

Review Article

# Review on CFD Analysis of Scavenging Process of Two Stroke Petrol Engine

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## Abstract

This study is based on numerical analysis of scavenging process of two stroke SI engine in two cases i.e. one with existing piston model and another with new piston model. The aim of this analysis is to study the process of scavenging and suggest modifications in order to increase its effectiveness. To simulate and analyze flow through engine three dimensions finite volume method with dynamic meshing is used. The modeling of piston was done in CATIA V5R20 and numerical analysis is performed on CFD Software ANSYS Fluent V 15.0.07.

**Keywords:** CFD, Air-mass fraction, CO<sub>2</sub>-mass fraction, scavenging, k-ε model, FVM, FEM, FDM.

## 1. Introduction

An internal combustion engine which has a power stroke during each revolution of the crankshaft is classified as a two stroke engine. Fig 1 shows a schematic layout of such a two-stroke engine. The simple two stroke engine use crankcase compression for the induction process, while the controlling of the timing and area of the inlet, transfer and exhaust ports are fulfilled by pistons. Depending on the manner of the introduction of fuel, both compression ignition and spark ignition two stroke engines had been developed in the past. The main advantages of two stroke engine over its nearer rival i.e. four stroke engine are its mechanical simplicity, superior power to weight ratio, lower production cost and lower maintenance cost.

The other advantages of two stroke engine are more uniform torque on crankshaft and comparatively less exhaust gas dilution. However, when applied to the spark ignition engine the two stroke cycle has certain disadvantage which have restricted its application to only small engine suitable for automobile, chainsaws, marines etc. in SI engine, the incoming charge consist of fuel and air. During scavenging, as both inlet and exhaust ports are open simultaneously for some time, there is a possibility that some of the fresh charge containing fuel escapes with the exhaust. This results in high fuel consumption and lower thermal efficiency. The other drawback of two stroke engine is the lack of flexibility, viz., the capacity to operate with the same efficiency at all speeds. At part throttle operating condition, the amount of fresh mixture entering the

cylinder is not enough to clear all the exhaust gases and a part of it remains in the cylinder to contaminate the charge. This result in irregular operation of the engine. The efficiency of two stroke engine depend to a great degree on the effectiveness of the scavenging process, since bad scavenging gives a low mean indicate pressure and hence, result in a high weight and high cost per bhp for the engine. The most difficult challenge for two stroke SI engines is the limitation of pollutant emissions without penalizing performance, overall dimensions and production costs.

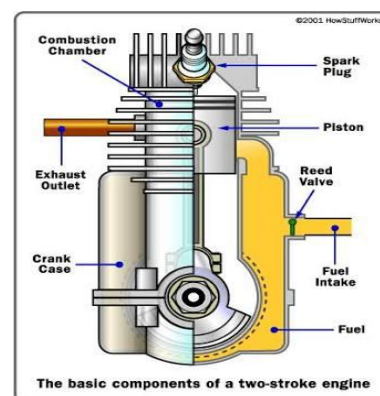


Fig.1 Schematic layout of Two Stroke Engine

## 2. Working

When the piston moves from bottom dead centre to top dead centre, the fresh air and fuel mixture enters the crank chamber through the valve. The mixture enters due to the pressure difference between the

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crank chamber and outer atmosphere. At the same time the fuel-air mixture above the piston is compressed. Ignition with the help of spark plug takes place at the end of stroke. Due to the explosion of the gases, the piston moves downward. When the piston moves downwards the valve closes and the fuel-air mixture inside the crank chamber is compressed. When the piston is at the bottom dead centre, the burnt gases escape from the exhaust port.

At the same time the transfer port is uncovered and the compressed charge from the crank chamber enters into the combustion chamber through transfer port. This fresh charge is deflected upwards by a hump provided on the top of the piston. This fresh charge removes the exhaust gases from the combustion chamber. Again the piston moves from bottom dead centre to top dead centre and the fuel-air mixture gets compressed when the both the Exhaust port and Transfer ports are covered. The cycle is repeated.

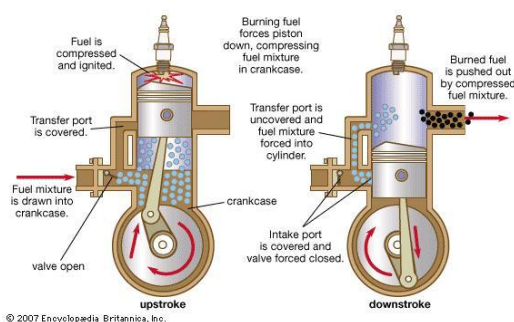


Fig.2 Working of Two Stroke Engine

2.1. Port timing of two stroke si engine

The two stroke engines have inlet and transfer ports to transfer the combustible air fuel mixture and an exhaust port to transfer exhaust gas after combustion. The sequence of events such as opening and closing of ports are controlled by the movements of piston as it moves from TDC to BDC and vice versa. As the cycle of operation is completed in two strokes, one power stroke is obtained for every crankshaft revolution. Two operations are performed for each stroke both above the piston (in the cylinder) and below the piston (crank case). When compression is going on top side of the piston, the charge enters to the crank case through inlet port. During the downward motion, power stroke takes place in the cylinder and at the same time, charge in the crank case is compressed and taken to the cylinder through the transfer port. During this period exhaust port is also opened and the fresh charge drives away the exhaust which is known scavenging. As the timing plays major role in exhaust and transfer of the charge, it is important to study the events in detail. The pictorial representation of the timing enables us to know the duration and instants of opening and closing of all the ports. Since one cycle is completed in one revolution i.e. 360 degrees of crank revolution, various positions are shown in a single circle of suitable diameter.

In two stroke engine ports are used in place of valve therefore it is called as port timing diagram

- 1) Inlet port: Inlet port opens 35° to 50° prior to TDC position which closes in the same amount after TDC place.
- 2) Exhaust port: Exhaust port open at 35° before BDC and closes 70° after BDC.
- 3) Transfer port: Transfer port opens 35° to 60° in proceed to BDC place and closes 35° to 60° after TDC place.
- 4) Ignition: Ignition takes place with Spark by 15° to 20° before TDC place as charge require for a while to ignite. It can be noted to the exhaust & transfer port open & close at the same angle on also side of BDC place.

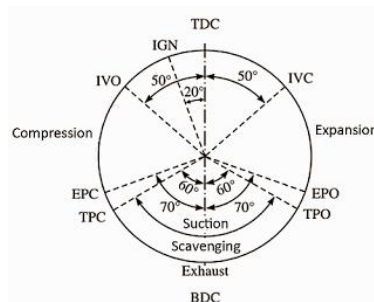


Fig. 3 Port Timing Diagram of Two Stroke Engine

3. Scavenging process

The scavenging process is the air exchange process of the engine where the burned gas is replaced with fresh air which is compressed and used for the combustion process in the next cycle. Fig.4 illustrates three theoretical processes.

A. Perfect scavenging : Ideally the fresh fuel air mixture should remain separated from the residual product of combustion with respect to both mass and heat transfer during the scavenging process, i.e., when delivery ratio > r/r-1, it is not retained).

B. Short circulating: The second type of scavenging process is that of short circuiting in which the fresh charge coming from the scavenge manifold directly goes out of the exhaust ports without removing any residual gas. This is a dead loss and its occurrence must be avoided.

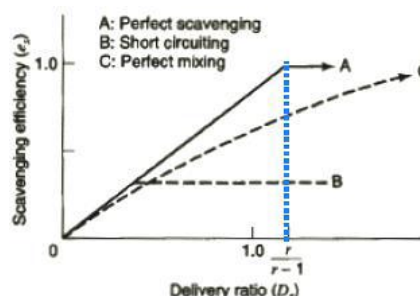


Fig. 4: Three theoretical Scavenging Process

C. Perfect mixing : In perfect mixing, the incoming fresh charge mixes completely and instantaneously with the cylinder contents, and a portion of this mixture passes out through the exhaust ports at a rate equal to that of the charge entering the cylinder. This homogeneous mixture consists initially of product of combustion only and then gradually changes to pure air. For the case of perfect mixing the scavenging efficiency can be represented by the following equation

$$\eta_{sc} = 1 - e^{-R_{del}}$$

### 3.1 Scavenging parameter

A. Delivery ratio ( $R_{del}$ ): The delivery ratio represents the ratio of the air volume, under the ambient condition of the scavenge manifold, introduced per cycle and a reference volume.

Delivery ratio,

$$R_{del} = \frac{V_{del}}{V_{ref}}$$

The delivery ratio on mass basis according to it, the delivery ratio is mass of fresh air delivered to the cylinder divided by a reference mass, i.e.

$$R_{del} = \frac{M_{del}}{M_{ref}}$$

Thus the delivery ratio is measured as air supply to the cylinder relative to the cylinder content. If  $R_{del} = 1$ , it means that volume that the scavenging that supply to the cylinder is equal to cylinder volume. Delivery ratio usually varies between 1.2 to 1.5 except for closed crank case scavenge where it is less than unity.

B. Scavenging efficiency: Scavenging efficiency is defined as the ratio of the volume the scavenge air which remains in the cylinder at the end of the scavenging to the volume of the cylinder itself at the moment when the scavenge and exhaust ports of the valves are fully closed. It is given by

$$\eta_{sc} = \frac{V_{ret}}{V_{ch}} = \frac{V_{ret}}{V_{ret} + V_{res}}$$

Scavenging efficiency indicates to what extent the residual gases in the cylinder are replaced with fresh air. If it is equal to unity, it means that all gases existing in the cylinder at the beginning of scavenging have been swept out completely.

C. Relative cylinder charge: Relative cylinder charge is a measure of the success of filling the cylinder irrespective of the compression of charge and is defined as

$$C_{ret} = \frac{V_{ch}}{V_{ref}} = \frac{V_{ret} + V_{res}}{V_{ref}}$$

The relative cylinder charge may be either more or less than unity depending upon the scavenging pressure and the port heights. It must be noted that all volumes referred to are at NTP condition. However,

recommends the use of inlet temperature and exhaust pressure as the reference. It can be shown that the delivery ratio, scavenging and trapping efficiency are related by the following equation

$$R_{del} = \frac{C_{ret} * \eta_{sca}}{\eta_{trap}}$$

D. Charging efficiency: The amount of fresh charge in the cylinder is a measure of the power output of the engine. The useful fresh charge divided by and the displacement volume is the charging efficiency defined as

$$\eta_{ch} = \frac{V_{ret}}{V_{ref}}$$

Charging efficiency is a measure of the success of filling the cylinder with fresh air. Naturally

$$\eta_{ch} = R_{del} * \eta_{trap}$$

E. Pressure loss coefficient (PI): The pressure loss coefficient is the ratio between the main upstream and downstream pressure during the scavenging period and represents the loss of pressure to which the scavenging air is subjected when it crosses the cylinder.

F. Excess air factor ( $\lambda$ ): The valve ( $R_{del} - 1$ ) is called the excess air factor  $\lambda$ . For example, if the delivery ratio is the excess air factor is 0.7. [1]

## 4. Computational Fluid Dynamics

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. CFD provides numerical approximation (called discretization) to the equations that govern fluid motion. Application of the CFD to analyze a fluid problem requires the following steps. First, the mathematical equations describing the fluid flow are written. These are usually a set of partial differential equations. These equations are then discretized to produce a numerical analogue of the equations. The domain is then divided into small grids or elements. Finally, the initial conditions and the boundary conditions of the specific problems are used to solve these equations. The solution method can be direct or iterative. In addition, certain control parameters are used to control the convergence, stability and accuracy of the method.[3] With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial experimental validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

All CFD codes contain three main elements:

- 1) A pre-processor, which is used to input the problem geometry, generate the grid, define the flow parameter and the boundary conditions to the code.
- 2) A flow solver, which is used to solve the governing equations of the flow subject to the conditions provided. There are four different methods used as flow solver:
  - (a) Finite volume method
  - (b) Finite element method
  - (c) Finite difference method
  - (d) Spectral method
- 3) A post-processor, which is used to massage the data and show the results in graphical and easy to read format.<sup>[3]</sup>

#### 4.1. Techniques for Numerical Discretization

In order to solve the governing equations of the fluid motion, first their numerical analogue must be generated. This is done by a process referred to as discretization. In the discretization process, each term within the partial differential equation describing the flow is written in such a manner that the computer can be programmed to calculate.<sup>[3]</sup> The space, where the flow is to be computed - the physical space, is divided into a large number of geometrical elements called grid cells. This process is termed grid generation (some authors use the term mesh with identical meaning). It can also be viewed as placing first grid points (also called nodes or vertices) in the physical space and then connecting them by straight lines - grid lines. The stability of the chosen discretization is generally established numerically rather than that of analytically as with simple linear problems. Special care must also be taken to ensure that the discretization handles discontinuous solutions gracefully. The Euler equations and Navier–Stokes equations both admit shocks, and contact surfaces.<sup>[10]</sup> There are various techniques for numerical discretization. Here we will introduce three of the most commonly used techniques, namely:

- (4.1.1) Finite volume method
- (4.1.2) Finite element method
- (4.1.3) Finite difference method
- (4.1.4) Spectral method

4.1.1. Finite volume method: The finite volume method (FVM) is a common approach used in CFD codes, as it has an advantage in memory usage and solution speed, especially for large problems, high Reynolds number turbulent flows, and source term dominated flows (like combustion). In the finite volume method, the governing equations partial differential equations (typically the Navier-Stokes equations, the mass and energy conservation equations, and the turbulence equations) are recast in a conservative form, and then solved over discrete control volumes. This

discretization guarantees the conservation of fluxes through a particular control volume. The finite volume equation yields governing equations in the form,

$$\frac{\partial}{\partial t} \iiint Q \, dV + \iint F \, dA$$

where  $Q$  is the vector of conserved variables,  $F$  is the vector of fluxes (see Euler equations or Navier–Stokes equations),  $V$  is the volume of the control volume element, and  $A$  is the surface area of the control volume element.

4.1.2. Finite element method: The finite element method (FEM) is used in structural analysis of solids, but is also applicable to fluids. However, the FEM formulation requires special care to ensure a conservative solution. The FEM formulation has been adapted for use with fluid dynamics governing equations. Although FEM must be carefully formulated to be conservative, it is much more stable than the finite volume approach. However, FEM can require more memory and has slower solution times than the FVM. In this method, a weighted residual equation is formed

$$R_i = \iiint W_i Q \, dV^e$$

Here,  $R_i$  is the equation residual at an element vertex  $i$ ,  $Q$  is the conservation equation expressed on an element basis,  $W_i$  is the weight factor, and  $V^e$  is the volume of the element.

4.1.3. Finite difference method: The finite difference method (FDM) has historical importance and is simple program. It is currently only used in few specialized codes, which handle complex geometry with high accuracy and efficiency by using embedded boundaries or overlapping grids (with the solution interpolated across each grid).

$$\frac{\partial Q}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} + \frac{\partial H}{\partial z} = 0$$

where  $Q$  is the vector of conserved variables, and  $F$ ,  $G$  and  $H$  are the fluxes in the  $x$ ,  $y$ ,  $z$ . Once the basic performance of two-stroke engines was described, the methodology to simulate the scavenging process will be treated in this section.

4.1.4 Spectral Methods: Another method of generating a numerical analog of a differential equation is by using Fourier series or series of Chebyshev polynomials to approximate the unknown functions. Such methods are called the Spectral method. Fourier series or series of Chebyshev polynomials are valid throughout the entire computational domain. This is the main difference between the spectral method and the FDM and FEM, in which the approximations are local. Once the unknowns are replaced with the truncated series, certain constraints are used to generate algebraic

equations for the coefficients of the Fourier or Chebyshev series. Either weighted residual technique or a technique based on forcing the approximate function to coincide with the exact solution at several grid points is used as the constraint. For a detailed discussion of this technique refer to Gottlieb and Orzag.<sup>[9]</sup>

## 5. Literature review

In developed and developing countries considerable emphasis is being laid on the minimization of pollutants from internal combustion engine. A two stroke cycle engine produces a considerable amount of pollutant when gasoline is used as a fuel due to short-circuiting. There is strong need to develop a kind of new technology which could minimize pollution from these engines. One of the techniques was direct fuel injection. Direct fuel injection has been carbon emission by timing the injection of fuel in such a way as to prevent escape of unburned fuel from the exhaust port during scavenging process. Many techniques have been followed by researchers to conduct the performance analysis of two stroke petrol engine employed in various parameters.

G. Ciccarelli *et al.* the novelty of engine lies in the cylinder head that contains multiple check valves that control scavenging airflow into the cylinder from a supercharged air plenum.

Deepak Bharadwaj *et al.* two stroke engine was developed to obtain a greater output from same size of engine. The engine mechanism eliminates the valve arrangement making mechanically simpler. Theoretically a two stroke engine developed twice the power of a comparable four stroke engine, thus making it more compact.

S.Kumarappa *et al.* direct injection system was developed which eliminates short circuiting losses completely and injection timing was optimized for the best engine performance and lower emission.

S.Gavudhama *et al.* develop a dome headed piston profile of two stroke 200 cc SI engine to improve the scavenging efficiency from 45.03 for flat headed piston to 49.3% for dome headed piston.

Rosli Abu Bakar *et al.* develop the scavenging profile with respect to the variation of speed of engine and find that that the profile for 5000rpm is considered good scavenging as more fuel in the cylinder. Assumption is made that flow analyzed until scavenging and combustion will not be included.

Ashish D. Sonparate *et al.* applied external vaporized carburetor which works on adiabatic vaporization of liquid gasoline fuel before introducing into the engine cylinder. This will improve engine efficiency and reduction in exhaust emission. When vaporized carburetor is used, it attributed to degree of turbulence which improves vaporization & mixing of fuel and air and it eliminates fuel droplet in the cylinder

Ramesh B.Poola *et al.* develop an optimal design for two stroke engine by applying two extra reed valve at transfer ducts, with an optimal secondary air flow through the reed valves. They apply copper catalyst in combustion chamber and high compression ratio of 9:1 and lean fuel air mixture (A/F=13.0 to 17.5 ). With this design the absolute brake thermal efficiency increases from 14.6 to 22.1% at 1.5 Kw, 2000rpm and from 17.7 to 23.3% at 2 Kw,3000rpm.

Pavan Kumar P.K. *et al.* taguchi method to be efficient technique for quantifying the effect of control parameters. The highest performance at se 4.555 A/F ratio, engine load 7.5 and 0.724 Kg/hr TFC for new carburetor where as for old carburetor results are 2.395 A/F ratio, load 8.2 Kg and 0.9054 Kg/hr TFC, which are optimum parameter setting for highest brake thermal efficiency. And % CO and ppm of HC is reduced by using variable carburetor system in both optimization and without optimization techniques.

Karthik Dhayakar *et al.* experimental study confirms that Two stroke engines have a good potential if dual spark plug technology is employed. Applying the dual spark plug in two stroke gasoline engine combustion process have improved hence efficiency of the engine is improved. Less fresh charge will move out in the scavenging process by applying the dual spark plug. It means scavenging process have been improved. On applying the dual spark plug in two Stroke Gasoline engine the problem of fuel economy will also be improved due to proper combustion inside the cylinder. More power can be generated from the same size engine by employing dual spark plug its mean improvement in power without changing the fuel input.

Abhishek Chakraborty *et al.* does experiment on the basis of variation in carburetor main-jet diameter and find that for better fuel consumption by which we get good average At 5 kg Load the minimum time taken for 5 cc. consumption of fuel is 58:60 (second: mili sec.) at 232 engine RPM in 4th gear in main jet size 90 compare to other. To get more RPM at 5 kg. Load the minimum time taken for 5 cc. consumption of fuel is 28:12 (second: mili sec.) at 528 engine RPM in 4th gear in main jet size 85 in compare to other.

## Conclusions

As two stroke engines are being replaced by four stroke engines because of inefficiency and more exhaust emission of pollutants, it can be reduced to some extent by improving scavenging of two stroke engine. This will be easily done with the help of software such like ANSYS Fluent, Catia etc. It helps in generating & analyzing relevant data without any experimental setup so project cost reduces tremendously. In the present work an optimal design

for the two stroke SI engine is being developed by incorporating the various changes to the piston crown of the two stroke engine. This method helps to improve scavenging and combustion process. Various modifications to the two stroke SI engine and use of latest concepts have resulted in widely varying improvements in the fuel economy and exhaust emissions. The optimal design can be evolved by incorporating only those modifications that give the maximum results with regard to brake thermal efficiency and exhaust emissions for various methods investigated.

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