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Injection modeling of Diesel Engine: A Review

Shankhdhar Vivek[a] , Kumar Neeraj[b]

[a] M.Tech Scholar , Moradabad Institute of Technology
[b] Asst. Proff. Mechanical Engineering Deptt., Moradabad Institute of Technology

Abstract: Diesel Engine is the most important part of our life. Our transportation, agricultural, defense, science fields are based on the diesel engine. With the increase the use of diesel engines our life many problems are raising. Pollution is major problem so it is necessary to engine manufacturer to invent new technology that how to increase efficiency, decrease fuel consumption rate, Increase work done and decrease exhaust emission. To improve these problems injection timing is the most important parameter. Injection Timing is the crank angle at which the fuel is injected in the combustion chamber. The advances of this angle there is a impact on the performance of the diesel engine. Delay Period increases with increase in injection advance angle. The reason for increase in delay period with increase in injection advance angle is that pressures and temperature are lower when injection begins. When injection advance angles are small, delay period reduces and operation of engine is smoother but power is reduced because large amount of fuel burns during expansions.

Key Words: Diesel Engine; Injection Timing; Ignition Delay

INTRODUCTION

Fuel injection system is called the heart of Engine. And it is a important system. With modern Diesel Engine the injection process (i.e. the injection rate and injection pressure) has a major impact on noise production, exhaust gas emission, fuel consumption and engine efficiency. It meters the fuel delivery according to the engine requirement, it generates the high injection pressure required for fuel atomization, for air-fuel mixing and for combustion and it contributes to the fuel distribution in the combustion system-hence it significantly affects engine performance emission and noise. [5] Higher injection pressure creates faster combustion rates which results in higher gas temperature as compared to the conventional low pressure system. [7]. Precise control over the fuel injection and spray formation is essential in making improvement to the combustion process.[9] In view of the ever-increasing demands on these engines, modeling of the fuel injection system has become an essential step in the fuel injection equipment design and optimization process.[1][5] Detailed modeling of the diesel spray development and combustion process inside the diesel engine requires the injection rate and velocity to be known as input [2] Automotive systems are becoming more and more complex and engine control. In particular common rail systems have been develop to reduce noise, exhaust emissions and fuel consumption and at the same time to increase performance [3]. The working principle is to inject a precise quantity of fuel at high pressure. The pressure demand is mapped against several parameters mainly engine speed and torque demand. [4] The world is currently facing dual crisis of fossil fuel depletion as well as environmental degradation. Also due to ever increasing the number of vehicles, energy demand is increasing; therefore steps have to be taken to reduce consumption. [6] At High load, Combustion temperature becomes the dominant factor, which increases the evaporation rate of the injected fuel with reduction in delay period, so injection advance is recommended only at light load conditions. The engine ran smoothly at light load conditions in dual fuel with this advance compared to standard timing. [8] Biodiesel is considered a promising alternative fuel for use in diesel engines, boiler and other combustion equipment. Although biodiesel has many advantages over diesel

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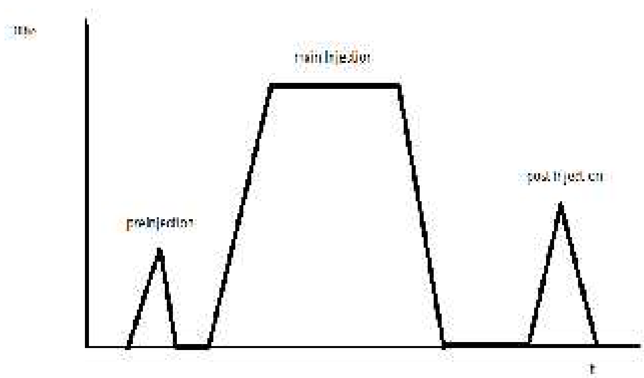
fuel, there are several problems that need to be addressed such as its lower calorific value, higher flash point, higher viscosity, poor cold flow properties, poor oxidative stability and sometimes its comparatively higher emission of nitrogen oxides. It is found that the lower concentration of biodiesel blends improve the thermal efficiency. [6]



The fuel is injected with a centrally arranged multi-hole nozzle. High injection pressure and many small holes in the injection nozzle see to good mixture formation, which can be supported by a swirl flow in the combustion chamber gases. The injected fuel should if possible not collide with the relatively cold piton wall, because in this way evaporation and then mixture formation are lagged and the formation of HC emissions is favored [15]. The fuel is injected in to the cylinder in parcels form. The parcels have to be generated at the nozzle, and logically this occurs stochastically. Typically, one determine the injection direction per parcels in a pre-given solid angle or spray cone area, and possibly an initial droplet size in accordance with a drop size distribution. [15]Output and efficiency of diesel engine are affected by the characteristics of the fuel spray injected into the combustion chamber. Injection characteristics are injection timing, Injection Duration, Injection rate and abnormal injection [18].

INJECTION TIMING:

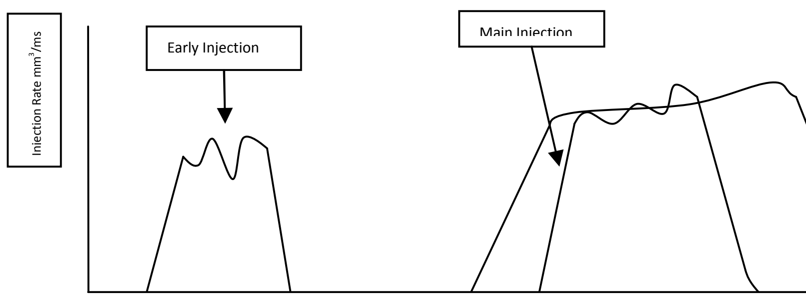
There is always time lag between Injection of fuel and burning of fuel. Injection timing is the Crank angle at which the fuel is injected in to the combustion chamber .

EARLY INJECTION

In Conventional HCCI combustion, fuel is injected early in the compression stroke, which allow sufficient mixing time for the formation of a homogeneous mixture [27].

MULTIPLE INJECTIONS

The first stage of combustion is premixed lean combustion which lowers NO_x emissions, while the second stage is diffusion combustion which occurs under high temperature and low oxygen conditions.[27]



BREAKUP MODELING:

Because of the different mechanism, two kinds of spray break up can be distinguished, primary breakup and secondary breakup. Primary break up results from properties given to the spray already by the internal nozzle flow, like turbulence and cavitations. For secondary breakup, aerodynamics processes are relevant that are not a result of internal nozzle flow. For primary break up modeling , we need information about the internal nozzle flow about its turbulence and cavitations. In dense diesel

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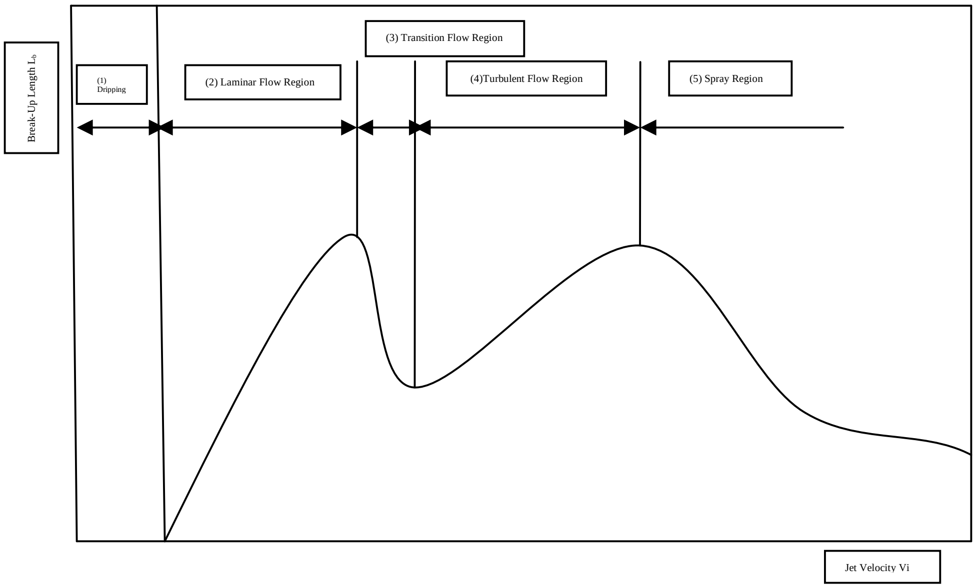
injection with strong primary breakup. The injection of liquid fuel into a gas eventually results in the formation of after injection. There is some unbroken portion which is referred to as the break-up length in the spray The break up length may



droplets, but the liquid jet breakup process depends on various conditions. Two different lengths can be identified breakup processes: the intact core length and the break up length. The break up length is defined as the distance from the nozzle exit to the point where droplets are formed on the liquid jet surface, whereas the intact core length refers to the distance from the nozzle exit to the point where the liquid jet breaks up into droplets at the jet centerline.[16] The droplets are injected at certain locations near the injector within the computational domain. The size of these droplets and the spray angle can be estimated from aerodynamics theories of liquid jet beak up. [17] The droplet velocity can be estimated as a fraction of the injection velocity. The droplets may be injected at the end of the intact core length and on a circle having a radius equal to that of the injector. Droplets may be injected at the end of the intact core length and random axial and radial locations from the injector axis. The injected liquid does not break-up instantly

have great effects on the atomization of the liquid fuel and the formation of the fuel-air mixture.

Break-up length and Break-up time is given by the following equations [19]-

$$L_b = 15.8\sqrt{\frac{\rho_l}{\rho_a}}\, d_o \quad [1]$$

$$t_b = \frac{28.6\rho_l}{\sqrt{\rho_a}}\frac{d_o}{\sqrt{\Delta P}} \quad [2]$$

Break up time also calculated by the following formula [25]

$$t_b = 4.351\frac{\rho_l d_n}{C_D^2(\rho_a \Delta P)^{0.5}} \quad [3]$$

Break up length is calculated by the following formula [26]-

$$S_b = C_1 \left(\frac{\rho_l}{\rho_a}\right)^{0.5} d_{inj}$$

[4]

Spray Characteristics

The fuel is injected into the combustion chamber of the diesel engine through a nozzle in the form of a liquid spray with high injection pressure. The fuel injected from the nozzle is disintegrated into numerous drops of different size and concentrations in the spray.[18]

Phase Divided Spray Mixing Model

The fuel droplets only exist around the nozzle, with the evaporation of the fuel droplets and the diffusion of spray, the fuel droplets become gaseous in short time and fuel-air mixture is formed [20] The fuel in combustion zones is in liquid phase during break-up period and turns to gaseous phase after break-up time.[21]

Concentration Distribution of Spray

The concentration distribution line of spray in stable region of gaseous flow is given by [22]

$$\frac{c}{c_m} = 1 - \left(\frac{r}{r_o}\right)^{1.5}$$

[5]

The calculation equation of r_o is given by [23]

$$r_o = \frac{x t_g \theta}{2}$$

[6]

Where

C = The concentration along radial direction of x section in the centerline of spray

C_m = The piston velocity

r = The radial distance away from the centerline of spray

r_o = The maximum radius of x section in the centerline of spray

Auto Ignition Modeling

J.C Livengood et.al gives an implicit relation among $\theta_{soi}, \theta_{soc}$ and physical in-cylinder parameters such as P(θ) , T(θ) ,X and equivalence ratio $\emptyset$ under the following integral form[13]-

$$\int_{\theta_{soi}}^{\theta_{soc}} \frac{A^{ai}(p(\theta))}{N_e} d\theta = 1$$

[7]

Where A^{ai} an Arrhenius is function and $p(\theta)$ is a vector of in-cylinder physical properties.

Spray Model

The fuel injection does not directly initiate the combustion. Combustion occurs after the ignition delay. Physical and chemical process must take place before starts. The physical processes are the vaporization of the fuel followed by its mixing with the air/burned- gases charge. Chemical process are the pre-combustion reaction which do not release significantly energy but lead to the auto ignition of the fuel-air burned gases mixture. This delay depends on the physical conditions of the mixture (pressure, temperature, composition, fuel/air ratio [10] [11]

Combustion Starts after ignition delay. The rate of heat release also depends on the physical conditions of mixture such as the fuel/air ratio and on other parameters such as available turbulent kinetic energy.[12] . After the initiation of fuel injection, the zones begin to form and penetrate into the combustion chamber. The initial conditions at the nozzle exit are obtained from the fuel injection process simulation. The initial jet velocity is calculated as follows[26]:-

$$u_0(t) = \frac{4\dot{m}_f(t)}{\eta_0 \pi d_{inj}^2 \rho_l}$$

[8]

Where η_0 and d_{inj} are the number and diameter of the nozzle holes and ρ_l is the density of the liquid.

Spray Angle

The two most commonly used correlation for spray angle by Hiroyasu and Arai and Reitz and Bracco have been implemented into the multi-zone model. The correlation by Hiroyasu and Arai is [19] :

$$\theta = 0.025\left(\frac{\rho_a \Delta P d_n^2}{\mu_a^2}\right)^{0.25} \quad [9]$$

Where μ_a is the viscosity of ambient gas. Reitz and Bracco correlation which appears to yield predictions in better agreement data is [25]:

$$tan\theta = \frac{1}{A}4\pi\left(\frac{\rho_a}{\rho_l}\right)^{0.5}\frac{\sqrt{3}}{6} \quad [10]$$

Where

$$A = 3.0 + 0.28\left(\frac{l_n}{d_n}\right) \quad [11]$$

And l_n is nozzle hole length

Fuel Injection Model

The fuel injection in to the combustion chamber is divided in to two categories Restrictive and capacitive. In capacitive elements such as control chamber and nozzle chamber , fluid pressure and temperature are calculated .For the pressure variable , the continuity equation is formulated in terms of pressure as follows[1] :-

$$\frac{dp}{dt} = B(p.T)\left[\frac{(m_{in} - m_{out})}{V\rho} + \frac{\alpha(p,T)dT}{dt}\right] \quad [12]$$

Where m_{in} and m_{out} are respectively the ingoing and outgoing mass flow rate of the volume V

B is bulk modulus,ρ is Density and cubic coefficient α

The temperature of the fluid in the volume is computed through solving the energy equation [1]

$$\frac{dT}{dt} = \frac{(mh)_{in} - (mh)_{out} - \left(\frac{dm}{dt}\right)h + Q}{\rho V C_p} + \frac{T\alpha dp}{\rho C_p dt} \quad [13]$$

Where h the enthalpy C_p the specific heat at constant pressure and Q the heat flow from the surrounding into the volume.

In resistive method such as throttle only the mass flow rate is calculated, using the modified Bernoulli equation:

$$m = \rho C_d(\lambda)A\sqrt{\frac{2\Delta p}{\rho}} \quad [14]$$

Where C_d is the discharge coefficient, for non-cavitating flowC_d is dependent on flow velocity, fluid density and viscosity only.This dependence is taken in to account by formulating into account by formulating the discharge coefficient as a function of a dimensionless flow number

$$\lambda = \frac{d_h}{v}\sqrt{\frac{2\Delta p}{\rho}} \quad [15]$$

Where d_h is the hydraulic diameter and v is the kinetic viscosity. The cross sectional area A can be constant or a function of lift as in the needle tip component

Fuel Tank: The rail

The rail is a pressurized fuel tank feeding the injectors. Two kinds of flow which allows keeping the right pressure and the

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running flow used by injectors. The rail system satisfies the following dynamical equation [3]:

$$P_r = \frac{K(P_r,T)}{V}\left(Q_{pmp} - Q_{inj} - Q_{hpv}\right) \quad [16]$$

Where P_r the rail pressure (Pa), T is is the fuel temperature (^oC) K is the bulk modulus (Pa) V is the rail and pipes volume (m^3), $Q_{pmp}, Q_{inj}, Q_{hpv}$ are respectively the H.P. pump flow, the injectors flow and HPV flow (m^3/s)

When the fuel is injected into the combustion chamber towards the end of compression Stroke, it is atomized in to very fine droplets. These droplets vaporize due to heat transfer from the compressed air and form a fuel-air mixture. Due to continued heat transfer from hot air to the fuel, the temperature reaches a value higher than its self-ignition temperature. This cause the fuel to ignite spontaneously initiating the combustion process The injected quantity of fuel per cycle is constant. As the pressure and temperature at the beginning of injection are lower for higher ignition advance, the delay period increases wit increase in injection advance.[14]

Droplet Diameter after breakup

In theory of combustion it is assumed that droplet after breakup having the same initial diameter which is equal to the sauter means Diameter having neglecting droplets size distribution and the details of the atomization process. The variation of droplet size from one fuel parcel to the next allowance is made depending on the operating condition [24].

How to Change the Injection Timing

Following are the steps which are followed to change the injection timing of a diesel engine-

1. Open the head of Cylinder.
2. Rotate the flywheel slowly and when the piston appear on the top of the cylinder mark this point on the flywheel as TDC (Top dead Center).
3. Open the cap of the pump.
4. Apply Drop Test.
5. For changing injection timing remove/add shims below in the pump. Usually 2-3 shims are already provided below the pump.
6. Apply drop test again and point this point as the injection point of the engine.

Drop Test

Remove upper cap and spring of the pump. Rotate the flywheel slowly and watch the fuel pump carefully. When the first drop of the fuel appears on the fuel exit side in the pump than this is the fuel injection point. Take the difference between TDC and fuel injection point. After removing and adding the shims repeat this process again and again and mark this point on the flywheel.

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