STUDY ON SPRAY NOZZLE OF DIESEL ENGINE

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ABSTRAK

Projek ini membentangkan kajian tentang pembangunan dan menganalisis teknologi yang sedia ada dari segi reka bentuk dalam pemancit diesel suntikan tidak langsung enjin diesel. Objektif projek ini adalah untuk mereka bentuk muncung semburan yang baru dengan menggunakan data dikira aspek yang dipilih, menghasilkan muncung dan muncung penyuntik yang baru boleh digunakan dan dapat berfungsi. Skop kajian ini adalah mengkaji semula peranti penting yang berkaitan dengan eksperimen, mengkaji sifat-sifat muncung semburan di penyuntik bahan api, menghasilkan muncung penyuntik bahan api baru menggunakan proses reka bentuk yang sesuai selepas ia menggunakan Solidworks dan menguji prestasi dan corak semburan baru muncung penyuntik menggunakan penguji muncung. Eksperimen telah dilakukan oleh membekalkan tekanan pada 104 bar dan 124 bar dengan menggunakan penguji muncung. Imej semburan dari muncung penyuntik telah ditangkap dan keputusan yang berdasarkan kriteria yang menunjukkan bahawa muncung baru penyuntik boleh berfungsi dengan baik. Muncung suntikan baru menduduki ruang yang lebih kecil berbanding dari muncung penyuntik yang sebelumnya yang terlalu besar. Muncung baru penyuntik menawarkan penambahbaikan ke atas muncung sebelumnya penyuntik dalam pemasangan.

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LIST OF ABBREVIATIONS

BSFC	Brake specific fuel consumption
CI	Compression ignition
DI	Direct injection
IDI	Indirect injection
L/D	Nozzle aspect ratio
Oh	Ohnesorge number
Re	Reynolds number
SMD	Sauter mean diameter
We	Weber number

CHAPTER 1

INTRODUCTION AND GENERAL INFORMATION

1.1 PROJECT BACKGROUND

Compression ignition (CI) or diesel engines are widely used for transportation, automotive, agricultural applications and industrial sectors because of their high fuel economy and thermal efficiency. The existing CI engines operate with conventional diesel fuel derived from crude oil. It is well known that the world petroleum resources are limited and the production of crude oil is becoming more difficult and expensive. In the study related to the nozzle injector should be enhanced for diesel engines especially for indirect injection (IDI) diesel engines. Because, they have a simple fuel injection system and lower injection pressure level. They do not depend upon the fuel quality and have lower ignition delay (ID) and faster combustion than direct injection (DI) diesel engines.

The combustion characteristics of IDI diesel engines are different from the DI diesel engines, because of greater heat-transfer losses in the swirl chamber. This handicap causes the brake specific fuel consumption (bsfc) of the IDI engine to increase and the total engine efficiency to decrease compared to that of a DI diesel engine. Because of these disadvantages of the IDI diesel engines, most engine research has focused on the DI diesel engines. However, IDI diesel engines have a simple fuel injection system and lower injection pressure level because of higher air velocity and rapidly occurring air-fuel mixture formation in both combustion chambers of the IDI diesel engines. In addition, they do not depend upon the fuel quality and produce lower exhaust emissions than DI diesel engines (A.A. Abdel-Rahman, 1998).

Every nozzle injection system made today requires that a calibrated device be used to accurately deliver a precise amount of fuel to each cylinder at the exact instant fuel is needed for combustion. An injector nozzle is one of the most important parts of a fuel injection system. Injectors deliver fuel to cylinders of internal combustion engines. The fuel is sprayed through an injector nozzle, typically at high pressure, to improve the mixing of fuel with air and therefore the combustion efficiency.

The basic operation of nozzle injector is fuel injected through the spray hole is assumed to form a liquid core which is then broken-up and atomized into fine droplets. They immediately start to evaporate until a combustible fuel air mixture is generated. Fuel spray atomization, air entrainment and fuel air mixing strongly depend on diameter, surface roughness, inlet chamfer radius, conicity of the spray hole. The compliance with predefined geometry parameters limits the manufacturing tolerances for spray holes which are more and more tightened by a trend towards shrinking hole diameter and increasing throughout (Erwin Peiner, 2009).

1.2 PROBLEM STATEMENT

Fuel consumption and exhaust gas emission of diesel engines depend on the geometry of the injector nozzle comprising spray holes and the diameter. Spray nozzles are carefully engineered to deliver specific performance under certain operating conditions. Their performance is affected by the nozzle type, spray pattern, capacity, operating pressure, material of construction, droplet velocity and spray distribution, angle and impact. In order to design this project, these nine parameters must be analyzed to produce the optimum nozzle injector.

For different applications, people attempt to manipulate the spray by changing the operating conditions to satisfy their own demands. In order to understand how and why changes in operating conditions change spray characteristics, studies on the spray characterisation and the basic physical mechanisms involved in the formation of spray have to be carried out while the application is considered. Currently, the physical mechanisms of the Diesel spray formation are not completely understood. Also, in response to the demand on improving the performance of the sprays, new technologies are being explored. The sprays generated by these new technologies need to be characterised to provide necessary information for their applications.

1.3 OBJECTIVE OF PROJECT

The overall aim of this project is to develop the new spray nozzle in fuel injector of diesel engine by using the vacuum hardening technique. Therefore the main objectives of the research are to design the new spray nozzle by using calculated data from previous researcher, Jeffrey P. DiCarlo and fabricate the new nozzle.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1) Boundary conditions: Material used for this project is high speed steel.
2) Analyze based on nine parameters to produce the optimum nozzle injector.
3) Fabricate the new fuel injector nozzle using the suitable process.
4) Tested the performance and atomization of new spray nozzle using the nozzle tester.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature review had been carry out with reference from sources such as journal, books, thesis and internet in order to gather all information related to the title of this project. This chapter covers about the previous experiment doing by researcher and to go through the result by experimental and numerical.

2.2 COMBUSTION CHAMBER

Combustion chamber design, which includes the shape of the cylinder head, the shape of the top of the piston and the air flow through the inlet ports, is one of the most important factors in efficient operation of the diesel engine. Because of the very short space of time available in a diesel engine in which the fuel and air can mix, various methods have been devised in an attempt to give improved mixing and combustion.

Combustion chambers can be of several designs but all are concerned in creating turbulence to the air during the compression stroke. In the diesel engine, the fuel is in the form of fine particles sprayed into the cylinder after the air has been compressed. To secure complete combustion, each particle of fuel must be surrounded by sufficient air. The mixing of the air and fuel is greatly assisted by the combustion chamber air turbulence. Some engines have helical inlet ports to provide additional swirl. Generally, combustion systems can be classified as direct and indirect injection types.

2.2.1 Direct Injection

With direct injection, the fuel is injected directly into the combustion chamber which is usually formed by a cavity in the piston crown. This cavity is carefully shaped to promote air swirl and the direction of the injector nozzle ensures that rapid mixing of the fuel and air assists complete combustion. The advantage is it is claimed that direct injection gives higher thermal efficiency with lower fuel consumption. This is brought about by the fact that no heat is lost or power wasted in pumping air through a restricted opening into the separate chamber or in discharging the gases from the chamber. This gives easier starting and generally this type of engine does not require a starting aid device, such as glow plugs. But the disadvantage is this kind of injection is prone to "diesel knock". This figure 2.1 shows that direct injection combustion chamber.

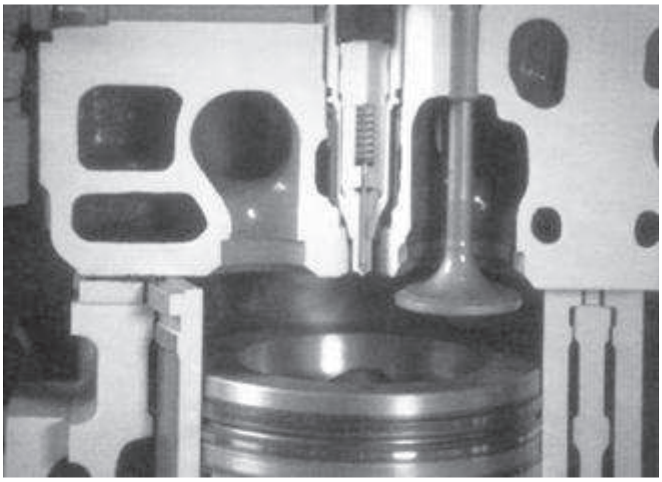


Figure 2.1: Direct injection combustion chamber

Source:http://www.splashmaritime.com.au/Marops/data/text/Med3tex/Engpropmed2.htm

2.2.2 Indirect Injection

The indirect injection or separate chamber system is where a separate small chamber is connected to the main chamber by a narrow passage or orifice. The pre-combustion chamber and the turbulence chamber (also called a compression swirl chamber) work on the same principle. The main physical difference is the location and size of the connecting passage. Figure 2.2 shows the swirl chamber.

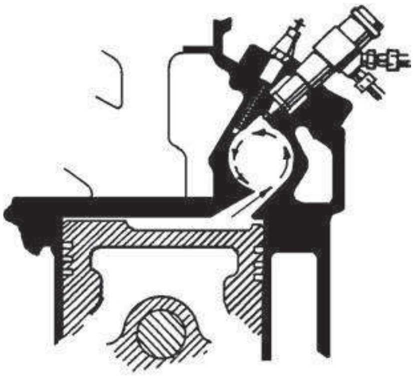


Figure 2.2: Swirl Chamber

Source:http://www.splashmaritime.com.au/Marops/data/text/Med3tex/Engpropmed2.htm

With pre-combustion chambers only about 30% of the combustion air is forced into the chamber, fuel is injected and primary burning takes place in the chamber. This prevents too sudden a rise in pressure which can contribute to the so called 'diesel knock'. The burning mixture of fuel and air is vigorously expelled through the connecting passage into the main combustion chamber or cylinder where an excess of air permits combustion to be completed. The advantages are the lower injection pressures can be used, resulting in less wear of injector nozzles; simpler design of nozzle equipment, which are easier to maintain, and smoother idling of the engine. Engine manufacturers may in some instances use either design in their range, depending on operating requirements. And the disadvantages are not as efficient as direct injection. It can also be prone to pre-combustion burn-out.

2.3 REVIEW OF SPRAY CHARACTERISTICS

The atomisation of liquids is a process of great practical importance. It finds application in many branches of industry: mechanical, chemical, aerospace, metallurgy, medicine, agriculture (Chigier, 1993). In this study, sprays generated by a technically advanced injection system (Indirect injection system) are examined. Investigations into Diesel sprays characteristics have concentrated on the effect of the injection system parameters and ambient conditions (pressure, temperature, density, viscosity) and on global parameters such as the spray tip penetration, break-up length and droplet size and velocity distributions (Figure 2.3).

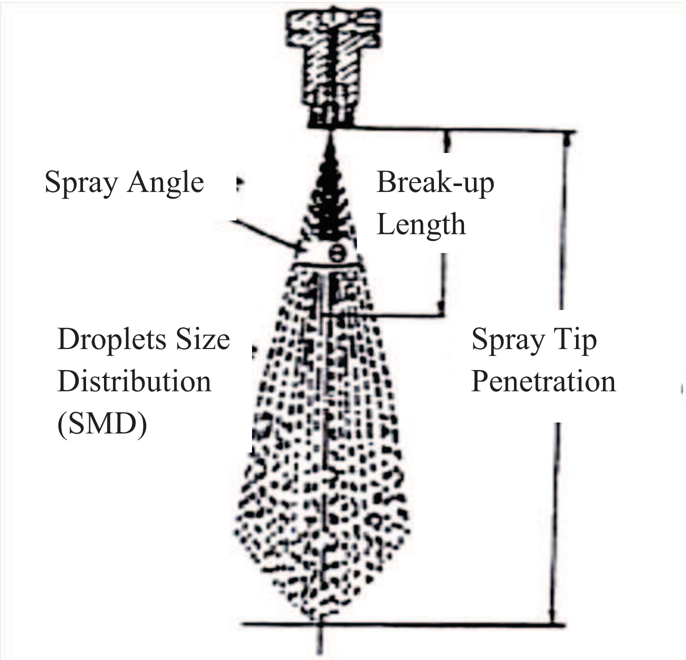


Figure 2.3: Spray parameters

Source: (Hiroyasu & Arai, 1990).

A list of works investigating Diesel sprays would be an extensive list. Therefore, in this chapter and the following one, a review of the literature to provide background about Diesel sprays, sprays in general and phase Doppler systems is undertaken.

2.3.1 Formation of liquid sprays

In the most basic sense, a spray is simply the introduction of liquid into a gaseous environment through a nozzle such that the liquid, through its interaction with the surrounding gas and by its own instability, breaks-up into droplets. The formation of a spray begins with the detaching of droplets from the outer surface of a continuous liquid core extending from the orifice of the injection nozzle (Figure 2.4).

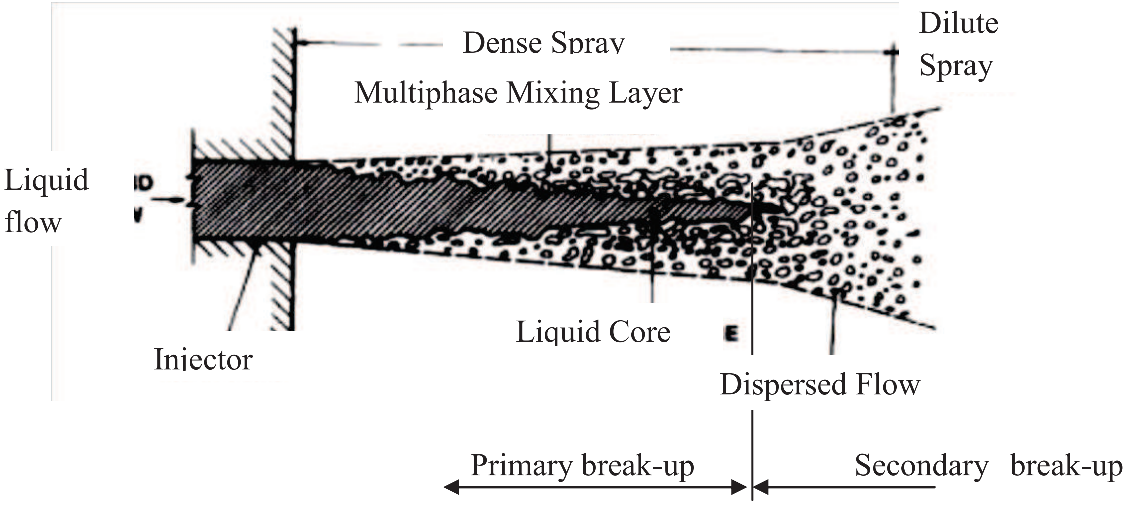


Figure 2.4: Sketch of the flow pattern of a pressure-atomised spray near the nozzle tip region

Source: (Faeth et al., 1995).

The detaching of the liquid core into ligaments or large droplets is called primary break-up, which involves the action of forces internal to the liquid jet. The liquid ligaments and large droplets will further break-up into small droplets due to the interactions between the liquid ambient gas or droplet collisions. The process of this further break-up is called secondary break-up. The near nozzle region, where the volume fraction of the liquid is usually larger than that of the ambient gas is called the dense spray region. Correspondingly, the downstream region where the volume fraction of the liquid is relatively low is called the dilute spray region.

2.3.2 Atomization process

2.3.2.1 Dimensionless criteria of the atomization process

To achieve a fuller understanding of the atomization process, a number of non dimensional numbers have been derived as follows:

1) Weber number (We): expresses the ratio of dynamic forces of an ambient gas to the surface tension. It defines the effect of external factors on the drop development.

$$\mathrm{We} = \frac{Inertia}{Surface\ tension} = \frac{n_g\, d u_d^2}{s_1} \tag{2.1}$$

Where n_g is the gas density, d the droplet diameter, u_d the droplet relative velocity and s l the liquid surface tension.

2) Reynolds number (Re): denotes the ratio of inertial force to viscous force.

$$\mathrm{Re} = \frac{Inertia}{Velocity} = \frac{n_1 U_d L}{\mu_1} = \frac{U_d L}{n_1} \tag{2.2}$$

Where v_l is the kinematic viscosity, n_l the liquid density and L the nozzle length.

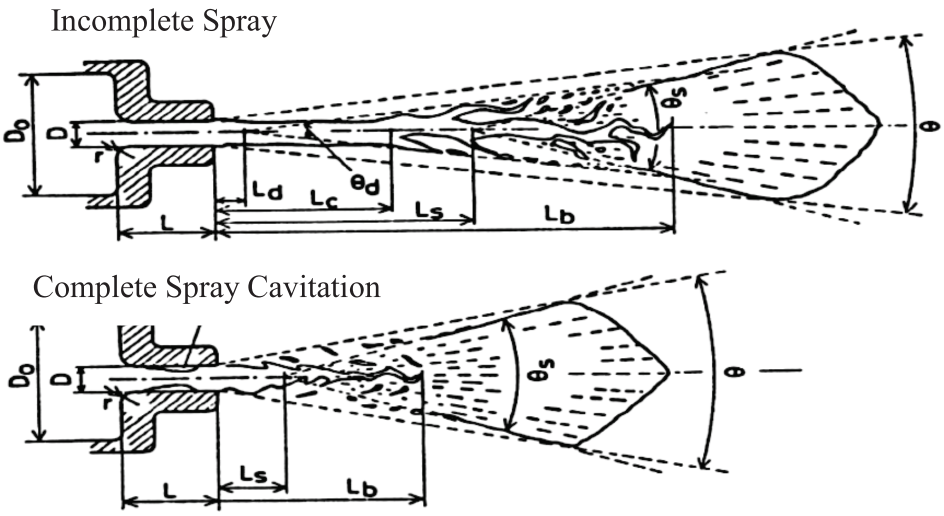
3) Ohnesorge number (Oh): defines the ratio of internal viscous forces to surface tension forces.

$$Z = \frac{Viscosity}{Tension} = \frac{\sqrt{We}}{Re} \tag{2.3}$$

These dimensionless numbers will be used in the structure of Diesel spray section to describe the break-up and the penetration length.

2.3.2.2 Mechanisms of atomization

The process of atomization is one in which liquid is disintegrated into drops and ligaments by the action of internal and external forces; it leads to the spray formation. It proceeds more easily if the liquid is present in a form that is more susceptible to disintegration: thin jets or liquid sheets, because they have the highest surface energy and thus the greatest instability (Lefebvre, 1989). Atomisation plays a major role in the combustion process, where a large amount of droplets are required for better vaporisation, mixing and combustion. The atomisation processes, as shown in Figure 2.5, can be divided into incomplete (laminar flow regime in the injection hole) and complete sprays (cavitating flow regime)



Incomplete Spray

Complete Spray Cavitation

Figure 2.5: Internal structures of complete and incomplete sprays

Source:(Hiroyasu & Arai, 1990).

The atomization process depends mainly on the injection velocity in the nozzle hole. The spray cannot be formed correctly (incomplete spray) for low injection velocities, causing an insufficient atomisation, with a long transformation process from liquid column to droplets. However, when cavitation (complete spray) is initiated in the injection holes, by increasing the injection velocity, dramatic changes occur in the spray structure. A rapid disintegration process from jet to fine spray appears.

2.3.2.3 Effects of injection pressure and nozzle shape on atomization

As previously mentioned, high injection pressures combined with small nozzle hole diameters can provide better spray formation, better air entrainment, better air-fuel mixing, and more homogeneous mixture with lower equivalence ratio and fewer over-rich regions. In a study of a 250 MPa high injection pressure Diesel spray, Minami et al. (1990) concluded that fuel droplets in the spray became finer with an increase in injection pressure, and even finer by using a smaller diameter nozzle hole. However, there are other ways to improve the spray atomisation, such as improvement of the nozzle configuration. Su et al. (1995) pointed out that the nozzle configuration has an important effect on the fuel atomisation. The configuration includes the following factors: the surface area of the nozzle hole, the entrance shape of the hole, the number of holes, the length to diameter ratio, the orientation of the nozzle holes with respect to the nozzle axis and the sac volume.

The authors used a mini-sac injector with two types of nozzle hole entrances: sharp-edged and round-edged inlet. Higher injection pressures resulted in longer spray tip penetrations, narrower spray angles and smaller particle sizes for both nozzle entrance shapes. The sharp edged inlet nozzle produced a wider spray dispersion angle, smaller SMD and a smaller value of particulate emission, compared to the round-edged inlet tip. Atomisation can also be improved by increasing the fuel flow velocity in the nozzle hole. Yoda and Tsuda (1997) found that an increase of the fuel flow velocity enabled the improvement of the atomisation without increasing the injection pressure. The atomisation can also be improved by enlarging the chamfer at the spray hole inlet, which also improved the fuel flow velocity at the spray hole outlet.

2.4 STRUCTURE OF DIESEL SPRAYS

2.4.1 Break-up length

The break-up length characterises a point of discontinuity, where the spray changes from a densely packed zone of liquid (bulk liquid, or interconnected ligaments and droplets), to a finely atomised regime of droplets. After the disintegration of the liquid column emerging from the nozzle, the generated droplets may further break-up into smaller ones as they move into the surrounding gas. Due to a relative velocity between the droplets and the gas, a surrounding non-uniform pressure develops, causing the particles to deform. Development of this deformation leads to break-up into smaller droplets. The forces associated with dynamic pressure, surface tension and viscosity control the break-up of a drop. To achieve a fuller understanding a dimensional analysis can be carried out.

Shimizu et al. (1984) measured the break-up length in the spray flow region by measuring an electrical resistance between the nozzle and a fine wire net located in the spray jet. The researchers found that the break-up length decreased with an increase in injection velocity, finally reaching a constant value. The same technique was applied by Hiroyasu and Arai (1990) for the effects of injection velocity, ambient pressure and nozzle geometry on the jet break-up length. Figure 2.6 displays the effects of these parameters on the break-up length. The injected liquid did not break-up instantly after the start of injection. There is about 10-30 mm of break-up length; even when the injection pressure is higher than 20 MPa.

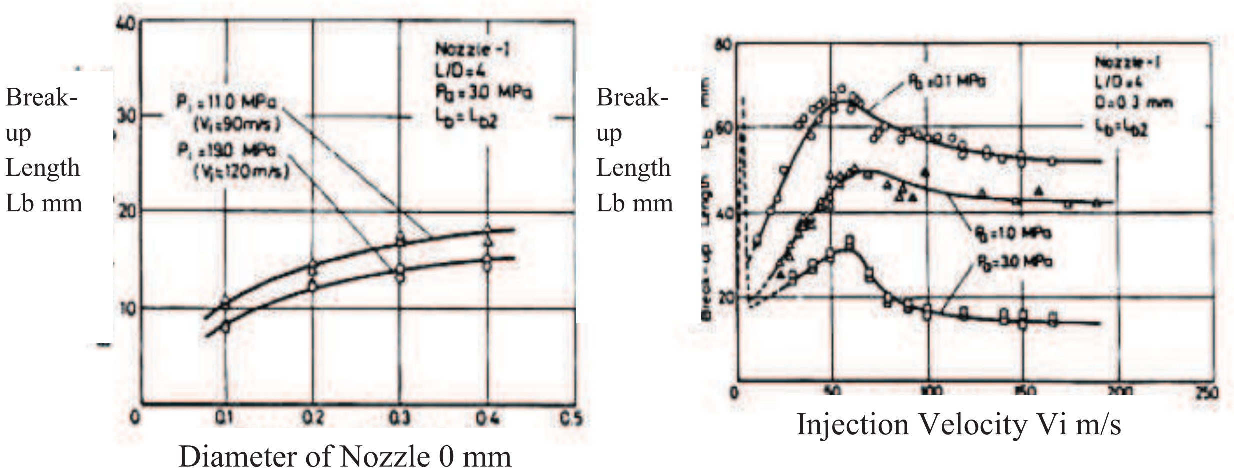


Figure 2.6: Effect of nozzle diameter and injection velocity on break-up length

Source: (Hiroyasu & Arai, 1990)

The authors also found that the break-up length varied inversely with ambient pressure, but its dependence on injection velocity is more complicated. Breakup processes and momentum both contribute to determine the break-up length, resulting in a non-linear dependence on injection velocity (Figure 2.7).

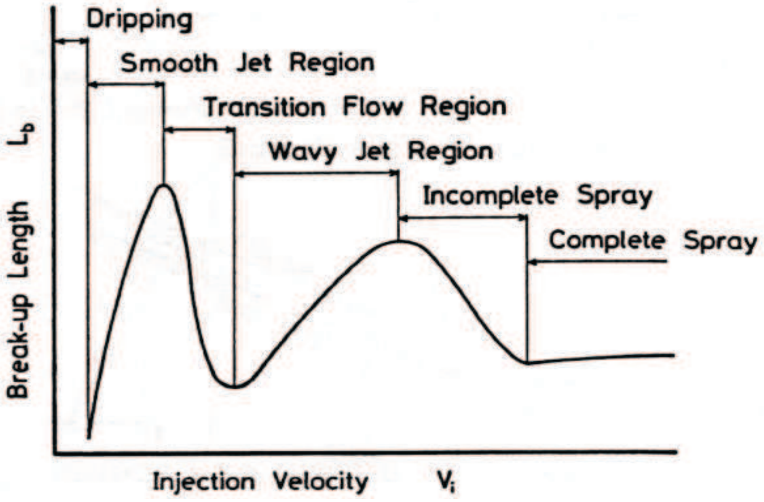


Figure 2.7: Break-up behaviour of a liquid jet

Source: (Hiroyasu & Arai, 1990).

A correlation valid for any complete region was developed considering the effect of the nozzle shape and the cavitation number on the break-up length.

$$\mathrm{L_b} = 7\mathrm{Dn}\left(1 + 0.4\ \frac{r}{d}\right)\left(\frac{P_a}{n_1 V_1^2}\right)^{0.05}\left(\frac{L}{D}\right)^{0.13}\left(\frac{n_1}{n_g}\right)^{0.5} \tag{2.4}$$

Yule and Filipovic (1992) measured the break-up zone characteristics of Diesel sprays injected into a high-pressure gas. Three different single-hole nozzle diameters were used: 0.265 mm, 0.213 mm and 0.46 mm with L/D ratio of 2, 3.6 and 1.65 respectively. The mean injection pressures during full opening pressure were 21 MPa, 31.2 MPa and 25.4 MPa and the injection durations were 1.36 ms, 1.5 ms and 1.9 ms correspondingly. The authors estimated the break-up length with indirect techniques which included the computation of the overall void fraction of the spray, as a function of time, and curve fitting a new penetration correlation that incorporated break-up time as an adjustable empirical constant. With curve fitting of the correlation to the measured spray tip penetration length, the breakup time, the break-up length and the characteristic velocity in the break-up zone were obtained:

$$\frac{\mathrm{L_B}}{\mathrm{D_N}} = 2.8\times\ 10^4 We_B^{-0.46} \tag{2.5}$$

$$\mathrm{t_b} = 8.9\times\ 10 We_B^{-0.46} Re_B^{-0.3}\,\frac{D}{U_{inj}} \tag{2.6}$$

$$\frac{U_{inj}}{U_b} = 3.17 Re_B^{-0.3}, \tag{2.7}$$

where $We_B = \frac{n_g U_B^2 D}{S_1}$, $Re_B = \frac{U_B D_e}{n_1}$, $D_e = D\left(\frac{n_1}{n_g}\right)^{0.5}$. These equations are applicable for Re_B<105. Note that the calculation of ReB is based on derived diameter De.

Yule and Salters (1995) found, with a flat probe, that Diesel spray break-up length is of the order of 100 nozzle diameters at gas density corresponding to those found at realistic operating conditions. Also the break-up length increases with liquid viscosity. In addition, the authors discovered that the unbroken liquid structure appears