? kinematic viscosity ?o film thickness

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Abstract

The fuel spray in gasoline engines problem has been an issue of importance for creating a suitable mixture during the engine load and speed variation to avoid knocking. This paper describes theoretical and experimental investigations for an important stage of injected gasoline called the primary fuel spray. This stage two dimensional (2D) is challenging because of the difficulty in determining velocity and length at very short time, so it was studied specially the dispersion of the sheet by using the linear instability sheet atomizer model (LISA). Experimentally the Phase Doppler Anemometer (PDA) is used at laboratory of Cardiff university to check the sheet length. The paper concerned on study the effects of some parameters on primary spray characteristics like as liquid fuel sheet thickness, velocity and length which are described the initial value of the fuel spray droplet. Injection pressure was varied 5, 13 and 14 MPa under combustion chamber pressure (ambient pressure) (0.1, 0.5 MPa), while the nozzle diameters is varied (0.2, 0.3, 0.4, 0.5 mm). LISA model was used to solve this stage of spray by using Pressure-Swirl type of injector. The results show at an increase of the injection pressure, the velocity increased, while the sheet thickness and length were decreased. When the ambient pressure was increased; sheet velocity decrease and slightly decreasing happened in sheet length and thickness. Comparison the results with experimental results showed a good agreement.

Index terms— experimental investigations, LISA, PDA, nozzle diameters.

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1 GJRE-J Classification

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2 Symbols

3 GDI

4 Gasoline

5 Introduction

he advantages of the gasoline direct-injection (GDI) engine over the port-injection engine are the improved fuel economy, reduced unburned hydrocarbons (UBH) and CO emissions, and more precise air-fuel ratio control. The injected gasoline consists three main stages (sheet, ligaments and finally drops) see Fig(**??**). The primary stage is an important part of the fuel injection which effects on the spray droplet diameter, penetration and shape of mixture **??**1]. Despite the large number of investigations carried out so far for droplet behaviour, while the primary stage is stilled not fully understood. The weak of understanding of the fuel sheet length and thickness needs further investigation.

researchers have investigated spray behaviour and atomization characteristics of high-pressure gasoline swirl injector for a direct injection gasoline engine. Recently, a comprehensive overview on the mixture formation and combustion control in a spark-ignited direct-injection gasoline engine was reported by Zhao et a1. (1995) **??**1]. In 2003, Kawahara [2] made an experimental investigation of primary spray structure under high pressure swirl injector which is used in gasoline direct injection engine, He used Ar-ion laser sheet and high speed video camera (1 Mfps). The objective of his work is to investigate the macroscopic and microscopic characteristics of gasoline injector for GDI engine by numerical approach applying the LISA (Linear instability Sheet Atomizer) breakup model and experimental method. The global spray behaviours such as spray tip penetration and spray data of fuel injector are captured by the Phase Doppler Anemometry, and the atomization characteristics such as spray droplet size and velocity distribution of the gasoline direct injector are measured by using phase Doppler Particle Analyzer system. The LISA breakup model is used to obtain the results of the numerical calculation. Based on the results of the calculation, the numerical results of models are compared with the experimental results such as spray shape, local SMD, axial mean velocity, and the distribution of the droplet breakup.

In the present work, the primary spray stage of injection theoretically and experimentally and the effects the pressure of the fuel injection -injector diameter and ambient pressure on the fuel speed-length and thickness of sheet.

6 II.

7 The Primary Stage Model (lisa)

While a variety of models of secondary breakup has been proposed, and tested in CFD codes, a reliable model for primary breakup is yet to reveal. Linear instability sheet atomizer or LISA model is mostly used in direct injection, spark ignition engines. Primary region model used the integral nozzle flow parameter i,e: mass rate, initial velocity, orifice diameter to predict the initial drop size distributions. The model well known as wave model by Reitz [3]. For this model the pressure swirl atomizer is imposed to create, angular momentum on the liquid flow resulting the swirling motion. Centrifugal force is caused by swirling motion in the liquid spreads it out in the form of conical sheet as soon as leave the nozzle. A hollow cone spray is produced after the injector. This sheet is breakup to droplet by exposing to aerodynamic instabilities. The hydrodynamic mechanism process of this stage as:III.

8 Sheet Growth Rate

This model assumes that a two-dimensional, viscous, incompressible liquid sheet of thickness 2h moves with relative velocity U through an inviscid, incompressible gas medium. The liquid and gas have densities of ? l and ? g , respectively, the viscosity of the liquid is ? l , and surface tension is ?. A coordinate system is used that moves with the sheet, and a spectrum of infinitesimal disturbances of the form [4].

9 (

)t ikx ? ? ? + = exp ? (1)

is imposed on the initially steady, motion-producing fluctuating velocities, and pressures for both the liquid and the gas. In Eq. (1) ? 0 is the initial wave amplitude, k=2?/? is the wave number. The most unstable disturbance has the largest value of ? r , denoted here by ?, and is assumed to be responsible for sheet breakup (ligaments). Thus, it is desired to obtain a dispersion relation ? = ?(k) from which the most unstable disturbance can be deduced.

Squire [5] has shown that two solutions for above equation to find growth rate (?), or modes, exist that satisfy the liquid governing equations subject to the boundary conditions at the upper and lower interfaces. For the first solution, called the sinuous mode, the waves at the upper and lower interfaces are in exactly phase. On the other hand, for the varicose mode, the waves are ? radians out of phase (see Figure 2). Clark and Dombrowski [6] used a second-order analysis to solve the equation of sinuous wave motion on a flat sheet and obtained a solution for liquid sheet length. To summarize, the theoretical analyses show that waves at the liquid surface are a major factor that causes liquid sheet instability and result ine disintegration. So, the present work is focused on growth of sinuous waves on the liquid sheet. Senecal et al [4] derived the dispersion relation for the sinuous mode from equation (1) to get the growth rate, which is given by:) [ ] ( ) [ ] ( ) ( ) 0 2 tan 4 tan 4 2 tan 4 tan 3 2 2 3 2 4 2 2 = + ? ? + + + + l l l l k k Q kh L k kh k iQkU kh k Q kh ? ? ? ? ? ? (2)

Where: Q=? g /? l and l = k 2 + ?/ ? l ? is kinematic viscosity

The dispersion relation can further be simplified based on the wavelength of the wave. (i) Squire [5] assumed that long waves grow on the interfaces so that tanh(kh)=kh. And in the limit of Q «khEq (2) reduces to wave growth equation for long waves given byh k h k QU k k l l ? ? ? ? ? 2 2 4 2 2 4 2 ? + + ? = (3)

This relation is similar to Dombrowski and John's expression [7] (ii) For the short waves, which means tanh(kh) is approximated to unity. It is assumed that the growth rate is independent of the sheet thickness and in the limit of Q«1, equation (3) reduces to:l l k k QU k k ? ? ? ? ? 3 2 2 4 2 2 4 2 ? + + ? = (4)

If viscosity is neglected, Eq. (**??**) for long waves reduces toh k h k QU l ? ? ? 2 2 ? = (5)

And Eq. (**??**) for short waves reduces tol k k QU ? ? ? 3 2 2 ? = (6)

To calculate maximum growth rate (?) for the inviscid long wave from Eq. (5), which occurs at a dimensionless wave number of k S h=1/2We g ,g long QWe U h 2 1 = ? ? ? ? ? ?? (7)

and the calculation maximum growth rate (?) for the short wave analysis, Eq. (**??**), which occurs atK S h=2/3We g , 3 3 2 Q We U h g short = ? ? ? ? ? ?? (8)

To check the wave length condition, the critical We number must be used. The critical We is given by We g =27/16. Above We g =27/16, the fastest growing waves are short, and below 27/16, the wavelengths are long compared to the sheet thickness.

Eq. (1) shows that the growth rate of short waves is independent of the sheet thickness. When the amplitude of gasoline sheet reached the maximum value, the breakup happened. At that moment the growth rate becomes (?), amplitude becomes (? b), the corresponding breakup time (t b) and the breakup length L. When substitute equation (**??**) into (1) and neglecting the imaginary part to calculate (? b), equation (1) becomes:( ) b b t ? = exp ? ? ? Which, it due to: ? ? ? ? ? ? ? ? ? = o b b t ? ? ln 1 (9)

The term ln (? b /? o) has an assigned value of 12 as suggested by [8].

IV.

10 Sheet Velocity

The centrifugal motion of the liquid within the injector creates an air core surrounded by a liquid film.

The thickness of the film, ? o , is related to the mass flow rate by [9]:( ) o o o l l d u m ? ? ?? ? =**(10)**

Where: d 0 is the atomizer exit, m l is the liquid mass flow rate, u the axial component of velocity at the exit and ? 0 is film thickness. This quantity depends on internal details of the injector and is difficult to calculate from first principles.

The sheet velocity, U l , is assumed to be related to the injector pressure drop, Î?"P, byl v l P k U ? ? = 2**(11)**

Some researcher has noted that k v is a function of the injector design and injection pressure. If the swirl ports are treated as nozzles, Eq. (11) is then an expression for the coefficient of discharge for the swirl ports, assuming that the majority of the pressure drop through the injector occurs at the ports. The coefficient of discharge for single-phase nozzles with sharp inlet corners and an L/D of 4 is typically 0.78 or less and 0.88 [10]. Physical limits on k v are such that it must be less than unity by conservation of energy, and it must be large enough to permit sufficient mass flow. To guarantee that the size of the air core is non-negative, the following expression is used:? ? ? ? ? ? ? ? ? = P D m k l l o l v 2 cos 4 7 . 0 max 2 ? ? ? ? (12)

where ? is the spray half-angle.

Assuming that the pressure drop is known, u l is found from? cos l U u = (13) V.

11 Sheet Thickness and Length

The initial half-thickness h o can be related to the film thickness (? o) within the nozzle diameter d o , by the expression Then, the sheet half-thickness at L is given by:[ ] o o o o o d L d h ? ? ? ? ? ? + ? = sin 2 cos / 2 (16)

Where: ? o is the film thickness, measured perpendicular to the injector axis, at the nozzleexit.

12 VI.

13 Drop Formations

The breakup occurs when the amplitude of the unstable waves is equal to the radius of the ligament; one drop will be formed per wavelength. In either the short wave or the long wave case, which are explained in eq. (??). At the point of breakup, fluid ligaments are formed with diameter calculated from the mass balance, as:s l k h d 16 = (17)

Where is the wave number corresponding to the maximum growth rate (?) and the sheet thickness (h) at the breakup location. l l l l l d d K 1 . 2 3 2 1 2 1 2 1 ? ? ? ? ? ? ? ? + = ? ? µ (19)

The physical mechanism of sheet disintegration proposed by [10] is adopted in order to predict the drop sizes (d D) produced from the primary breakup process.

The procedure of calculation this stage of gasoline in primary stage was explained in the figure (5) below.

14 VII.

15 Experimental Analysis

Laser Doppler Anemometry (LDA) is a nonintrusive absolute laser diagnostic system that is capable of recording the transient nature of a seeded flow-field. However, when applied to sprays the droplets the mselves act as the seeding particles. Phase Doppler Anemometry (PDA) is an extension of LDA that allows the simultaneous measurement of velocity component and droplet diameter size. This technique is used for other numerous applications but will be described here in relation to spray applications. First the principles of operation will be briefly explained, and then the method of data collection and post-processing techniques will be described.

Several techniques have been developed to measure properties of sprays such as the droplet size. Most techniques use radiation as a probe at optical wavelengths. In a two-phase injector, the sensitivity and dynamic range of such techniques must allow measurement of dense sprays with a droplet size distribution that may vary over one or two orders of magnitude. Phase Doppler Anemometry (PDA) is the standard technique for spray investigations **??**10, 11 and 12]. It gives both size and velocity information on individual droplets. The experiment was done under conventional ambient conditions (1 bar, pressure and 21 o C, temperature), fuel was a gasoline and injected at 10 MPa pressure and environmental temperature, the diameter f the nozzle is 0.2 mm.

The data was acquired at 5mm downstream the tip of nozzle, which expected exist of a parent drop d D . Ten points in radially direction at 5mm downstream, the data was acquired.

This experiment was done in Laser laboratory of university of Cardiff in Wales, United Kingdom.

16 VIII.

17 Results and Discussion

The paper concerned on study the effects of some parameters on primary spray characteristics like as liquid fuel sheet thickness, velocity and length which are described the initial value of the fuel spray droplet.

Figure (6) shows the effect of injection pressure on the sheet thickness of gasoline injected inside combustion chamber under conventional condition of air (1 bar pressure and 21 o C). The results show that the sheet thickness decreases when the injection pressure of the gasoline is increased, this is due to the increasing in the axial and angular fuel velocity which is force the fuel outer side and increases the air core inside the nozzle.

Also, figure (6) showed the effects of the injector hole diameter on the sheet thickness of injected gasoline directly to combustion chamber, when increase the diameter of the injector, the liquid sheet thickness increased too. When increasing the diameter of the injector, the sheet velocity decrease and due to the increasing in thickness. **??**), shows the effect of the injection pressure on the velocity of the fuel at the nozzle exit, which proportional by square root to the injection pressure, it is clear that in the equation (9). When the **??**) presented the effect of fuel injected pressure on the liquid sheet length. From the figure, it's clear that the increasing the injection pressure affect to decreasin g in the fuel sheet length due to increasing in the velocity and increase in the dispersion and growth rate which affects on increasing the wave amplitude then happening of the breakup. The fuel injection pressure play an important rule of spray mechanism. There is an limitation for increasing the injection pressure at gasoline engines due to the droplet size and mixture [4].

Injection pressure (Mpa) The effect of the fuel injection pressure on the fuel sheet velocity was presented in figure (9). The results showed that an increasing in the fuel pressure caused the increasing in the fuel velocity due to increasing in the dragging force on the droplets. Which affects a fast transferring the momentum from the droplet to the surrounding air. There is no effect of the ambient pressure at high injection pressure. Figure (10) showed the effect of the injection pressure on the liquid sheet thickness, where increase the pressure slightly decrease the thickness of the sheet due to the increasing the dragging force which decreasing the velocity which increased the ligament region and then droplet phenomena. Also low effect of the ambient pressure at high injection. In the figure (11), the behaviour of the sheet length had a slightly decreased when increasing the injection pressures because of dependence of sheet length on thickness.

18 Conclusions

? The primary sheet breakup seen to have the ability of describing and presenting the fuel spray typical in DISI engines. So from this research, we concluded that the increasing in injection of fuel pressure would made decreasing in length of sheet and thickness, but increasing the velocity. ? The strategy developed has been tested on simple case of swirl injector (pintle type) under the typical conditions predicted a quantitative results with a good agreement with a similar test cases of the experimental.

? The primary stage of the gasoline spray play an important role in fuel mixture condition. Both sheet length and thickness are affected on the rate of droplet evaporation and the time required to complete mixture. So high length and thickness of the fuel sheet mean the rate time of creating ligaments and droplet is high. Finally that delays the combustion process. ? Variable pressure injector is the main demand for the modern technology engine to provide the optimum sheet length and thickness the avoid knocking.

References Références Referencias [1] [2]

Figure 1:

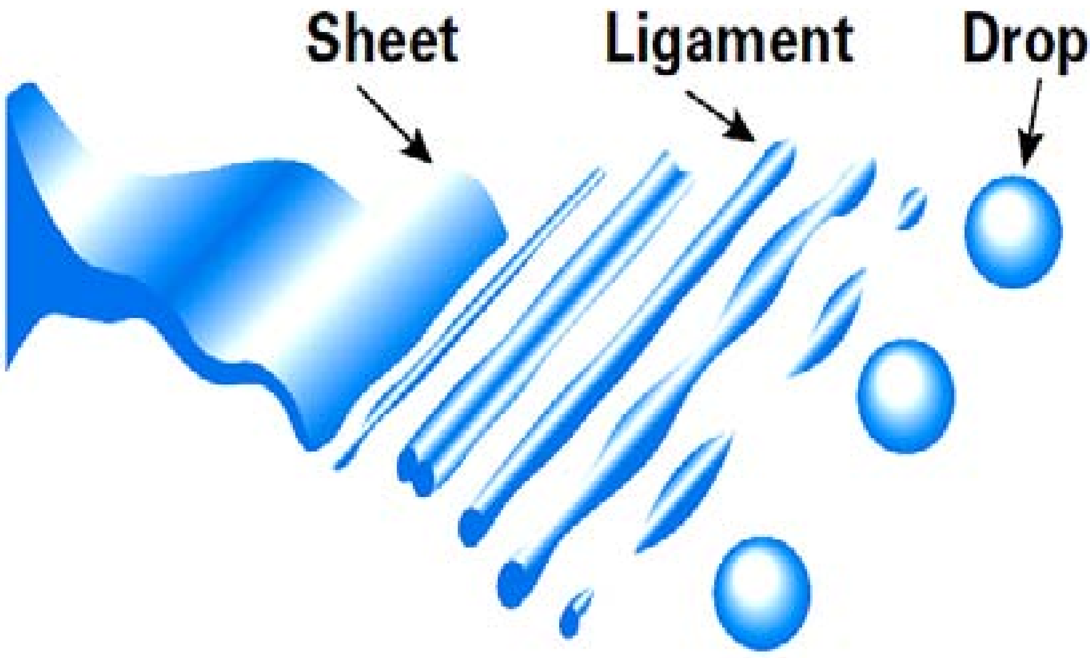

Figure 2:

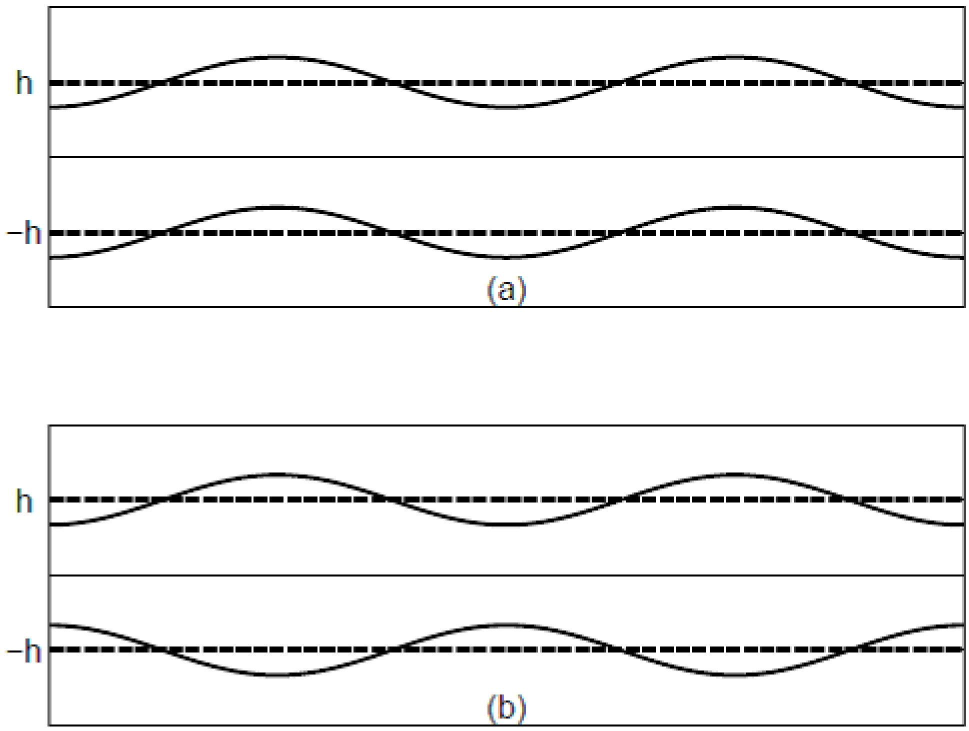

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Figure 3: Figure 2 :

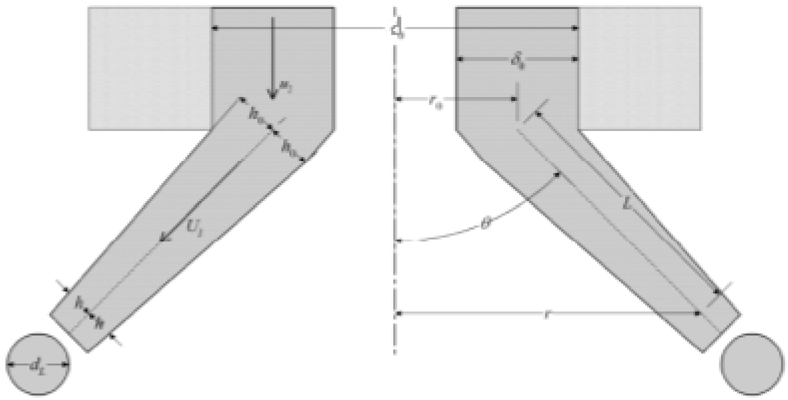

Figure 4:

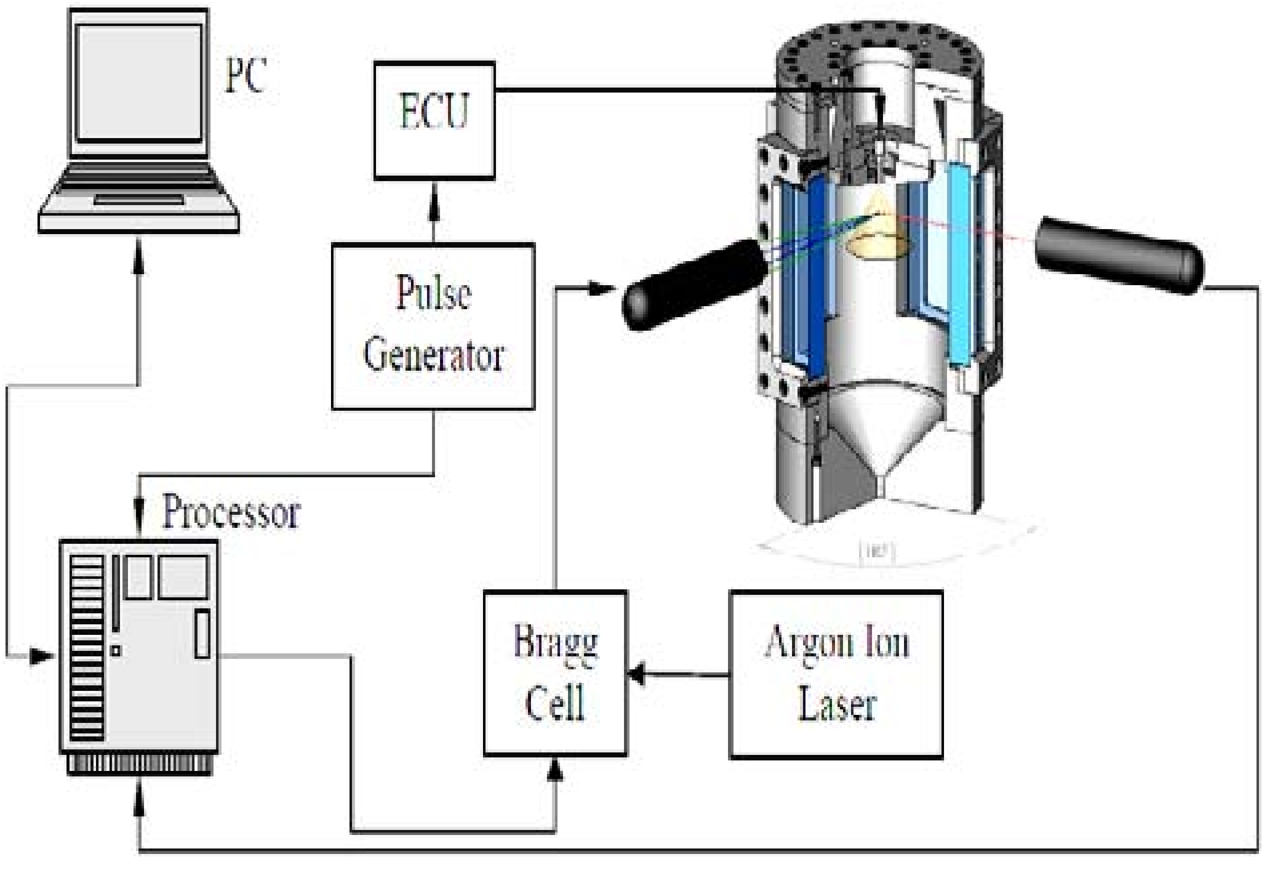

Figure 5: (

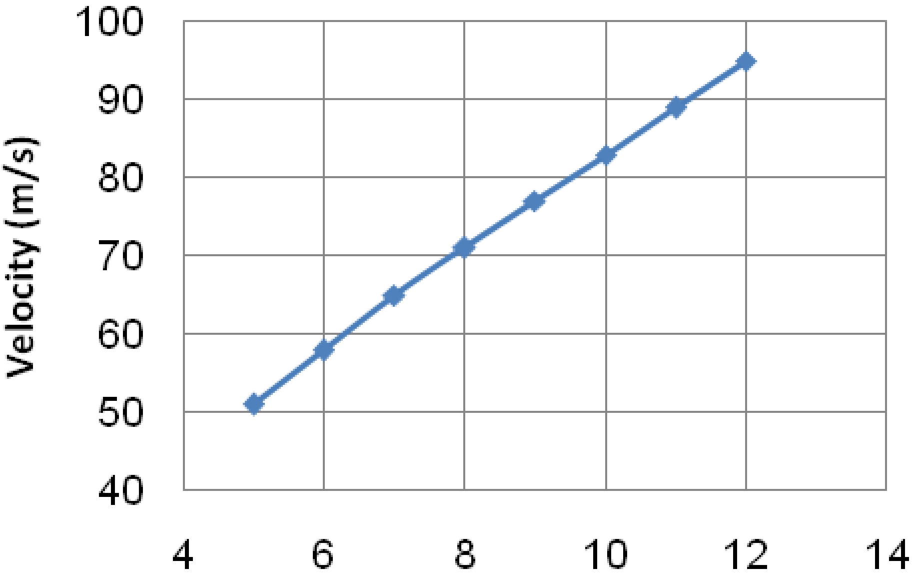

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Figure 6: Figure 3 :

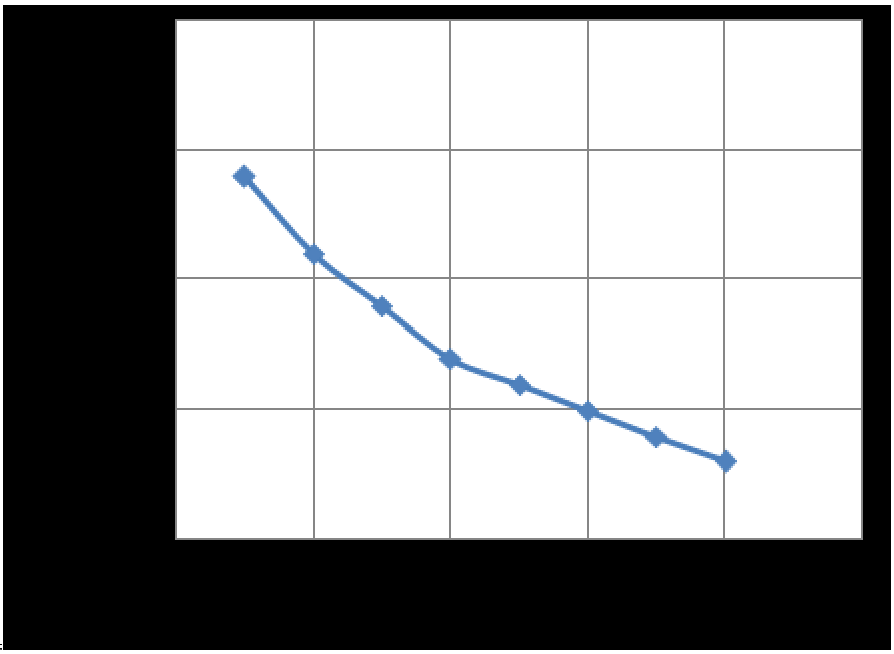

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Figure 7: Figure 4 :

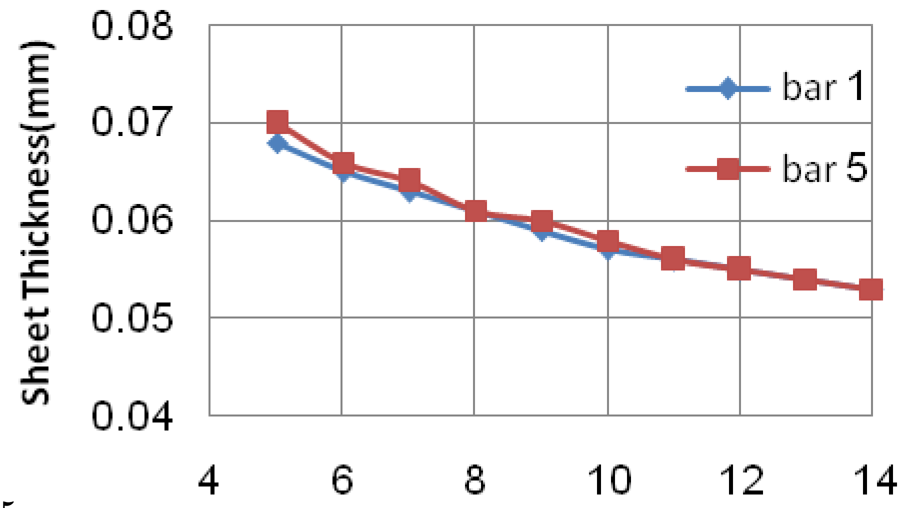

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Figure 8: Figure 5 :

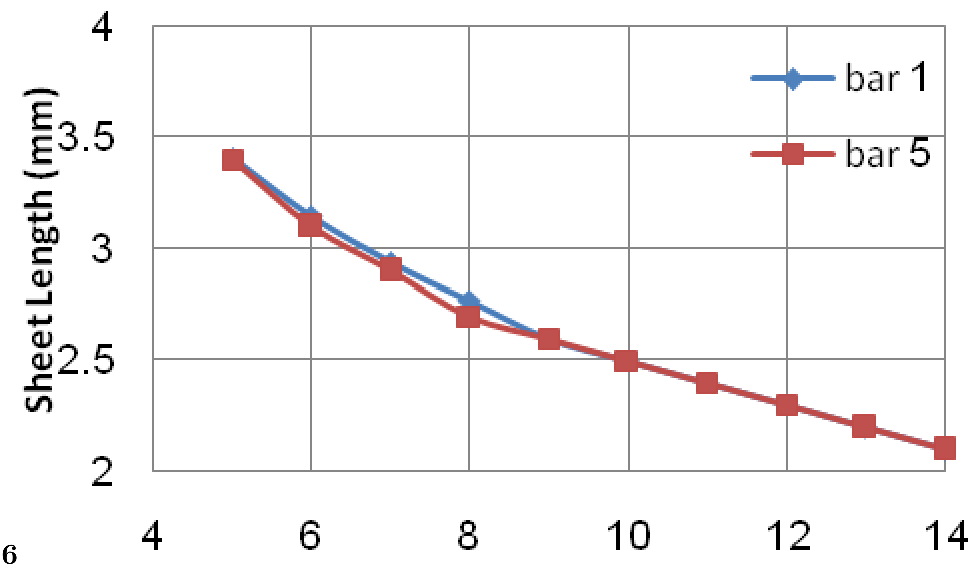

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Figure 9: Figure 6 :

of

		IX.
used parameters		
Mass of fuel injected	9	mg
Injection duration	6	ms
Viscosity	3x10-3	N/s
Density	745	kg/m3
Surface tension	2.25	N/m
Injection pressure	5,?14	MPa
Spray half angle	60	degree
Nozzle diameter	0.2,?,0.5 mm	

Figure 10: Table of

18 CONCLUSIONS

[Kawahara] , Kawahara .

[Chryssakis ()] *A Unified Fuel Spray Breakup Model For Internal Combustion Engine Applications, A dissertation submitted IN Doctor of Philosophy (Mechanical Engineering*, Christos Chryssakis . 2005. The University of Michigan

[Clark and Dombrowski ()] ‘Aerodynamic instability and disintegration of inviscid liquid sheets’. C J Clark , N Dombrowski . *Proc. Roy. Soc. A* 1972. 329 p. .

[Boretti (1989)] ‘Experimental Study of a two phase Flow in the Near Field of an Air Blast Atomizer’. A Boretti . *ASME/ASCE Mechanics Conference Forum on Turbulent Flows*, (La Jolla, CA) 1989. July 1989. 76.

[Squire ()] ‘Investigation of the instability of a moving liquid film’. H B Squire . *British Journal of Applied Physics* 1953. 4 p. .

[Gal et al. ()] ‘Laser Sheet Dropsizing of dense sprays’. P Le Gal , N Farrugia , D A Greenhalgh . *Optics & Laser Technology* 1999. 31 p. .

[Han et al. ()] ‘Modeling atomization processes of pressure-swirl hollow-cone fuel sprays’. Z Han , S Parrish , P V Farrell , R D Reitz . *Atomization and Sprays* 1997. 7 p. .

[Senecal et al. ()] ‘Modeling highspeed viscous liquid sheet atomization’. P K Senecal , D P Schmidt , I Nouar , C J Rutland , R D Reitz , M L Corradini . *Int. J. Multiphase Flow* 1999. 25 p. .

[Reitz ()] ‘Modelling Atomization processes in High pressure Vaporizing Spray’. R Reitz . *Atomization and spray Technology* 1987. 3 p. .

[Sirignano and Mehring ()] ‘Review of theory of distortion and disintegration of liquid streams’. W A Sirignano , C Mehring . *Prog. Energy Combust Sci* 2000. 26 p. .

[Dombrowski and Johns ()] ‘The aerodynamic instability and disintegration of viscous liquid sheets’. N Dombrowski , W R Johns . *Chemical Engineering Science* 1963. 18 p. .

[Dombrowski and Hooper ()] ‘The ambient Density on Droplet Formation in Sprays’. N Dombrowski , P C Hooper . *Chem. Eng. Sci* 1962. 17 p. 291.