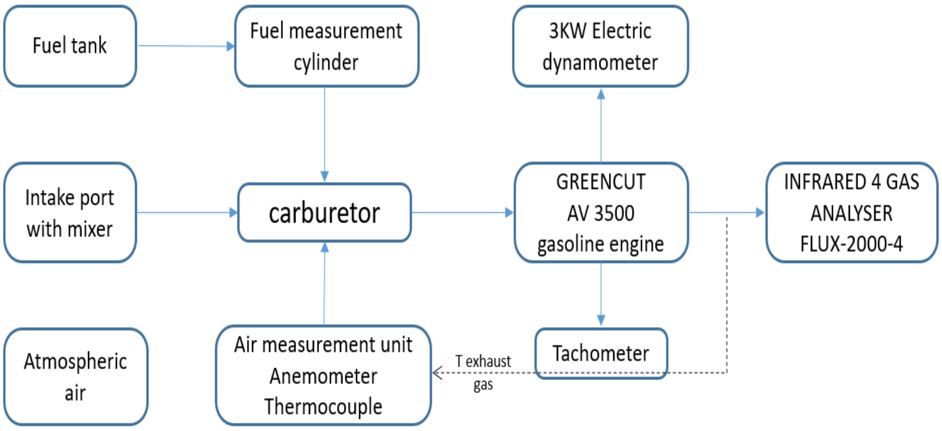

Fig. 1. Overall experiment instruments layout.

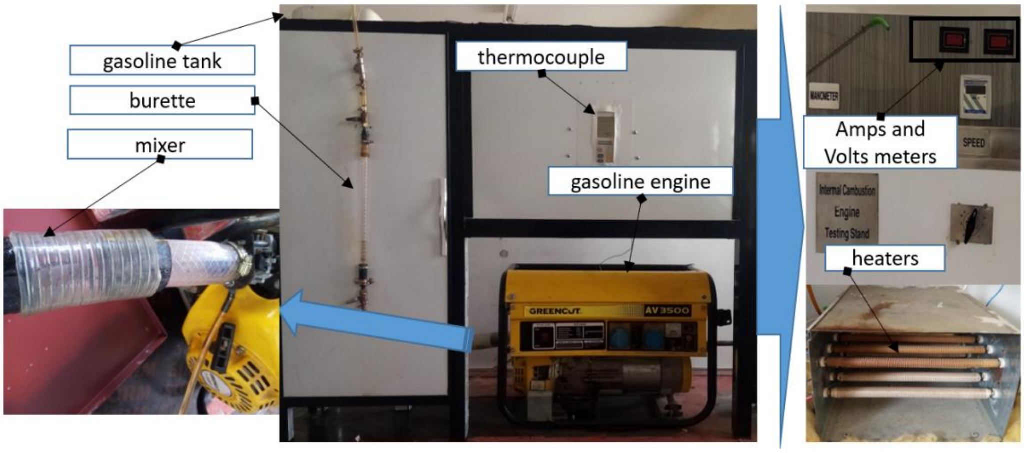

Fig. 2. Test equipment's photograph.

3 Computational Analysis

3.1 CFD Process Setup

Fig. 3 illustrates the 3D model of the engine geometry. Combustion chamber, intake and exhaust ports, intake and exhaust valves were established by using the Pre-processor design modeler of internal combustion engine IC Engine (Fluent) tools. After meshing the model by using the mesh tool to discretize the solution equations, the model is transferred to a Fluent setup, the air is used as a working fluid. k-ε turbulence model was used in the CFD model. Four models of mixer are simulated as shown in Figure (9), 20mm diameter,0.2mm thickness for each one, and 12mm depth of model (a)and (c),72mm^2 passing cross-section area.

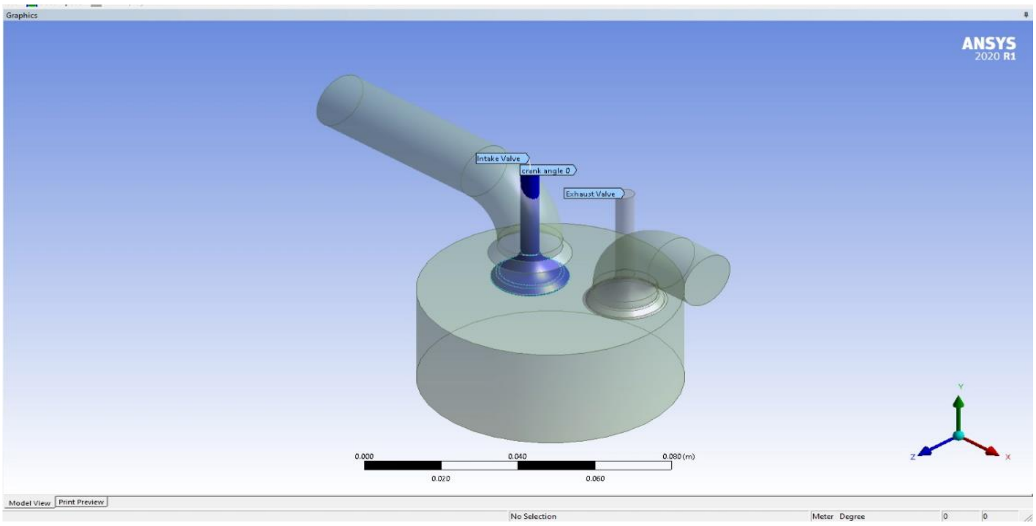

Fig. 3. Geometry model created in fluent.

3.2 Mathematical Equations

CFD generally solves fluid motion by solving the Navier-Stokes equation of mass, momentum, and energy equation. (13).

Continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho.\mathrm{u})}{\partial \mathrm{x}} + \frac{\partial(\rho.\mathrm{v})}{\partial \mathrm{y}} + \frac{\partial(\rho.\mathrm{w})}{\partial \mathrm{z}} = 0 \tag{1}$$

X-Momentum Equation

$$\rho\frac{\partial \mathrm{u}}{\partial t} + \rho u\frac{\partial \mathrm{u}}{\partial \mathrm{x}} + \rho v\frac{\partial \mathrm{u}}{\partial \mathrm{y}} + \rho w\frac{\partial \mathrm{u}}{\partial \mathrm{z}} = \rho g_x - \frac{\partial \mathrm{p}}{\partial \mathrm{x}} + \mu\frac{\partial^2 \mathrm{u}}{\partial \mathrm{x}^2} + \mu\frac{\partial^2 \mathrm{u}}{\partial \mathrm{y}^2} + \mu\frac{\partial^2 \mathrm{u}}{\partial \mathrm{z}^2} \tag{2}$$

Y-Momentum Equation

$$\rho\frac{\partial \mathrm{v}}{\partial t} + \rho u\frac{\partial \mathrm{v}}{\partial \mathrm{x}} + \rho v\frac{\partial \mathrm{v}}{\partial \mathrm{y}} + \rho w\frac{\partial \mathrm{v}}{\partial \mathrm{z}} = \rho g_y - \frac{\partial \mathrm{p}}{\partial \mathrm{y}} + \mu\frac{\partial^2 \mathrm{v}}{\partial \mathrm{x}^2} + \mu\frac{\partial^2 \mathrm{v}}{\partial \mathrm{y}^2} + \mu\frac{\partial^2 \mathrm{v}}{\partial \mathrm{z}^2} \tag{3}$$

Z-Momentum Equation

$$\rho\frac{\partial \mathrm{w}}{\partial t} + \rho u\frac{\partial \mathrm{w}}{\partial \mathrm{x}} + \rho v\frac{\partial \mathrm{u}}{\partial \mathrm{y}} + \rho w\frac{\partial \mathrm{w}}{\partial \mathrm{z}} = \rho g_z - \frac{\partial \mathrm{p}}{\partial \mathrm{z}} + \mu\frac{\partial^2 \mathrm{w}}{\partial \mathrm{x}^2} + \mu\frac{\partial^2 \mathrm{w}}{\partial \mathrm{y}^2} + \mu\frac{\partial^2 \mathrm{w}}{\partial \mathrm{z}^2} \tag{4}$$

3.3 The Standard k-ε Model

The standard k-ε model has two model equations one for the turbulence kinetic energy (k) and one for dissipation rate (ε). The model transport equation for k is derived from the exact equation, while the model transports equation for ε was obtained by using the physical analysis. The standard model uses the following transport equations for k and ε (14).

The turbulent kinetic energy (k):

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k - \rho\varepsilon \tag{5}$$

The energy dissipation rate (ε):

$$\frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_i}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}G_k - \rho C_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{6}$$

Where:

G: Turbulent production term of kinetic energy.

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{7}$$

model constants

$C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92, C_\mu = 0.09\ , \sigma_k = 1.0\ , \sigma_\varepsilon = 1.3$

3.3 Boundary Conditions

The simulation work of this study has been applied on four models of the combustion chamber, including the intake port with mixer, piston, exhaust port, inlet valve, and exhaust valve. The boundary conditions were set as the velocity inlet and pressure outlet.

Boundary conditions at the inlet

$$\left.\begin{array}{l} u = u_{in} \\ v = w = 0 \end{array}\right\} \tag{8}$$

Boundary conditions at the outlet

The pressure outlet is zero**.**

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} = \frac{\partial w}{\partial z} = 0 \tag{9}$$

$$\frac{\partial k}{\partial x} = \frac{\partial \varepsilon}{\partial x} = 0 \tag{10}$$

Boundary conditions at the solid walls

A No-slip boundary condition is applied to all of the wall surfaces.

$$u = v = w = 0 \tag{11}$$

4 Results and Discussion

4.1 Experimental Results

This analysis of data is carried out based on variable engine speeds with and without the mixer. The approach of this data analysis is carried out to study the output data behaviour towards the manipulation of engine speed and loads. Figs 4 and 5 demonstrate the effect of the mixer position through the intake port on fuel consumption and exhaust gas emissions in constant engine speed at 2760 rpm, nine points are investigated with 10cm each and moved forward, results show the distance of 20cm between the carburettor inlet hoe and mixer is the more effective distance in which fuel consumption enhanced by 24% which is from 14.7ml/min without mixer to 11.1ml/min with mixer. While The carbon monoxide volume percentage is lower on the condition with mixer 0.82%volume. and higher on the condition without mixer 2.46% volume with 67% improvement. This means that the closest mixer position causes high turbulence air motion through the carburettor, carrying a large volume of fuel and forming a rich air-fuel mixture; on the other hand, the further away swirl created slightly decreases through the pipe length, so the swirl position should be carefully selected. BSEC was lower with swirl flow as shown in Fig, 6, as well as carbon monoxide composition decreased as shown in Fig 7.

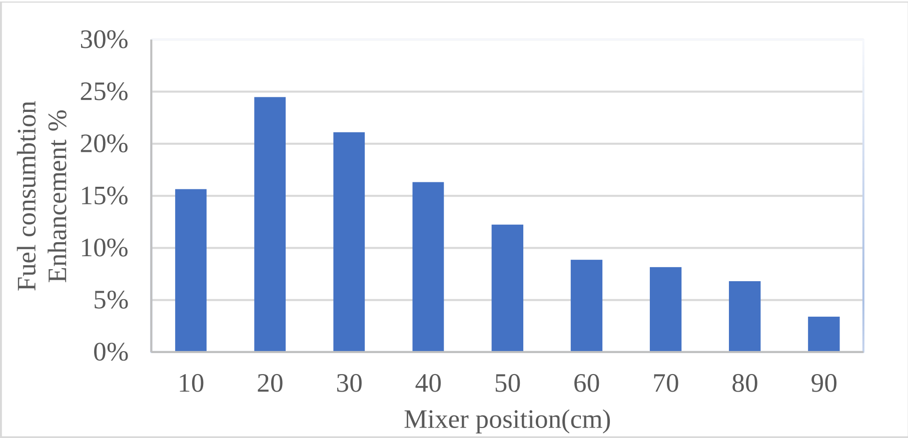

Fig. 4. Fuel consumption enhancement at various points intake pipe.

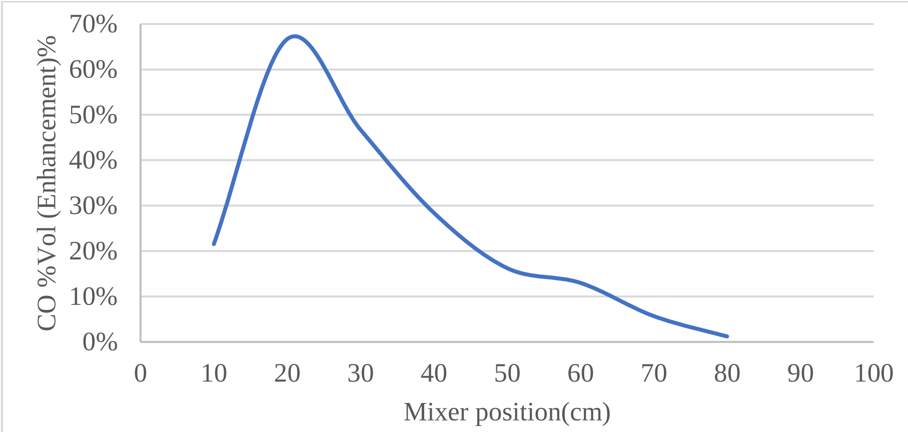

Fig. 5. CO % vol. Enhancement at the various points intakes pipe.

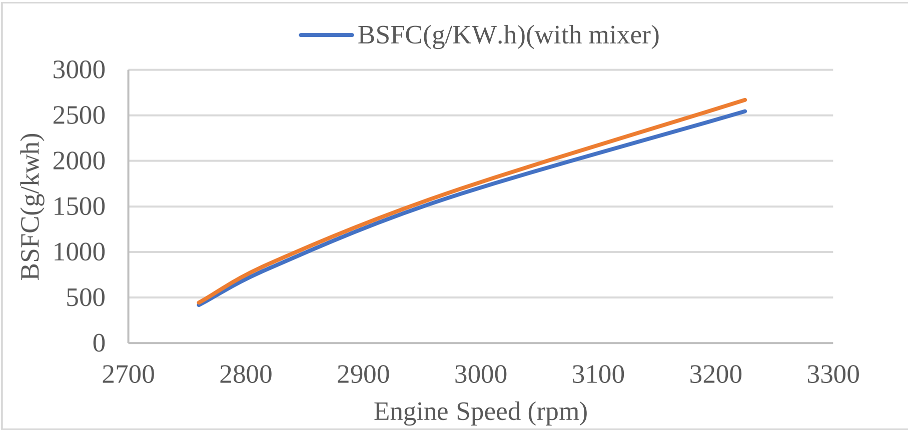

Fig. 6. Effect of different intake manifold configurations on BSFC for various engine speeds.

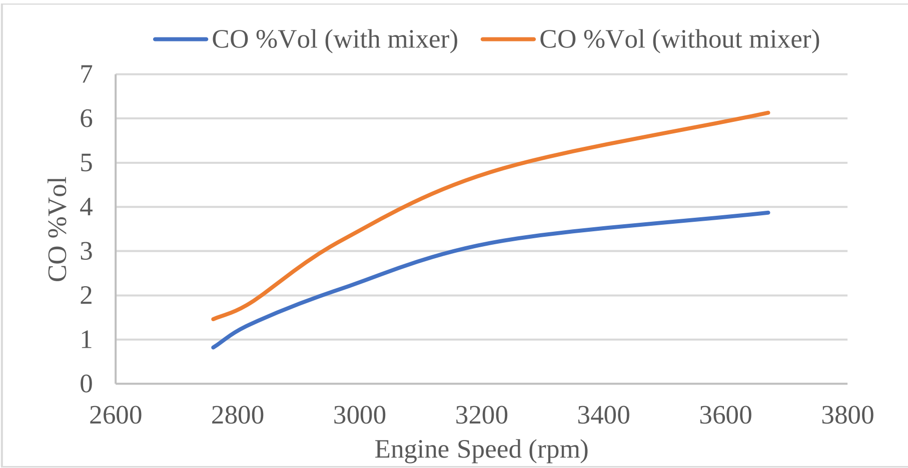

Fig. 7. Effect of different intake manifold configurations on CO emission for various engine speeds.

4.2 Theoretical Results

A higher intake air pressure is preferred to increase air density which allows for better combustion in a shorter time, improve fuel consumption, power output, and reducing of exhaust pollutants level. Fig. 9 demonstrates the turbulence intensity for four models of swirl generators. Based on Fig. 8 model 2 has the greatest turbulence intensity as well as the pressure drop. The higher the turbulence intensity, the higher the pressure drop. In this case, the more efficient model 1can be applied to increase the air pressure entering the combustion chamber which improves the air-fuel mixing process which leads to improving the combustion process.

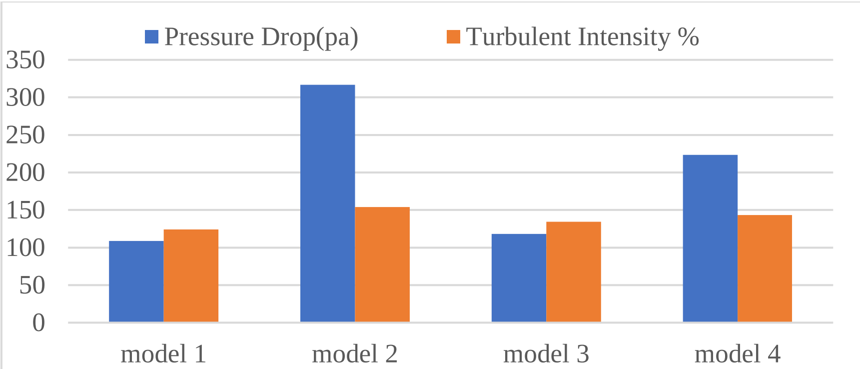

Fig. 8. Pressure drops across the mixer and turbulent intensity created by the mixer for four designs of mixed

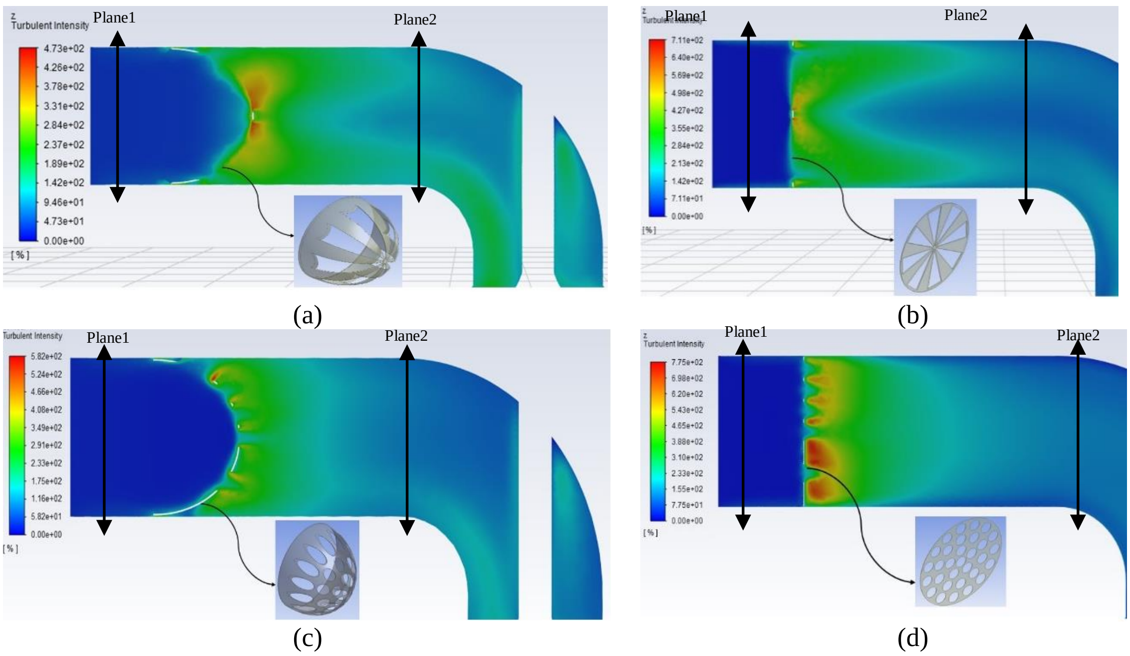

Fig. 9. Visualization of CFD simulations: Turbulence intensity for various shapes of m

5 Conclusion

Based on the experimental and numerical results it can be concluded that:

1- adding a swirl generator to the air intake port can improve the characteristics of the airflow, especially on the pressure and turbulence intensity.

2- Test with an intake port equipped with a swirl generator approved an improvement of fuel consumption and CO emission level.

3- CFD analysis shows that the shape of the swirl generator, blade number, blade area have a significant role in the airflow pattern.

4- CFD analysis can be applied to optimize the intake port of an IC engine.

Nomenclature

ICE	Internal Combustion Engine
SI	Spark Ignition
BSEC	Break specific fuel consumption
CFD	Computing Fluid Dynamic
k-ε	Turbulence model (k: turbulent energy, ε: Turbulent dissipation energy)
CO	Carbon monoxide
Model 1,2,3,4	Figurer (9). a, b, c, d respectively

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