“MODELLING OF ROTARY FUEL INJECTOR TO ENHANCE SWIRL & TURBULENCE IN COMBUSTION CHAMBER”

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TO WHOMSOEVER IT MAY CONCERN

This is to certify that, **Mr. Ashutosh Kaushal (R140206012)**, **Mr. Kunal Dutt (R140206028)** and **Mr. Rizwan Akhtar Ansari (R140206048)**, bachelor students of Automotive Design Engineering, University of Petroleum & Energy Studies, have worked on **"MODELLING OF ROTARY FUEL INJECTOR TO ENHANCE SWIRL & TURBULENCE IN COMBUSTION CHAMBER"**. They have successfully completed the project for fourth year at University of Petroleum & Energy Studies, Dehradun (Uttarakhand).

Their contribution in the project is significant and useful to us. I wish for their best future.

Sharma

Mr. PANKAJ KUMAR SHARMA

M-Tech (Mechanical), Assistant Professor

DECLARATION

We, **Mr. Ashutosh Kaushal (R140206012), Mr. Kunal Dutt (R140206028) and Mr. Rizwan Akhtar Ansari (R140206048),** students of B-Tech (Automotive Design Engineering), University of Petroleum & Energy Studies, Dehradun hereby declare that the dissertation entitled **"MODELING OF ROTARY FUEL INJECTOR TO ENHANCE SWIRL & TURBULENCE IN COMBUSTION CHAMBER"** embodies the report of our project work carried out at 'University of Petroleum & Energy Studies, Dehradun' under the guidance of **Mr. Pankaj Kumar Sharma, M-Tech(Mechanical)** Assistant Professor. This work has been submitted for the partial fulfillment of the requirement for the award of the honorable degree 'Bachelor of Technology in Automotive Design Engineering'.

Date: May13,'2010

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We offer our kind regards to our peers and friends and to all of those who have supported us in any respect to improve the quality of our work.

ABSTRACT

Fuel injector is an important component of the fuel injection system assembly. A good and sophisticated design of the fuel injector helps in proper mixing of fuel and air to form an optimum combustible mixture and also facilitates the precise and timely injection of fuel into the engine cylinder for proper initiation of combustion process leading to reduction in emissions.

In our dissertation, we have highlighted the working of a normal fuel injection system with the help of a working model consisting of a fuel pump that can be driven with the help of motor and mechanical injector assembly. Various factors involved in proper selection of an injector are also mentioned. Also, modeling of Rotary Fuel Injector is described with the help of a software model and its analysis is done under some boundary conditions prevailing at the time of injection such as pressure of fuel at the nozzle, temperature of combustion chamber etc. Iterations were done in order to show the variation of various parameters with respect to each other with the help of ANSYS software. The results are being displayed in the form of pictures, graphs etc.

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ABBREVIATIONS

ATDC	after top dead center
BMEP	break mean effective pressure
BTDC	before top dead center
CAI	controlled auto-ignition
CFD	computational fluid dynamics
CI	compression ignition
CN	cetane number,
CR	compression ratio, common rail
DI	direct injection
DISI	direct injection spark ignition
GDI	gasoline direct injection
HCCI	homogeneous charge compression ignition
Re	Reynolds number
SOC	start of combustion
SR	swirl ratio
VCO	valve covered orifice
VVT	variable valve train
We	Weber number
Z	Ohnesorge number

1.0 LITERATURE REVIEW

1.1 Introduction to Fuel System

Fuel injection system forms an integral component in the operation of CI engines. The effective operation of the fuel-injection system determines the important parameters of engine performance like power output, economy etc. The crucial tasks of initiating and controlling the combustion process are performed by the fuel-injection system.

1.2 Components of Fuel-Injection System

The fuel-delivery system incorporates the following components:

1. Fuel tank
2. Fuel pump
3. Fuel inline filter
4. Fuel rail(fuel delivery pipe)
5. Fuel injectors
6. Fuel pressure regulator
7. Fuel return pipe

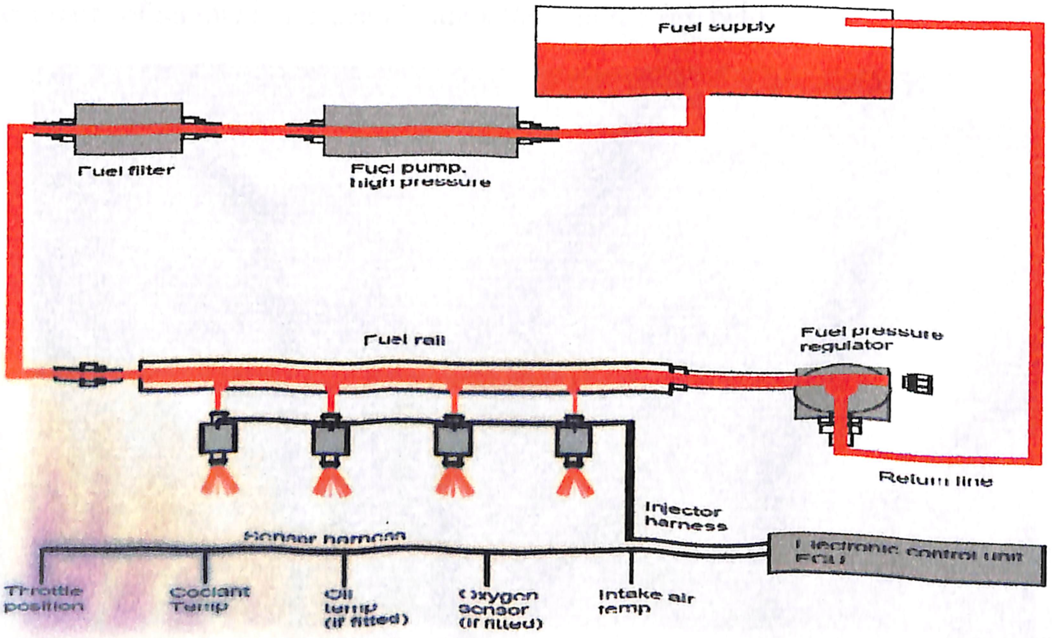


Fig.1.2 Components of Fuel Injection System Assembly

Fuel in the fuel tank is pumped by an electronic/mechanical fuel pump controlled by the circuit open relay. Fuel flows through high pressure fuel lines to fuel filter. Here, the accumulated fuel is purified. Fuel then reaches the fuel rail up to the pressure regulator where it remains under pressure. Fuel is maintained at a specified pressure just above the intake manifold pressure leading to a constant pressure drop regardless of engine load across all fuel injectors. A pulsation damper absorbs the pressure variations in the fuel rail caused due to opening and closing of injector nozzle. It is used in some engines and is mounted to the fuel rail. The fuel in the fuel rail is supplied to the injectors and is injected into the cylinders at high pressure. The excess fuel utilized during engine operation is returned back to the fuel tank through low pressure fuel lines. The fuel circuit continues to rotate in similar fashion.

1.3 Fuel Injector

Fuel injector is an electro-mechanically operated device, which is fed by 12V power supply either by the fuel injection relay or ECU (Electronic Control Unit). A sophistically designed fuel injector ensures quick and complete combustion inside the engine cylinder. It also helps in increasing the surface area of the fuel droplets leading to better mixing by atomization of fuel into very fine droplets. Atomization is achieved by pressurizing the fuel through small orifice. The fuel utilized by the injector is supplied by the common fuel rail. ECM controls the injector pulse width by monitoring the input signals from various engine sensors and also gets varied for cold engine starting problems and warm-up periods.

The typical parts of an injector assembly are shown in the fig. below

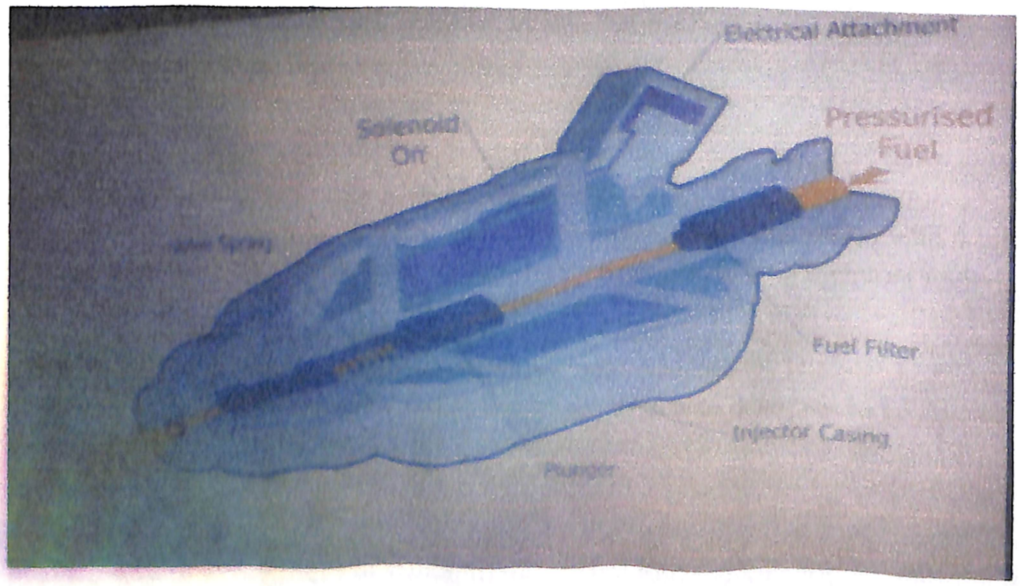


Fig.1.3 Electromagnetic Fuel Injector

When the ECM provides ground to the injector, circuit gets completed and current starts to flow into the injector. This results in energizing of electromagnetic coil (solenoid) inside the injector. The energizing of the coil results in lifting of nozzle valve from its seat and fuel is sprayed into the combustion chamber in a finely atomized particle. The degree of atomization of the fuel injected into the combustion chamber depends upon the geometry of the nozzle of the injector and the amount of swirl or turbulence generated during the injection of fuel spray.

1.4 Fuel Injector Selection

(i) **BSFC (Brake Specific Fuel Consumption)**: It is the quantity of fuel required to generate 1HP of power for 1 hour. The value of BSFC should be known, so as to know what size of injectors is needed.

$$\text{BSFC} \times \text{Peak HP} = \text{lbs/hr}$$

Example: for naturally aspirated engines BSFC is 0.45, if maximum HP generated by an engine, say, Maruti800, is 37hp then as per above relation

$$0.45 \times 37 = 16.65 \text{ lbs/hr}$$

Hence, the injectors are so designed to be able to flow 16.65 lbs/hr to maintain 37hp.

(ii) **Horsepower**: Injectors are designed for a specific application. As per application, there are various sizes of injectors with high flow rate per hour are available. For example; how much horse power the injector can support can be calculated as:

$$\text{HP} = (\text{lbs/hr} \times \text{No. of injector} \times \text{DC}) / \text{BSFC}$$

Where; HP= Peak Horse Power
Lbs/hr= injector flow rate
DC= injector duty cycle
BSFC= Brake Specific Fuel Consumption

Example: let's suppose we have a 4 cylinder engine generating 90hp, with 4 injectors (1 injector per cylinder). We require 80% duty cycle for all the injectors with BSFC=0.45, then as per above relation

$$(90 \times 0.45) / (4 \times 80) = 3.375 \text{lbs/hr}$$

Hence, those injectors are selected or the injectors are so designed to be able to flow 3.375lbs/hr while maintaining 90hp.

(iii) **Fuel pressure**: Fuel pressure is generated by the fuel pump that supplies the fuel under pressure to the fuel rail which in turn is fed into the injector. By altering the fuel pressure, we can change the flow rate of the injector.
Example: if we require 20lbs/hr of fuel flow rate and there is an injector that is capable of producing 18lbs/hr while working at 85% duty cycle, say, then it is possible to use more fuel pressure in order to make the injectors flow more, while maintaining small size of the injector.

1.5 Injector Nozzle

Nozzle forms a very important part of the injector assembly. It is that part of an injector assembly which sprays the liquid fuel into the engine cylinder for further combustion process to take place. A sophistically designed injector nozzle performs following functions:

(i) One of the crucial functions performed by the nozzle is proper atomization of injected fuel into the cylinder so that optimum mixing of fuel and air can be obtained for better combustion.

(ii) Proper circulation or distribution of injected fuel to the required areas within the combustion chamber for proper combustion. Proper distribution of fuel inside the combustion chambers depends upon various factors like injection pressure, density of air in the cylinder and fuel properties.

(iii) The nozzle should be able to prevent the fuel from striking on the walls of the combustion chamber or surface of piston directly. This helps in preventing smoky exhaust that is caused because of fuel particles hitting the walls decomposes resulting in production of carbon deposits.

(iv) In order to form correct burning mixture, the nozzle helps in mixing of fuel and air especially in case of non-turbulent type of combustion chamber.

Nozzle geometries are so designed to enhance swirl flow inside the combustion chamber. Swirl motion is the organized rotation of charge about cylinder axis and is generated by the angular momentum of intake air. The swirl generated depends on the type of nozzle used for fuel injection. In CI engines generally following types of nozzles are used:

(i) Pintle Nozzle
(ii) Single hole nozzle
(iii) Multi-hole nozzle
(iv) Pintaux

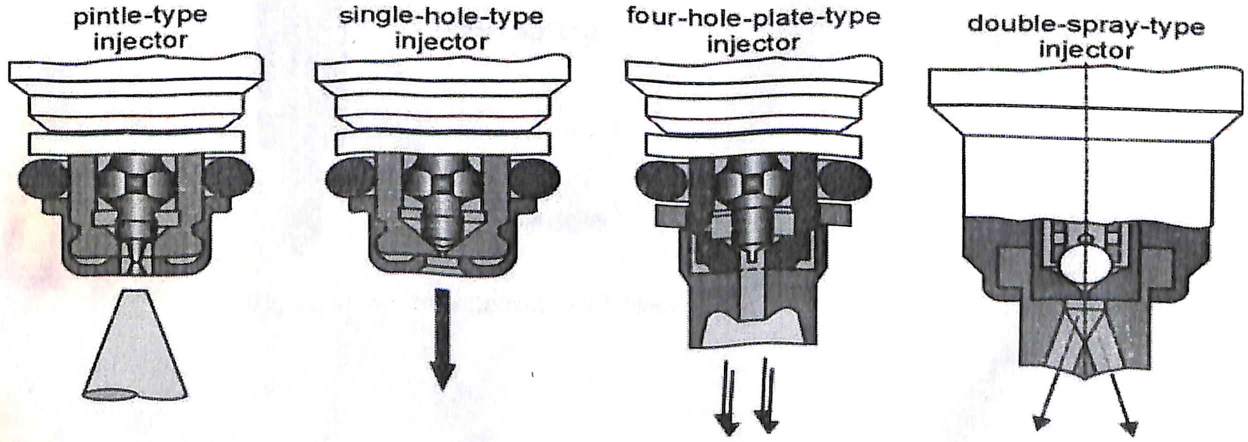


Fig.1.5 Typical Design of Injector Nozzle, Classified by the Spray Shape

1.6 Direct Injection Diesel Engines

The task of the injection system is to achieve a high degree of atomization in order to enable sufficient evaporation in a very short time and to achieve sufficient spray penetration in order to utilize the full air charge. The fuel injection system must be able to meter the desired amount of fuel, depending on engine speed and load, and to inject that fuel at the correct time and with the desired rate. Further on, depending on the particular combustion chamber, the appropriate spray shape and structure must be produced.

Usually a supply pump draws the fuel from the fuel tank and carries it through a filter to the high-pressure injection pump. Dependent on the area of application and engine size, pressures between 100 and 200 MPa are generated. The high pressure injection pump carries the fuel through high-pressure pipes to the injection nozzles in the cylinder head. Excess fuel is transported back into the fuel tank.

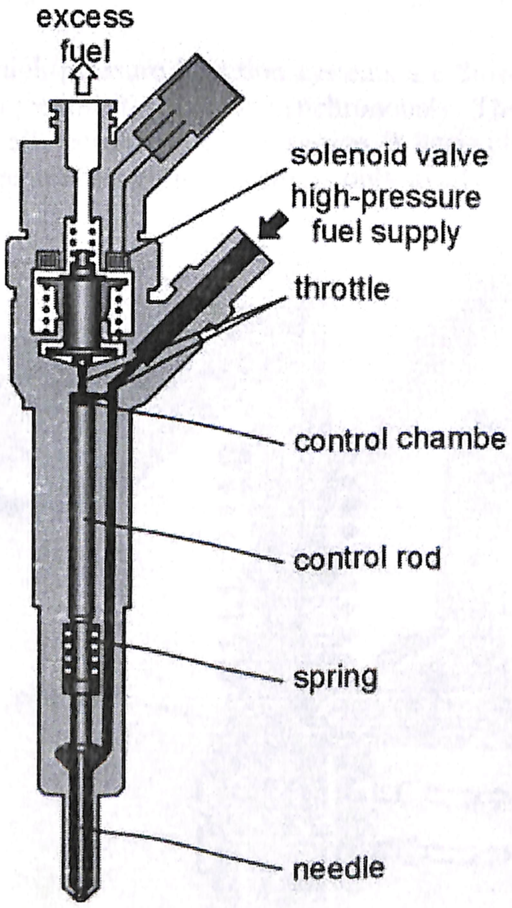


Fig.1.6 (i) A Typical Common Rail Injector

Today, two main groups of high-pressure injection systems exist. Concepts belonging to the first one are the so-called common rail injection systems. Here, pressure generation and the injection event are not coupled, and the injection pressure is not dependent on engine speed. Compared to the injection systems that are driven by a camshaft, this enables a significantly greater flexibility of injection and mixture formation. Fuel under high pressure is stored inside the rail, which usually consists of a thick-walled closed pipe. A high-pressure fuel pump continuously feeds the rail. A pressure sensor adjusts the desired rail pressure via an additional valve that controls the mass flow of excess fuel back to the fuel tank. Hence, the rail pressure is not dependent on engine speed, and an optimal adjustment to the actual operating point of the engine can be achieved. Short pipes connect the rail with the injectors.

The volume of the rail is large enough to suppress pressure fluctuations due to injection. Injection timing and duration are controlled by solenoid valves and are independent of the pressure generation. Hence, the common rail injection system is capable of keeping the injection pressure at the desired level and of performing pre-injections (reduction of noise and nitric oxides), main injections, and post injections (reduction of soot raw emissions, heating of catalysts) with variable duration and timing according to the demands of the actual operating point.

The second main group of high-pressure injection systems are those in which the generation of injection pressure and the injection itself occur synchronously. These systems are driven by a camshaft, which is mechanically coupled with the engine. A basic characteristic of these systems is the intermittent pressure generation high pressure is only available during a small crank angle interval.

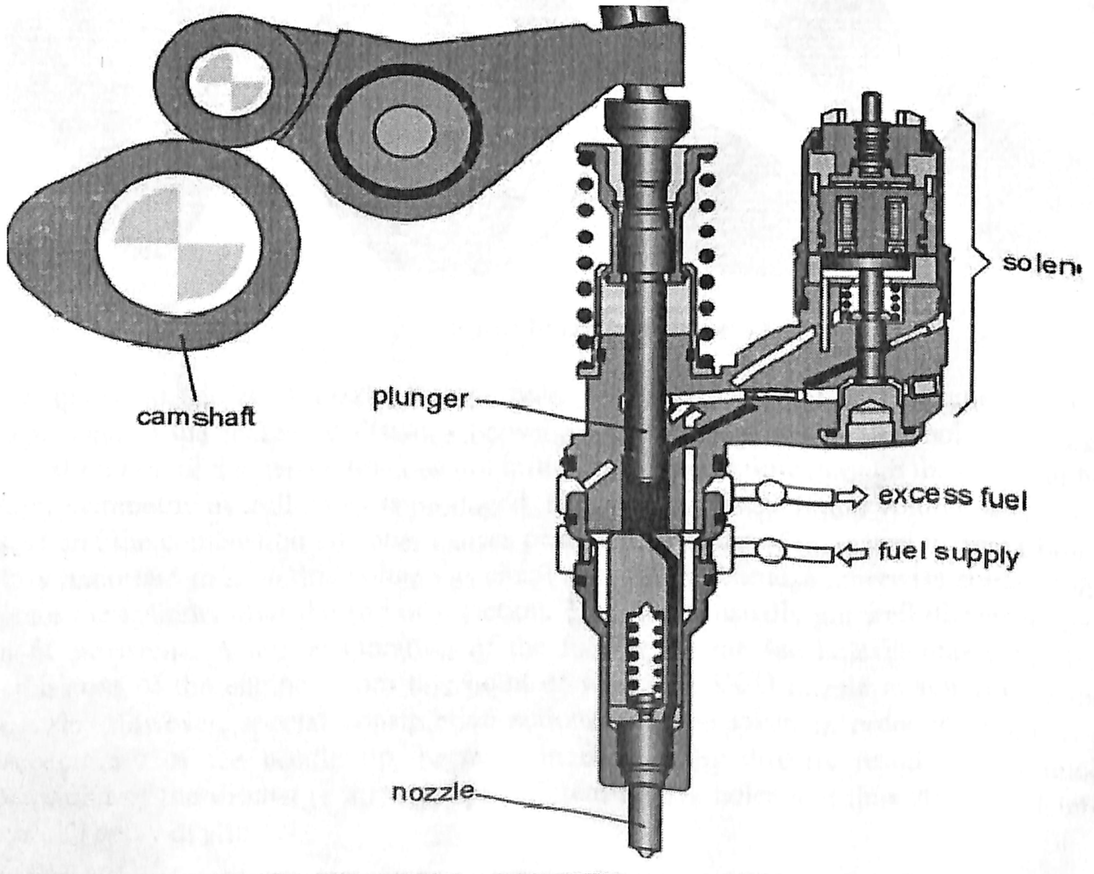


Fig.1.6 (ii) Unit Injector

In the case of the so-called unit injector system (UIS), the pump and the injection nozzle are combined into a single unit. Each cylinder of the engine is equipped with such a unit, which is driven by the cam via a rocker arm for example. The omission of the high-pressure pipes between the pump and the injector allows significantly higher peak injection pressures (about 200 MPa and more) than in the case of the unit pump system.

1.7 Types of Nozzle

The most important part of the injection system is the nozzle. The fuel is injected through the nozzle holes into the combustion chamber. The number and size of the holes depends on the amount of fuel that has to be injected, the combustion chamber geometry, and the air motion (swirl) inside the cylinder. In direct injection diesel engines, two main nozzle types, the sac hole nozzle and the valve covered orifice nozzle (VCO), are used.

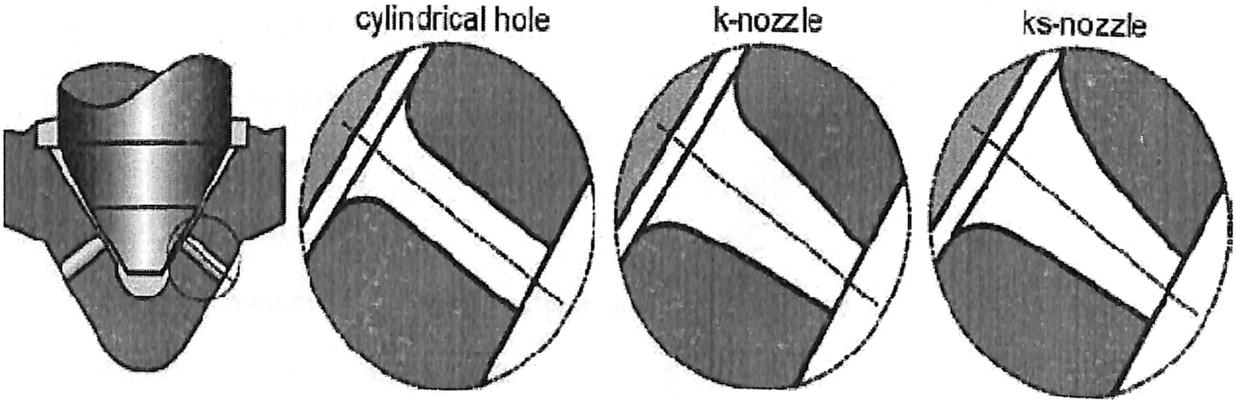


Fig.1.7 Nozzle hole geometries

Compared to the VCO nozzle, the sac hole nozzle has an additional volume below the needle seat. Due to the increased distance between needle seat and injection hole, an eccentricity or radial motion of the needle tip does not influence the mass flow through the different holes, and a very symmetric overall spray is produced. However, the large liquid volume between the needle seat and the combustion chamber causes problems in terms of increased hydrocarbon emissions. It is important to keep this volume as small as possible, because otherwise some of this fuel can enter the cylinder after the end of injection. This fuel is usually not well dispersed and increases soot emissions. A late evaporation of the fuel inside the sac hole increases the hydrocarbon emissions of the engine. From this point of view, the VCO nozzle is superior to the sac hole nozzle. However, special constructive actions must be taken in order to suppress any radial eccentricity of the needle tip, because an eccentricity directly results in an uncontrollable variation of the discharge through the different nozzle holes and thus strongly deteriorates the overall spray quality.

- When the fuel exits from the nozzle orifice, it exits with a very high velocity of the order of 400-500 m/s. The value of the fuel jet velocity depends on the inlet pressure of fuel to injector (p_{inj}), pressure of charge inside the cylinder during combustion (p_{cyl}), the density of the driving fuel (ρ_f) and coefficient of discharge from the nozzle orifice(C_d). The equation for the relation is:

$$V_f = C_d \sqrt{2 (p_{inj} - p_{cyl}) / \rho_f}$$

- The quantity of fuel to be metered for injection per cycle depends upon the power output of the engine. Various other factors that affect the volume of fuel to be injected are the nozzle orifice area, time of one injection, fuel jet velocity and the number of injections per second for one orifice. The relation is given as:

$$Q = (\pi/4 \times d^2 \times n) \times V_F \times (\theta/360 \times 60/N) \times (N_i/60)$$

Where; Q= volume of fuel injected per second, m^3/s

d= diameter of one orifice, m

n= number of orifices

V_F= fuel jet velocity, m/s

θ= injection duration as per crank angle, in degrees

N_i= no. of injections per minute, m^3/s

2.0 SPRAY FORMATION

2.1 Process of Formation of Charge

2.1.1 Liquid jet break-up regimes

The two parameters which govern the different breakup mechanism are relative velocity & the property of liquid & surrounding medium. First point droplet formation & distance between the nozzles characterized the break-up length for different break up mechanism.

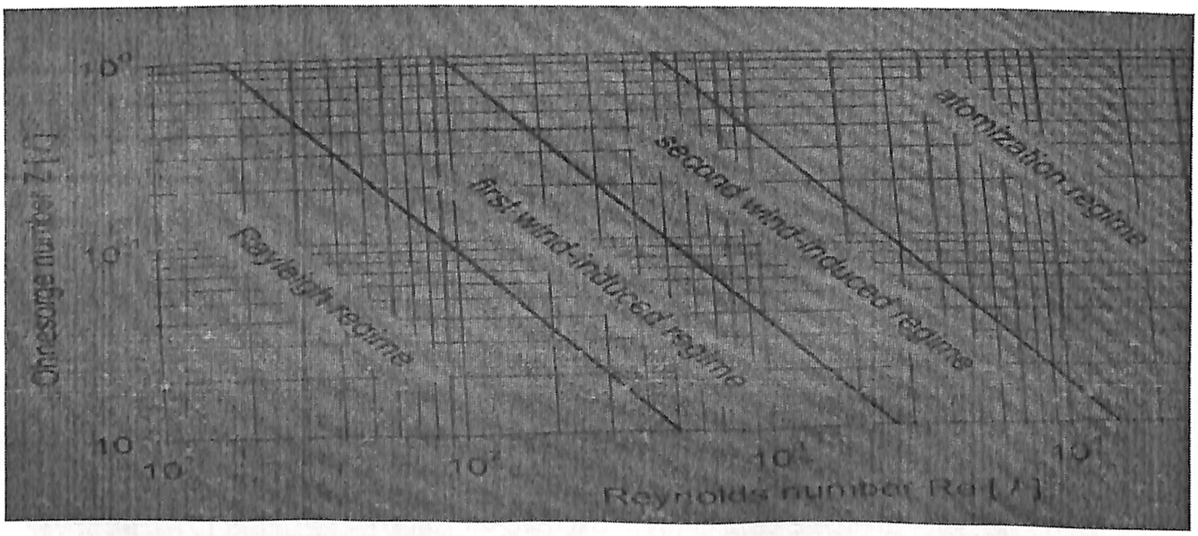
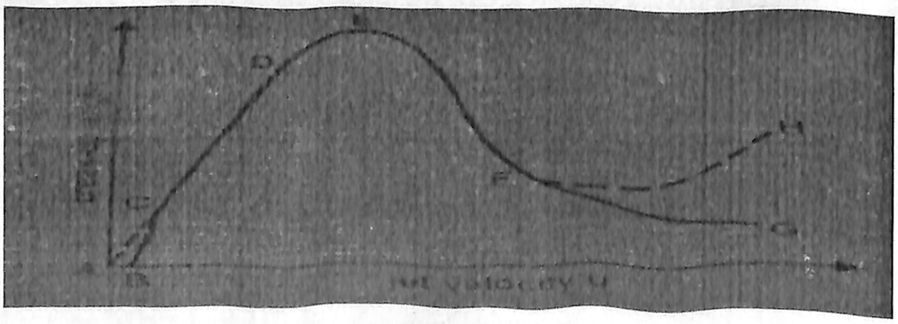


Fig2.1.1 (i) Reynolds's Number plot

$$Z = \frac{\sqrt{We_l}}{Re} = \frac{\mu_l}{\sqrt{\sigma \rho_l D}},$$



2.1.1 (ii) Surface of jet break up

From the above fig.

(i) Dripping occurs at low velocities & avoid the continuous jet formation. With the increase in velocity a layer of continuous jet forms. It is called Rayleigh regime. Oscillation of the jet core causes the break up. Formation of droplets takes place and get separate from the jet.

(ii) As the jet velocity increase breakup reduces, but droplet size is still more than nozzle hole diameter. In the first wind induced regime, aerodynamics comes into effect causing a change in various forces.

(iii) During second wind induced regime, flow inside the nozzle hole becomes more random and unpredictable. Reason for the jet break up is jet turbulence & increased aerodynamic effect due to a large difference between velocity of gas & jet.

(iv) Diameter of droplet reduces and break up length also and Reynolds no. Increases. Attainment of atomization regime takes place if intact length becomes zero. A conic spray form and spread as leaving the nozzle it means that the vertex of cone situated inside the nozzle hole, at this condition there are still some droplets in the spray have larger diameter than the nozzle hole.

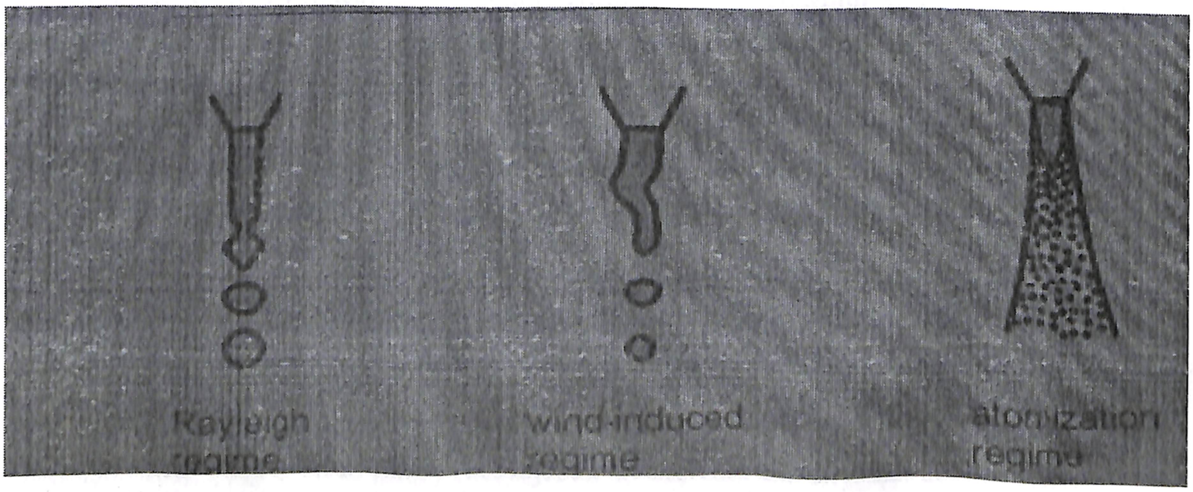


Fig. 2.1.1 (iii) Schematic description of jet break-up regimes

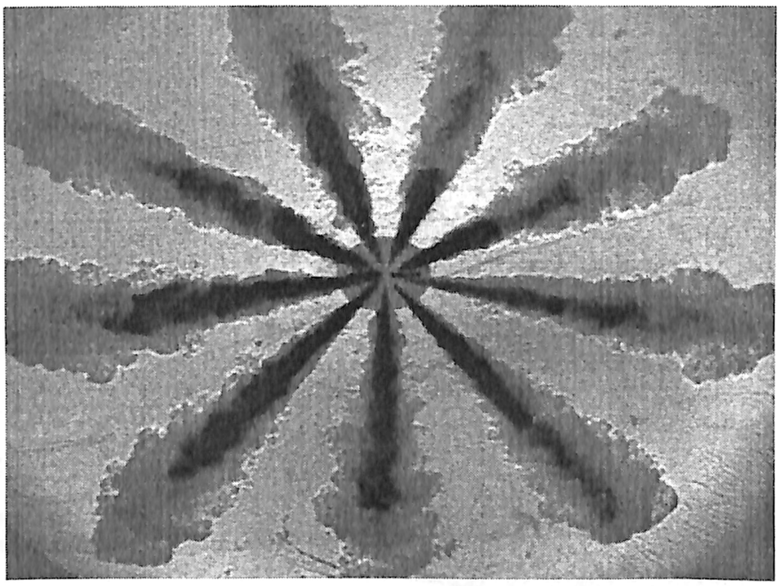


Fig. 2.1.1 (iv) Distribution of liquid (black) and vapour (gray) in an evaporating high-pressure Diesel sprays from a multi-hole nozzle under engine like conditions.

Break up of injected jet is very important for the formation of combustible mixture inside the combustion chamber. In diesel engine combustion chamber, swirling motion can be provide to the inducted air which help in increasing the atomization of the jet injected. These limits can be further stretched using a rotary injector. Swirling air has some direction whether in the clockwise or anticlockwise direction, a counter direction is provided injected jet, whether by the rotating tip or by spiral hole in the injector. When these counter moving gas & jet collides burst takes place causing formation of atomized charge. This works efficiently in multipoint sac hole or VCO nozzle.

(i) First wind induced regime is caused by aerodynamic forces inside the combustion chamber. By providing suitable motion to air inducted inside the chamber, disintegration can be increase.

(ii) This concept is used in rotary fuel injector to decrease the physical delay.

(iii)Jet rotating in clockwise direction strikes with the air swirling in the anticlockwise direction & a burst take place which causes formation of small droplets.

(iv)Pressure energy of fuel is use to rotate the tip of injector.

(v) A component of V= rw is imparted to jet.

2.2 Structure of Engine Sprays

2.2.1 Full-Cone Sprays

A schematic description of a full-cone high-pressure spray is given in Fig. The graphic shows the lower part of an injection nozzle with needle, sac hole, and injection hole. Modern injectors for passenger cars have hole diameters of about 180 μm and less, while the length of the injection holes is about 1 mm.

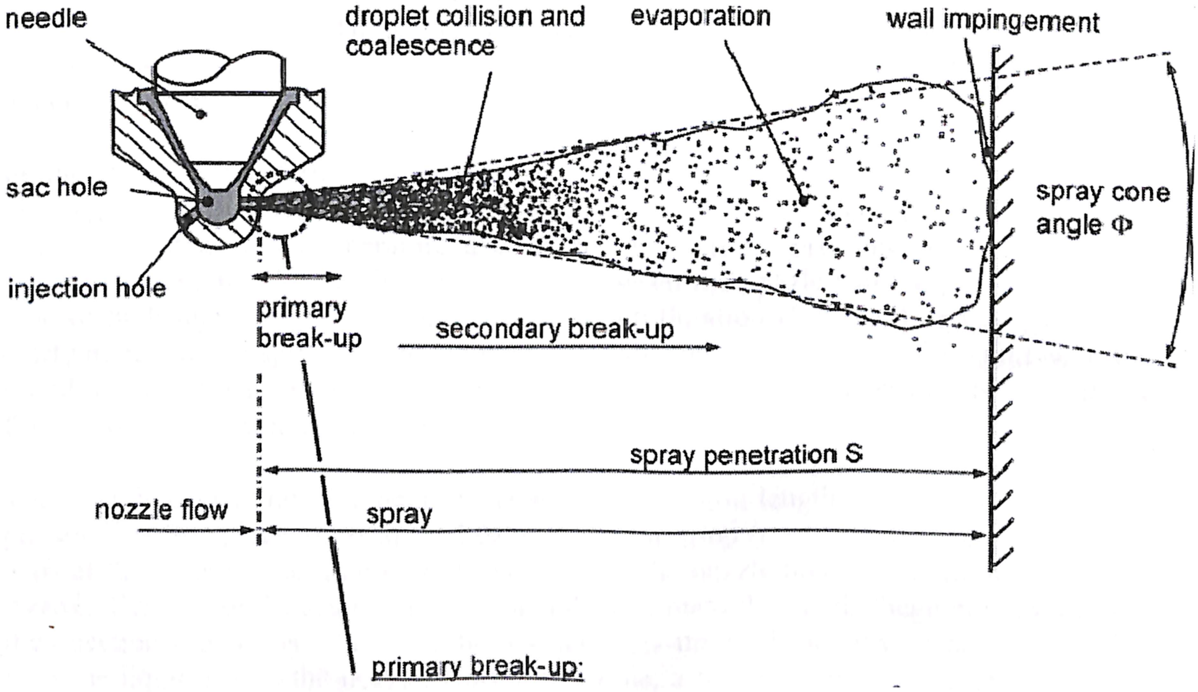


Fig. 2.2.1. Break-up of a full-cone diesel spray

Today, injection pressures of up to 200 MPa are used. The liquid enters the combustion chamber with velocities of 500 m/s and more, and the jet breaks up according to the mechanisms of the atomization regime.

Today, injection pressures of up to 200 MPa are used. The liquid enters the combustion chamber with velocities of 500 m/s and more, and the jet breaks up according to the mechanisms of the atomization regime.

Immediately after leaving the nozzle hole, the jet starts to break up into a conical spray. This first break-up of the liquid is called primary break-up and results in large ligaments and droplets that form the dense spray near the nozzle. In case of high-pressure injection, cavitation and turbulence, which are generated inside the injection holes, are the main break-up mechanisms. The subsequent break-up processes of already existing droplets into smaller ones are called secondary break-up and are due to aerodynamic forces caused by the relative velocity between droplets and surrounding gas, as described in the previous section. The aerodynamic forces decelerate the droplets. The drops at the spray tip experience the strongest drag force and are much more decelerated than droplets that follow in their wake.

For this reason the droplets at the spray tip are continuously replaced by new ones, and the spray penetration S increases. The droplets with low kinetic energy are pushed aside and form the outer spray region.

Altogether, a conical full-cone spray (spray cone angle Ø) is formed that is more and more diluted downstream the nozzle by the entrainment of air. Most of the liquid mass is concentrated near the spray axis, while the outer spray regions contain less liquid mass and more fuel vapour. Droplet velocities are maximal at the spray axis and decrease in the radial direction due to interaction with the entrained gas. In the dense spray, the probability of droplet collisions is high. These collisions can result in a change of droplet velocity and size. Droplets can break up into smaller ones, but they can also combine to form larger drops, which are called droplet coalescence.

In the dilute spray further downstream the main factors of influence on further spray disintegration and evaporation are the boundary conditions imposed by the combustion chamber such as gas temperature and density as well as gas flow (tumble, swirl). The penetration length is limited by the distance between the nozzle and the piston bowl. In the case of high injection pressure and long injection duration (full load) or low gas densities (early injection) the spray may impinge on the wall, and the formation of a liquid wall film is possible. Liquid wall films usually have a negative influence on emissions, because the wall film evaporates slower and may only be partially burnt.

The time-dependent development of the spray penetration length S can be divided into two phases. The first phase starts at the beginning of injection ($t = 0$, needle begins to open) and ends at the moment the liquid jet emerging from the nozzle hole begins to disintegrate ($t = tbreak$). Because of the small needle lift and the low mass flow at the beginning of injection, the injection velocity is small, and the first jet break-up needs not always occur immediately after the liquid leaves the nozzle. During this time, a linear growth of S over t is observed, during the second phase ($t > tbreak$), the spray tip consists of droplets, and the tip velocity is smaller than during the first phase. The spray tip continues to penetrate into the gas due to new droplets with high kinetic energy that follow in the wake of the slower droplets at the tip (high exchange of momentum with the gas) and replace them. The longer the penetration length, the smaller the energy of the new droplets at the tip and the slower the tip velocity.

The very high relative velocities between jet and gas phase induce aerodynamic shear forces at the gas-liquid interface. Due to the liquid turbulence that is created inside the nozzle, the jet surface is covered with a spectrum of infinitesimally small surface waves. Some of these waves are amplified by the aerodynamic shear forces, become instable, are separated from the jet, and form primary droplets. However, the instable growth of waves due to aerodynamic forces is a time dependent process and cannot explain the immediate break-up of the jet at the nozzle exit. Furthermore, aerodynamic forces can only affect the edge of the jet, but not its inner structure, which has been shown to be also in train of disintegration. Hence, aerodynamic break-up, which is the relevant mechanism of secondary droplet disintegration, is of secondary importance.

A second possible break-up mechanism is turbulence-induced disintegration. If the radial turbulent velocity fluctuations inside the jet, which are generated inside the nozzle, are strong enough, turbulent eddies can overcome the surface tension and leave the jet to form primary drops. Turbulence- induced primary break-up is regarded as one of the most important break-up mechanisms of high-pressure sprays.

A further potential primary break-up mechanism is the relaxation of the velocity profile. In the case of fully developed turbulent pipe flow (large *L/D* ratios, no cavitation), the velocity profile may change at the moment the jet enters the combustion chamber. Because there is no longer a wall boundary condition, the viscous forces inside the jet cause an acceleration of the outer jet region, and the velocity profile turns into a block profile. This acceleration may result in instabilities and in break-up of the outer jet region. However, in the case of high-pressure injection, cavitation occurs, *L/D* ratios are small, and the development of the velocity profile described above is very unlikely.

Another very important primary break-up mechanism is the cavitation-induced disintegration of the jet. Cavitation structures develop inside the nozzle holes because of the decrease of static pressure due to the strong acceleration of the liquid (axial pressure gradient) combined with the strong curvature of the streamlines (additional radial pressure gradient) at the inlet edge. Hence, a two-phase flow exists inside the nozzle holes. The intensity and spatial structure of the cavitation zones depends on nozzle geometry and pressure boundary conditions. The cavitation bubbles implode when leaving the nozzle because of the high ambient pressure inside the cylinder.

2.2.2 Hollow-Cone Sprays

In order to achieve maximum dispersion of the liquid at moderate injection pressures and low ambient pressures, hollow-cone sprays are usually used. Hollow cone sprays are typically characterized by small droplet diameters, effective fuel air mixing, reduced penetration, and consequently high atomization efficiencies. These sprays are used in conventional gasoline engines, where the fuel is injected into the manifold, and in direct injection spark ignited (DISI) engines.

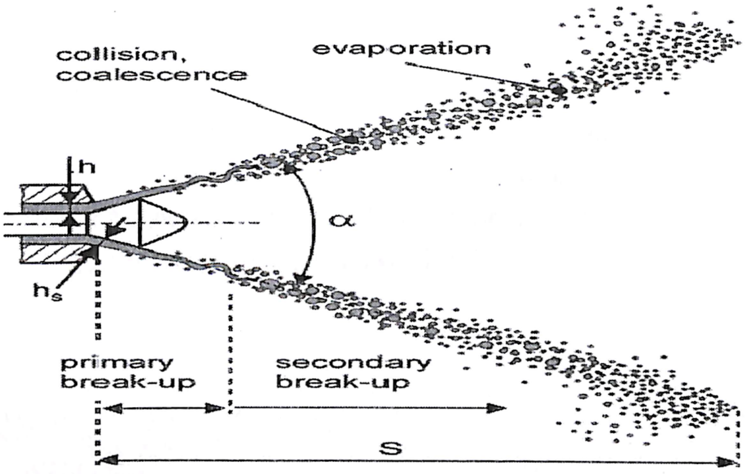


Fig. 2.2.2 Hollow-cone sprays. Example: outwardly opening nozzle

Fig. 2.6 shows the typical structure of such a spray. The liquid emerging from the nozzle forms a free cone-shaped liquid sheet inside the combustion chamber, which thins out because of the conservation of mass as it departs from the nozzle and subsequently disintegrates into droplets. Two nozzle concepts exist: the inwardly opening pressure-swirl atomizer and the outwardly opening nozzle. In the case of a swirl-atomizer, a cylindrical and strongly rotating liquid film leaves the nozzle. The radial velocity component, which is caused by the rotational motion, results in the formation of the free cone-shaped liquid sheet. In the case of an outwardly opening nozzle, the geometry of the needle causes the liquid to form the cone-shaped liquid sheet.

The primary break-up of the liquid sheet is induced by turbulence and aerodynamic forces. First, the liquid film with initial thickness h_s and spray angle α becomes thinner because of the conservation of mass as it departs from the nozzle. The secondary break-up of the droplets is aerodynamically induced, and is governed by the break-up mechanisms.

3.0 ROTARY FUEL INJECTOR

3.1 Construction

The basic design of the rotary injector is same as that of the **multi-point fuel** injector having multiple holes along the periphery of the injector nozzle. In our design we have incorporated a rotating disc type structure having vanes in it. This is installed with the injector nozzle tip. These vanes will rotate with the pressure of the fluid to be injected and also rotate the tip of the injecting nozzle thus creating swirl in the flow of the fluid.

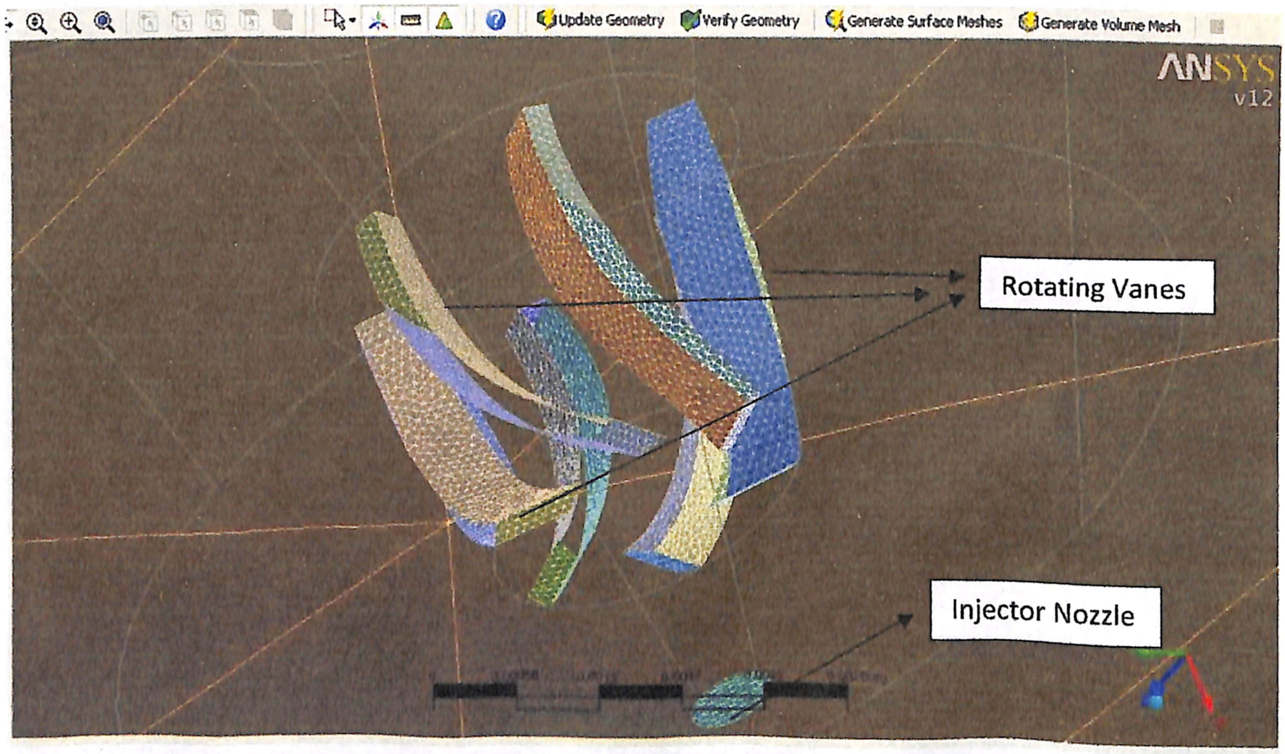


Fig.3.1 Rotating Vanes in Rotary Fuel Injector

The material of the rotating vanes is selected to be not much harder because it will require higher pressures to rotate. The shape of the vanes has to be very fine so that the fluid striking the blades of the vanes hit at maximum incidence angle to rotate them at a higher speed in order to transform the flow of the fluid entering into swirling motion. The swirling motion of the fluid here is carried to the tip of the injecting nozzle that sprays the fluid into the combustion chamber resulting in better combustion of fuel.

3.2 Working

The working of the Rotary Fuel Injector is similar as that of normal injectors used till the time when fuel reaches the fuel rail and is injected into the fuel injector at high pressures by the injection pump. The fuel to be injected under pressure now strikes the blades/vanes of the rotating disc cum injecting nozzle that rotates the vanes at high speeds creating turbulence and swirl to the motion of the fuel. The swirl and turbulence created to the flow of the fluid raises the temperature of the fuel. This fuel when injected into the cylinder mixes with the air and burns instantly without causing much knocking during combustion. The injection of fuel is shown in fig below

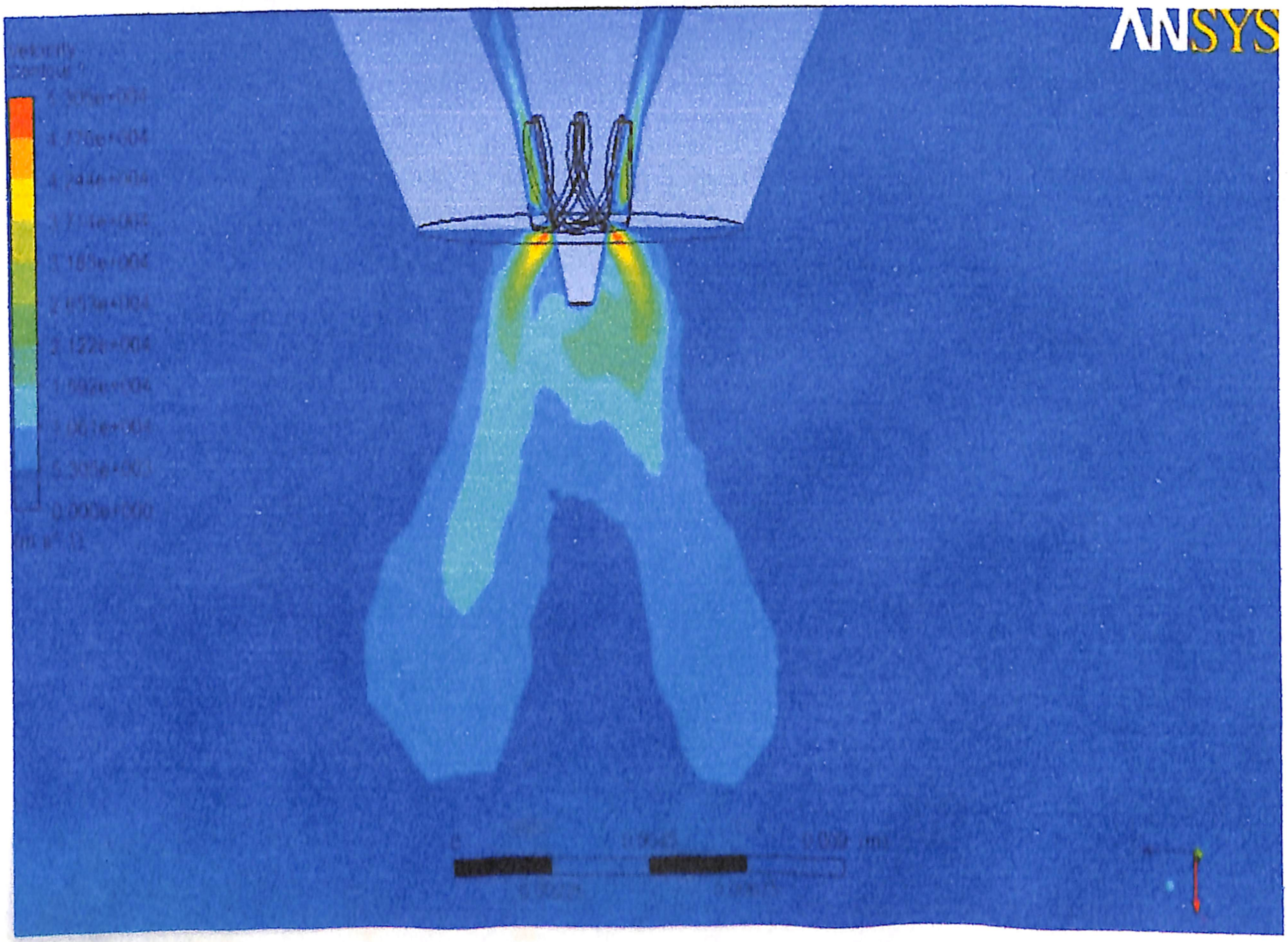


Fig.3.2 Advancement of injected fuel into the engine cylinder showing velocity contours

It can be seen from the fig. above that maximum velocity of the fuel to be injected is at the nozzle tip shown by the reddish zone. As the injection advances the velocity decreases due to resistance of air present in the cylinder. Towards the bottom of the cylinder the velocity contours are at minimum value.

3.3 Stages of Advancement of Injected Fuel throughout the cylinder

The swirl and turbulence created and the mixing of fuel and air throughout the cylinder can be visualized in various stages starting from the tip of the injector till the combustible mixture reaches the bottom dead centre of the cylinder. The stages are as follows:

Stage 1: The first stage starts when fuel is just at the tip of the injector when the injector fires for the first time. It is shown in the fig. below

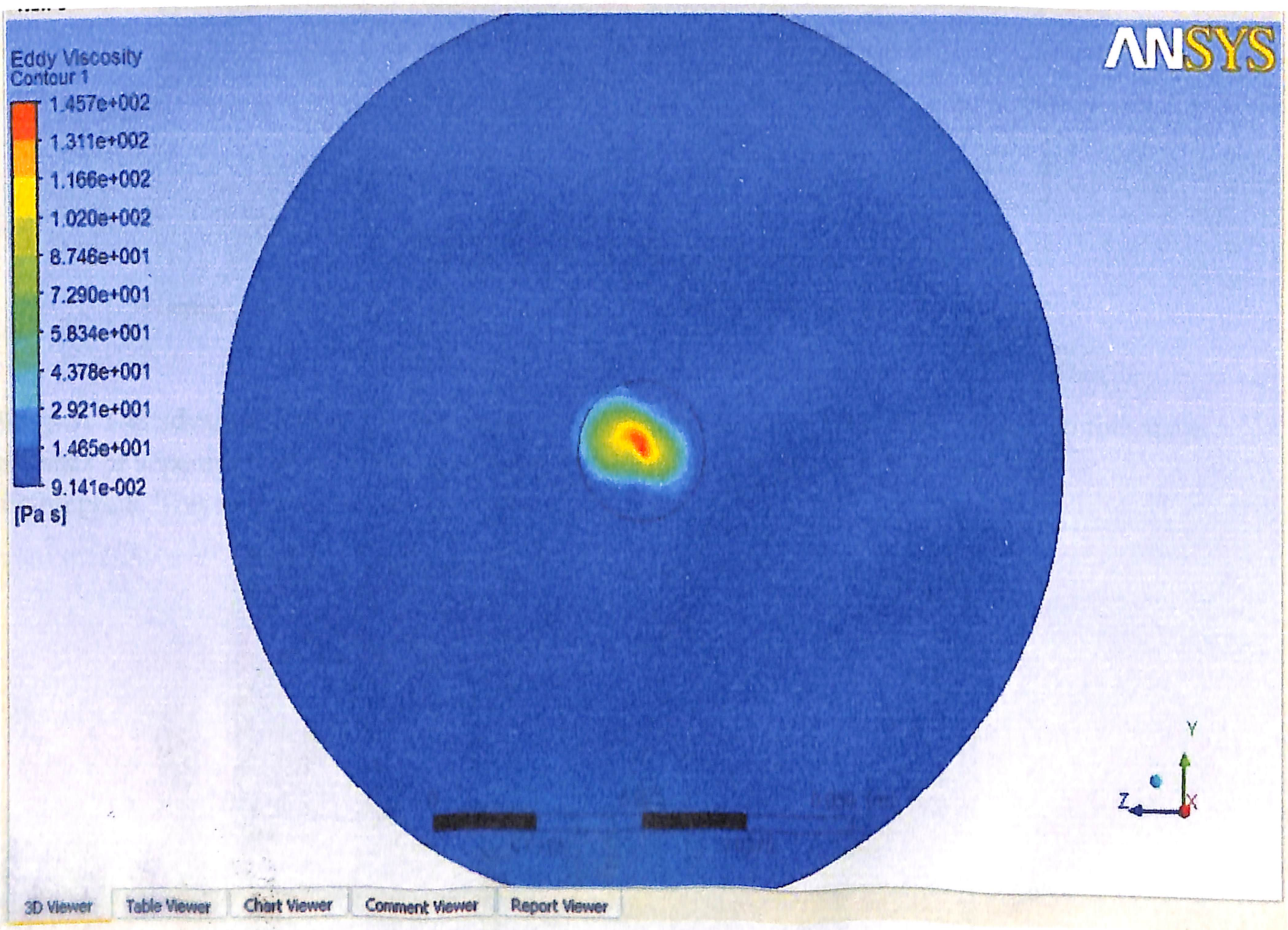


Fig.3.3 (I) Start of swirl advancement of fluid motion

We can see from the fig. that as soon as the fuel is injected from the injector nozzle tip it starts to advance further while mixing with the air. The swirling motion of the fluid gets transferred to the air. At this stage the velocity contours of the fluid motion is maximum. This is indicated by the reddish color zone in fig. The injected fuel disintegrates the air molecules into small fragments and tries to form a homogeneous combustible mixture.

Stage2: The velocity contours of the fuel-air mixture start to advance and spread throughout the engine cylinder. This is shown in the fig. below

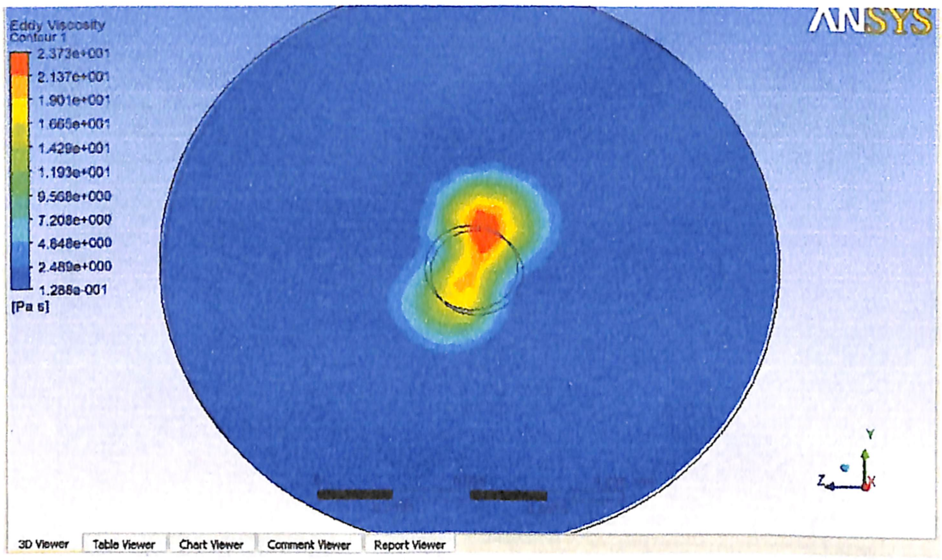


Fig.3.3 (II) further advancement of injected fluid

Stage3: The advancement of flame continues to advance further within the cylinder. In this stage the start of separation of the integrated flame occurs and the flame structure begins to disintegrate. This is shown in the fig. below

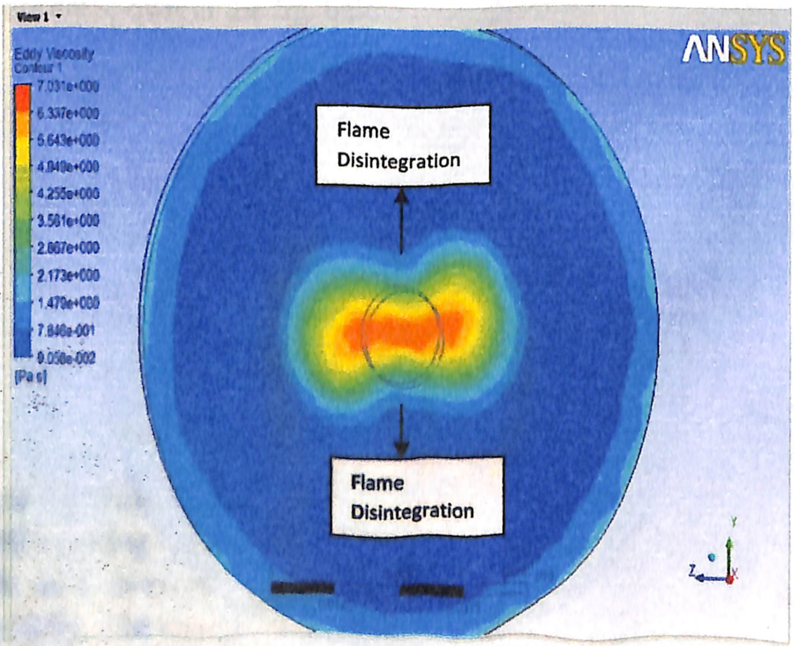


Fig. 3.3 (III) Start of disintegration of flame

Stage4: In this stage the flame propagation advances further and spreads around more than half of the cylinder volume. The separation of the flame also grows to its next stage. This is shown in the fig. below

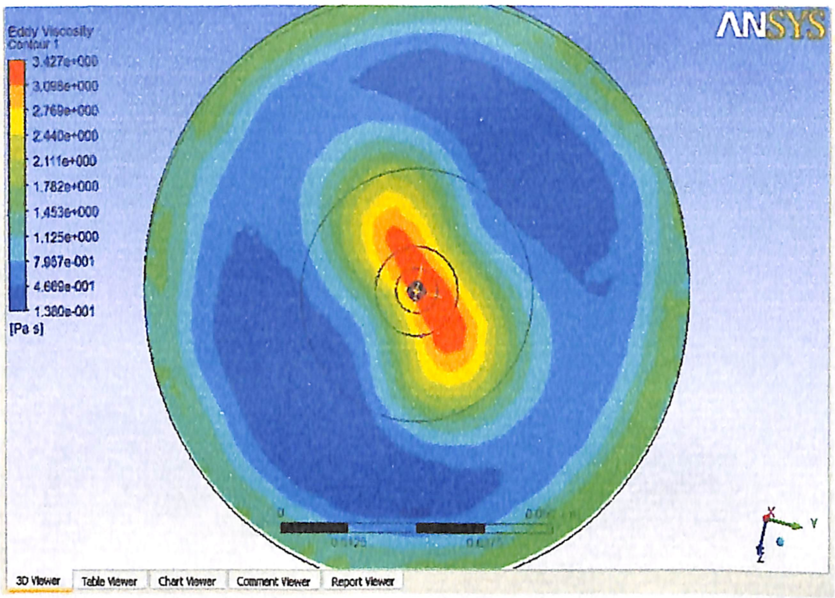


Fig.3.3 (IV) further injection swirls and flame disintegration advance

Stage5: The flame now tries to cover the overall volume of the cylinder and finally disintegrates into two halves. The disintegration of the flame divides the flame into separate velocity contours. The separated velocity contours continues to advance individually. The two separated velocity and pressure contours are shown in the fig. below

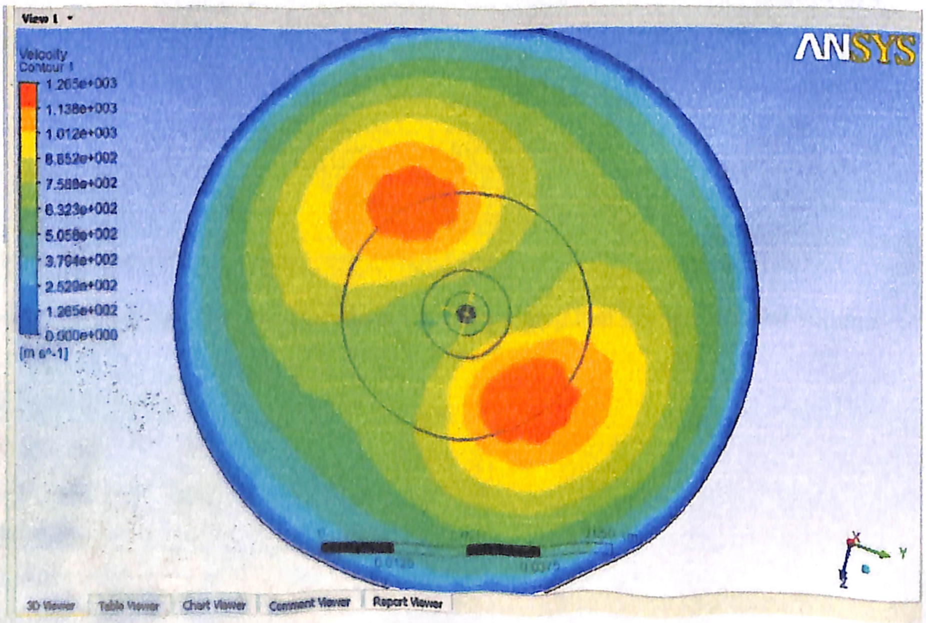


Fig.3.3 (V) Separation of flame into individual flame velocity contours

Stage6: This stage marks the final dissociation of two individual flames formed in the previous stage. The fuel-air mixture finally covers the whole cylinder volume and disintegrates completely. The swirl motion then starts to flow in upward direction in order to cover the areas around the walls of the cylinder so that fuel droplets do not remain attached to the cylinder walls.

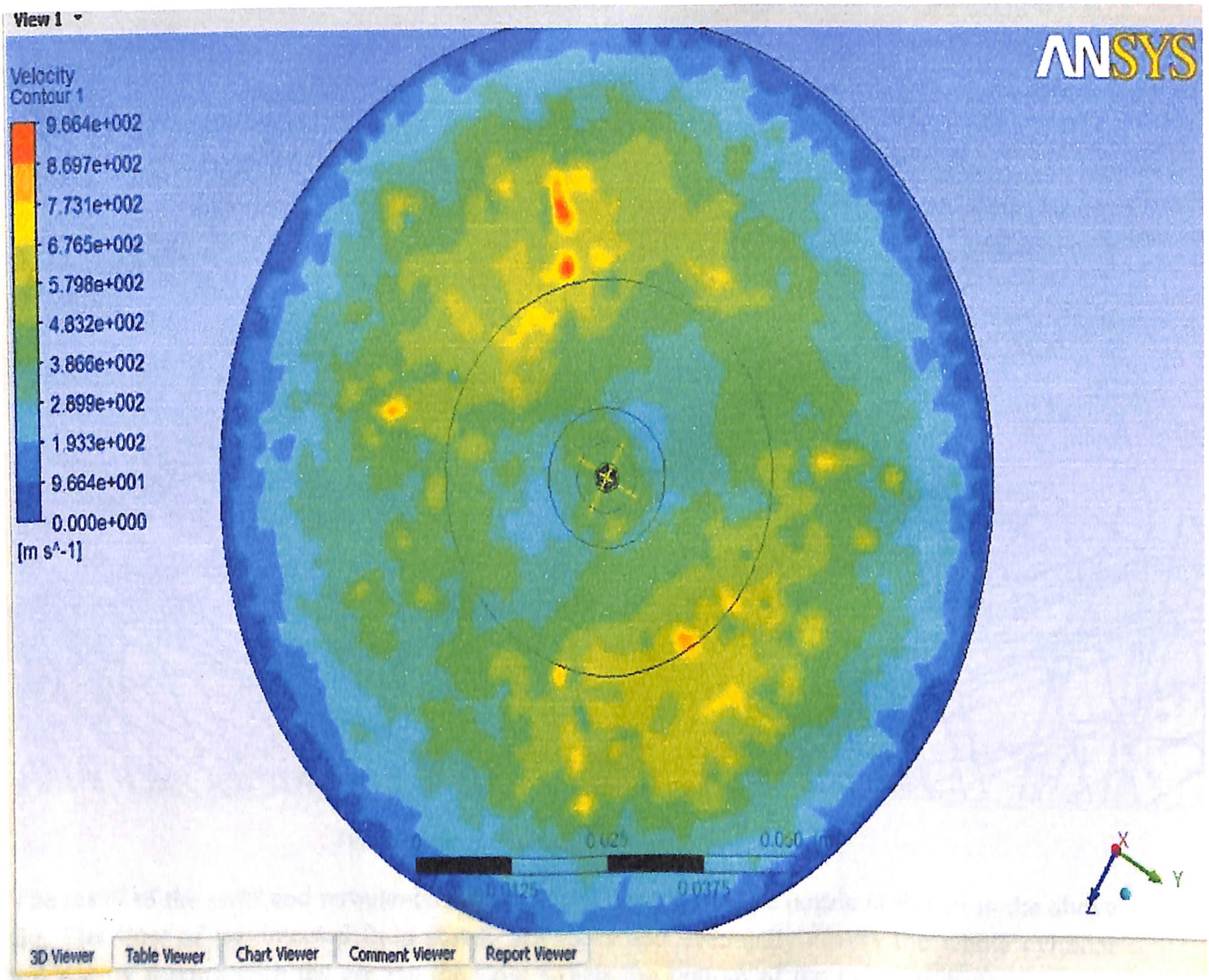


Fig.3.3 (VI) Complete advancement of injected fuel into the cylinder volume

3.4 Overall visualization of swirl created inside the cylinder volume

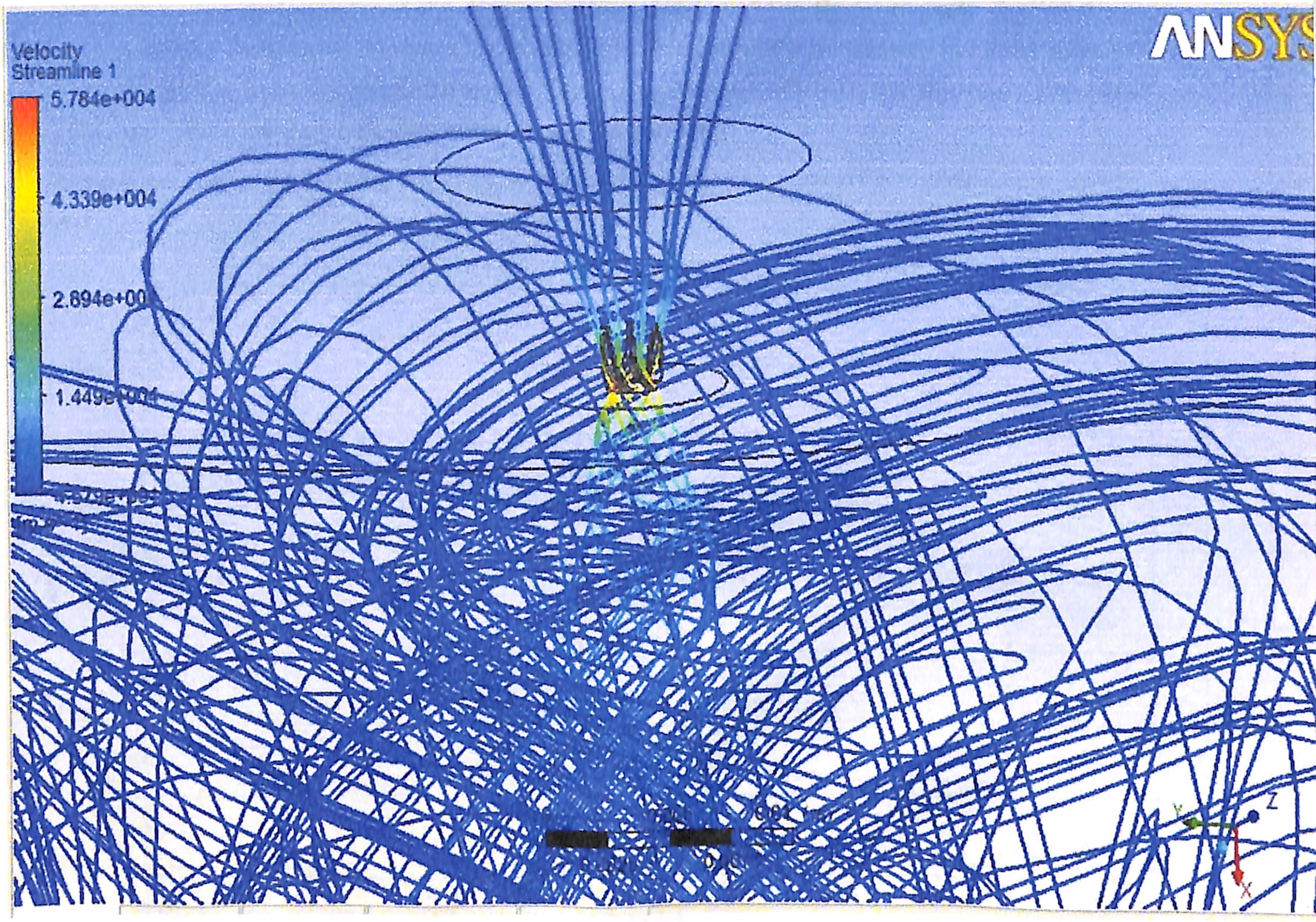


Fig.3.4 Injection Flow inside the cylinder volume

The result of the swirl and turbulence created at the injection of the nozzle is shown in the above fig. The flow of the injected fluid slowly advances and eventually covers the whole cylinder volume by mixing with the air. As the flow strikes the bottom of the cylinder surface, it gets swirled in the upward direction and tries to cover the areas around the cylinder walls and prevents the deposition of fuel droplets thus reducing the emissions by preventing the formation of carbon deposits. This is the main advantage of the rotary type of fuel injector. As compared to the normal injectors, the normal injectors are not able to maintain the swirling flow inside the combustion chamber for larger durations. The flow disintegrates quickly as it advances through the cylinder volume.

3.5 Pressure Plot for Rotary Fuel Injector

The pressure vs the distance from the center of the cylinder of the flame is plotted after running the analysis of the flow from the injector under specific boundary conditions such as inlet air temperature=25^{0}C , cylinder pressure at the time of injection= 50-100atm, injection pressure= 200-1500bar. The plot that was generated is shown below

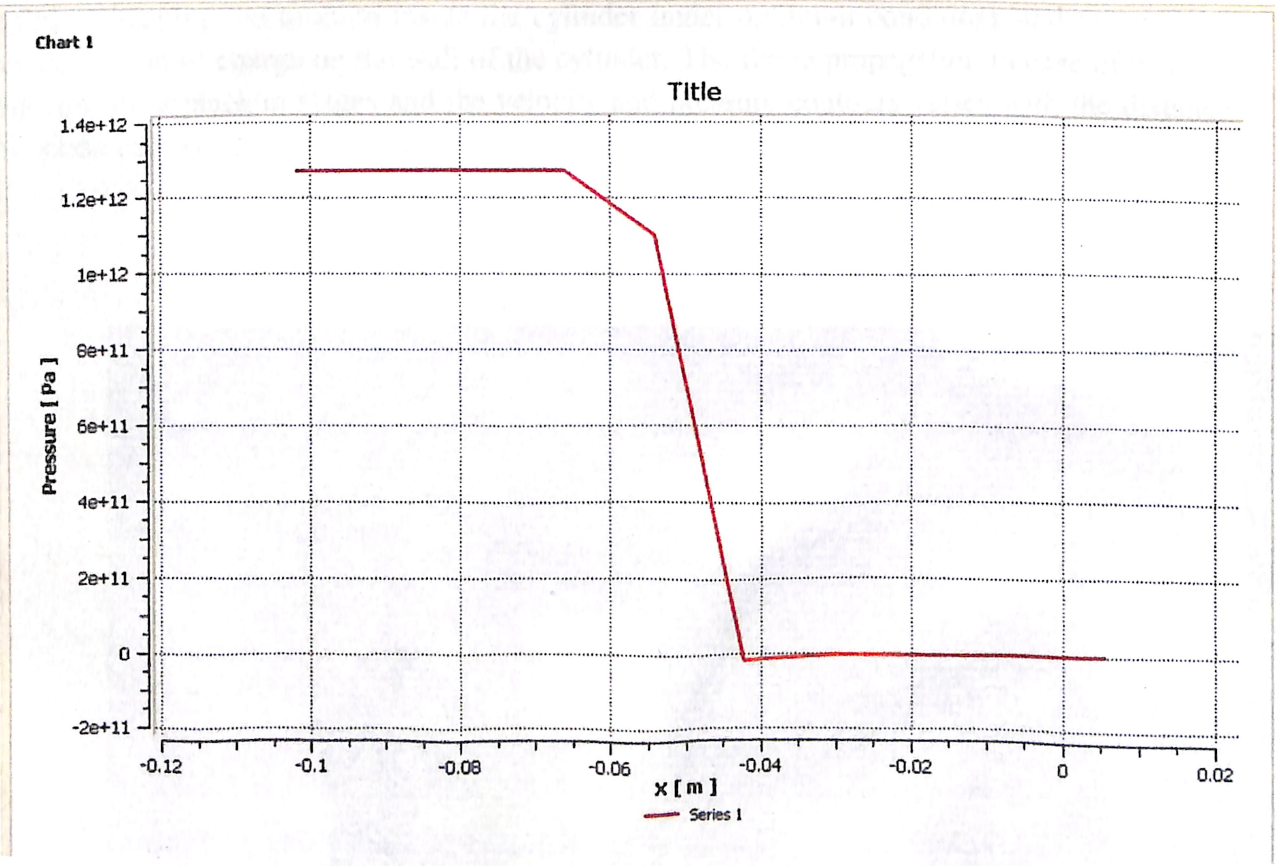


Fig3.5 Pressure vs distance from the centre of the cylinder

From fig. it can be observed that at minimum distance the pressure contours that are generated are of maximum value and remain static up to nearby distance. As the distance is further increased the velocity of the fuel injected goes on gradually decreasing that result in reduction of pressure contours. But after a certain time period of or after the flame has reached a certain distance the pressure contours become constant and no further changes are encountered in the pressure of the fuel-air mixture.

4.0 RESULTS & DISCUSSION

It can be seen that as compared to other normal injectors **the rotary fuel injector** is far more advanced and helps in proper mixing of fuel and air in the combustion chamber. The design of the injector is complex as compared to other injector designs but it offers much swirl and turbulence to the flow as compared to other injector designs. The rotation of the injector nozzle helps in keeping the mixture inside the cylinder under optimum conditions and preventing the accumulation of charge on the wall of the cylinder. The flame propagation in case of rotary fuel injector takes place in stages and the velocity and pressure contours varies with the distance of injection and the locus of the center of the cylinder.

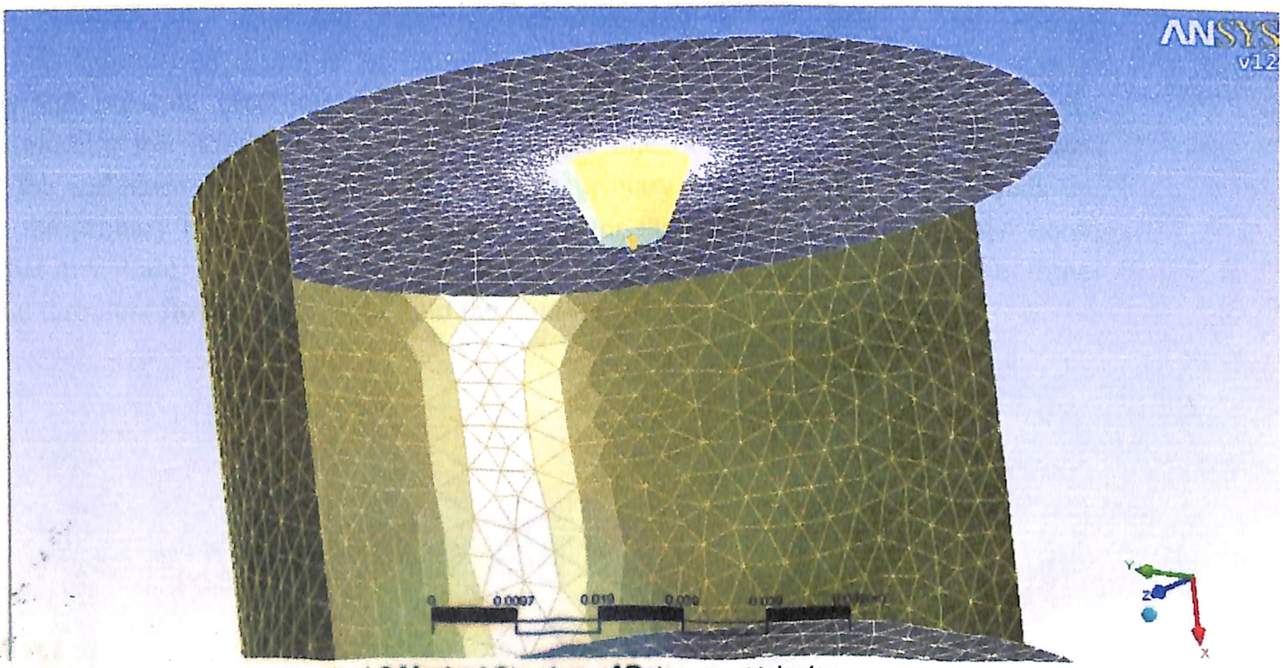


Fig4.0 Meshed Structure of Rotary Fuel Injector

5.0 CONCLUSION

It can be concluded that replacing the normal fuel injectors with the rotary injectors can lead to optimum mixture formation and can reduce the emissions to a greater extend. A systematic and precise control of mixture formation with modern high pressure injection systems, including fully variable rate shaping, variable nozzle geometry, pressure-modulated injection etc., will become crucial for realizing future combustion concepts. However, due to of the growing number of free parameters, the prediction of spray and mixture formation is becoming increasingly complex. For this reason, the optimization of the in-cylinder processes using 3D computational fluid dynamics (CFD) is becoming increasingly important.

The basic challenge in describing the evaporation process of fuel droplets is the choice of an appropriate reference fuel that represents relevant behaviour of the fuel. Future mixture formation and combustion concepts for diesel as well as gasoline engines will utilize almost exclusively high-pressure direct injection. The higher the injection pressure, the more energy for spray and mixture formation must be provided by the injection system itself, and the more important the influence of internal nozzle flow on primary and secondary spray break-up. Especially the primary break-up, which is responsible for the starting conditions of the liquid droplets that penetrate into the cylinder volume, is significantly influenced by the three-dimensional turbulent flow that emerges from the nozzle holes.

6.0 REFERENCES

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[3] Internet Sources