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Spray Behavior Comparison in Diesel Engine with Biodiesel as Fuel

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Abstract

Sprays are among the very main factors of mixture formation and combustion quality in almost every internal combustion engine. In present study spray penetration depth of various spray models are compared with the variation in injected pressure. The Mahua oil is taken as a biodiesel is the present study and Hiroyasu model can be used for predicting the performance of Mahua biodiesel. Hiroyasu model is found best model among all models studied for high injected pressure. The penetration depth difference of Hiroyasu and Arregle models increased sharply with lapse of time.

Keywords: biodiesel; penetration depth; injection pressure; spray.

1. Introduction

Due to an increase in oil price and further stringent emission control regulations, the investigation of alternative fuels has attracted more and more attention. The requirements for the energy security and environmental protection lead to an increasing efforts in the utilization of alternative fuels in the automobile engines. As an alternative diesel fuel, biodiesel fuel is a clean and renewable energy source. Biodiesel fuel is presently of great interest and an important research subject for PM reduction from diesel engines to meet further stringent emission control regulations.

Roisman et al. (2007) there have been many experimental and theoretical investigations on the diesel spray penetration and cone angle at the ambient pressure in the chamber. These work suggested that spray penetration was determined by two major factors, inertia of liquid/air mixture in the steady conical spray region and the particular conditions near the leading spray edge. It is suggested that the diesel spray penetration length decreased with increase of in-cylinder pressure, and tip penetration decreased due to increase of vaporization rate at the high ambient gas temperature. Fang et al. (2008) experimentally investigated spray and combustion characteristics of diesel, biodiesel, and diesel-biodiesel blended fuels by using visualization system in a small-bore HSDI diesel engine. They reported that the longer penetration and ignition delay were observed with higher biodiesel content. Kuti et al. (2010) studied effect of injection pressures at 100 MPa and 200 MPa respectively on the ignition and combustion characteristics of biodiesel fuel spray injected by a common-rail injection system for a direct-injection diesel engine was investigated. Two biodiesel fuels (namely biodiesel fuel from palm oil (BDFp) and biodiesel fuel from cooking oil (BDFc)) and JIS#2 diesel fuel were utilized in this research. They suggested that, at all injection pressures, the biodiesel fuel palm oil (especially BDFp) gave a longer spray tip penetration and a smaller spray angle under non-evaporating conditions while liquid-phase penetration length was longer for biodiesel fuels than for diesel under evaporating conditions. Using a simplified model for air entrainment by the sprays, the BDFp and BDFc exhibited lower mass ratios of air to fuel than diesel. The ignition delay was longest for the BDFc while it was shortest for the BDFp. Xiangang et al. (2010) studied the effect of injection pressure on nonevaporating spray and spray flame characteristics of biodiesel fuel injected by a common rail injection system in a constant volume combustion vessel. Two biodiesels, biodiesel from palm oil (BDFp) and biodiesel from cooked oil (BDFc) were investigated, including JIS#2 Diesel. Injection pressures of 100, 200 and 300 MPa and ambient environment typical of diesel engine were used. Nonevaporating spray result showed that biodiesel fuels give longer spray tip penetrations and narrower spray angles especially for BDFp. Integrated flame luminosity of BDFp and BDFc show lower values compared to that of diesel at injection pressure of 100 MPa, and integrated flame luminosity of BDFp and BDFc is even lower than that of diesel at injection pressures of 200 and 300 MPa. At an injection pressure of 300 MPa, the soot formation was extremely low for BDFp and BDFc. This indicates that significant soot reduction can be achieved by using BDFp and BDFc at high injection pressures. Hossainpour et al. (2009) has been used a CFD code to study the detailed modeling of spray and mixture formation in a caterpillar heavy-duty diesel engine. With respect to the liquid-phase, spray calculations are based on a statistical method referred to as the Discrete Droplet method (DDM). The predicted results were validated by comparing with existing experimental data. A good agreement between the predicted and experimental values ensures the accuracy of the numerical predictions collected with the present work. Showry et al. (2010) used commercial validation tool FLUENT was used for numerical simulation. This tool solves the basic governing equations of fluid flow that is continuity, momentum, species transport and energy equation using FVM. Turbulence was modeled by using standard k-ε model. Injection was modeled using lagrangian approach. The reaction was modeled using non–premixed combustion which considers the effects of turbulence and detailed chemical mechanism into account to model the reaction rates. The specific heat for all the species was approximated by using piecewise polynomials. They reported that simulation has been carried for triple injection and comparison with experimental results and have shown good agreement. Rao et al. (2007) this work involves the analysis of the combustion, performance and emission characteristics of a direct injection diesel engine fuelled with jatropha methyl ester (JTME), diesel and their blends. JTME is prepared by the alkali transesterification of Jatropha oil with methanol. The combustion parameters are determined by measuring in-cylinder pressure with respect to crank angle. The results show that ignition delay, maximum heat release rate and combustion duration are lower for JTME and its blends compared to diesel. Though JTME and its blends recorded lower Brake thermal efficiency, they have lower tail pipe emissions as compared to diesel, except for nitrogen oxides. Bakar et al. (2008) studied Fuel injection pressures in diesel engine plays an important role for engine performance obtaining treatment of combustion. The present diesel engine using direct injection, the pressures can be increased about 100-200 Mpa bar in fuel pump injection system. According to the result, the best performance of the pressure injection has been obtained at 220 bar. Jin et al.(2009) This paper presents an experimental study on the spray characteristics of diesel-methyl ether (DME) blended fuels by phase doppler anemometry (PDA) Blended fuels with DME mass fractions of 15%, 30% and pure diesel fuel were used to evaluate the effect of the DME concentration on spray pattern, droplet size and velocity. The data for spray velocity vector and droplet size field were obtained. The experimental results revealed that the micro-explosive function existed in the jet of diesel-methyl ether (DME) blended fuels and the radial velocity of the blended fuels spray is larger than that of conventional diesel fuel spray near the nozzle exit. Downstream part of the spray, the radial velocity and its attenuation rate of blended fuels are much more uniform and smaller than those of pure diesel spray. At the centreline of the spray, the attenuation rates of all spray axial velocities are similar. With the increase of DME concentration in the fuel, the spray angles and the exit velocity increase and the droplet size deceased. Kim et al. (2010) The purpose of this study was the experimental investigation of Soybean oil Methyl Ester (SME) and DiMethyl Ether (DME) spray characteristics injected through the common-rail injection system under various ambient pressures. A high pressure chamber that can be pressurized up to 4 MPa was utilized for a change of ambient pressure. In order to compare the spray development and atomization characteristics, the images of SME and DME were obtained by using a high speed camera with two metal halide lamps under various ambient pressures in the spray chamber.

From these spray images, the spray characteristics such as the spray penetration from the nozzle tip, maximum radial distance, and spray diameter were measured and analyzed. In addition, the Sauter Mean Diameter (SMD) of two fuels under ambient pressure was analyzed using the droplet measuring system. It was revealed that the axial distance of spray from the nozzle tip of the SME spray is longer than that of DME spray under same injection condition. The axial penetration, maximum radial distance, and spray diameter decreased when the ambient pressure in the chamber increased. As the ambient pressure increased, the SMD decreased and the DME spray showed a superior atomization performance compared to the SME spray. Wang et al. (2010) Spray characteristics of biodiesels (from palm and cooked oil) and diesel under ultra-high injection pressures up to 300 MPa were studied experimentally and analytically. The study showed that biodiesels give longer injection delay and spray tip penetration. The approximately linear relationship of non-dimensional spray tip penetration versus time suggests that the behavior of biodiesel and diesel sprays is similar to that of gaseous turbulent jets and estimation on spray droplet size showed that biodiesels generate larger Sauter mean diameter due to higher viscosity and surface tension. He et al. (2008) the spray tip penetration of biodiesel increased and its spray cone angle decreased when the ambient pressure become lower. Also, the penetration more affected by the ambient pressure than the injection pressure. There are various spray models available in the literature and these models can predict spray performance of engine at various parameters but no study reported so far for high injected pressures. The present study aimed to compare the spray performance on Mahua biodiesel with different spray models available.

2. Methodology

The spray tip penetration is defined as the maximum distance measured along the spray axis to which the spray can reach from the nozzle tip. In the present study five different models are selected to compare the effect of injection pressure on penetration depth for these models. The selected models of the study are given below.

Wakuri et al, 1960 developed a semi-empirical/semi-analytical model based upon a measurement series where diesel fuel was injected with pressures up 76 MPa into a gas atmosphere up to 873 K and 2.4 MPa.

$$S = 1.189 C_a^{0.25} \left(\frac{\Delta P}{\rho_g} \right)^{0.25} \left(\frac{d_0 t}{\tan(\theta)} \right)^{0.5} \qquad (1)$$

Dent, 1971 proposed the following correlations for spray tip penetration.

$$S = 3.07\left(\frac{\Delta P}{\rho_a}\right)^{1/4}(d_n t)^{1/2}\left(\frac{294}{T_g}\right)^{1/4} \qquad (2)$$

Hiroyasu and Aria, 1990 proposed the following correlations for spray penetration before and after breakup.

Before breakup, $0 < t < t_b(l)$

$$S = C_d\left(\frac{2\Delta P}{\rho_l}\right)^{0.5} t \qquad (3)$$

After breakup, $t_b(l) \leq t$

$$S = 2.95\left(\frac{\Delta P}{\rho_a}\right)^{0.25}(d_n t)^{0.5} \qquad (4)$$

Where breakup time, t_b is

$$t_b = 4.351\left(\frac{\rho_l d_n}{C_d^2(\rho_a \Delta P)^{0.5}}\right) \qquad (5)$$

Schihl et al., 1996 analyzed the existing spray penetration models and proposed the following phenomenological cone penetration model.

$$S = 1.414 C_v^{0.5}\left(\frac{\Delta P}{\rho_g}\right)^{0.25}\left(\frac{d_0 t}{\tan(\theta)}\right)^{0.5} \qquad (6)$$

Arregle, 1999 used a simple equation with different coefficients which have been fitted with experimental results on a Diesel spray. This equation depends only on the nozzle diameter, injection pressure, the gas density and the time.

$$S = d_n^{0.307}.P_i^{0.262}.\rho_g^{-0.406}.t^{0.568} \qquad (7)$$

3. Results and discussion

The results are first validated with the experimental results of Lustgarten, 1973 and parameter of the validation is given in Table 1. The results are validated and shown in Fig.1. and it is clear from the graph that the Hiroyasu and Arai, 1990 and Schihl, 1996 gives almost same values thus for Pi=140 MPa any of these two model can be selected for performance prediction of biodiesel.

The above study (Lustgarten, 1973) deals with low injection pressure and no results are available for behaviour of spray performance of diesel engine for high injection pressure above 200 MPa, thus the present study deals with spray tip penetration for different models at high injection pressure. A computational programme has been developed in MATLAB for the calculation. The range of parameter of present study are given in Table 2.

Fig.2. shows the effect of injection pressure on penetration depth for different models. The penetration depth is monotonically increases with the lapse of time for all models. With increase in time the penetration depth increases and a maximum value of 0.182 m for Hiroyasu and Aria, 1990 ; Schihl, 1996 and minimum value of 0.12 m for Arregle, 1999. The Fig.3. show the effect of injected pressure of pi=250 on penetration depth of various model with time and its seen from the figure that as the time passes the penetration depth increases sharply after 0.4 milliseconds and same phenomenon is observed in Fig.4,5. At very injected pressure of the order of 350 MPa there is sharp increase in penetration depth is observed and shown in Fig.5, for Hiroyasu and Aria, 1990 and Schihl, 1996 the penetration depth of the order of 0.22 m is observed as at such high injection pressure as Hiroyasu and Aria, 1990 consider all the properties viz. (gas density, injected pressure, nozzle diameter, gas temperature) and Arregle, 1999 didn't consider gas temperature thus has low penetration depth as shown in Figs.[2-5], throughout the time span in comparison to other spray models of the present study.

4. Conclusions

In the present study performance comparison various spray models at different injection pressure and same operating condition has been carried out and some important conclusion are drawn here:

1. The model validation is carried out and results of Hiroyasu model was found in good agreement.
2. The penetration depth monotonically increases with increase in time and maximum and minimum penetration depth of the order of 0.21 m and 0.13 m for Hiroyasu model and Arregle model, respectively.
3. For the entire range of injected pressure Hiroyasu model gives best performance among all models

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Nomenclature

S : spray Tip Penetration

ΔP : pressure drop across the nozzle

t : time after start of injection

ρ_l : liquid fuel density

P_i : Injected pressure

d_n : nozzle diameter

T_g : gas temperature

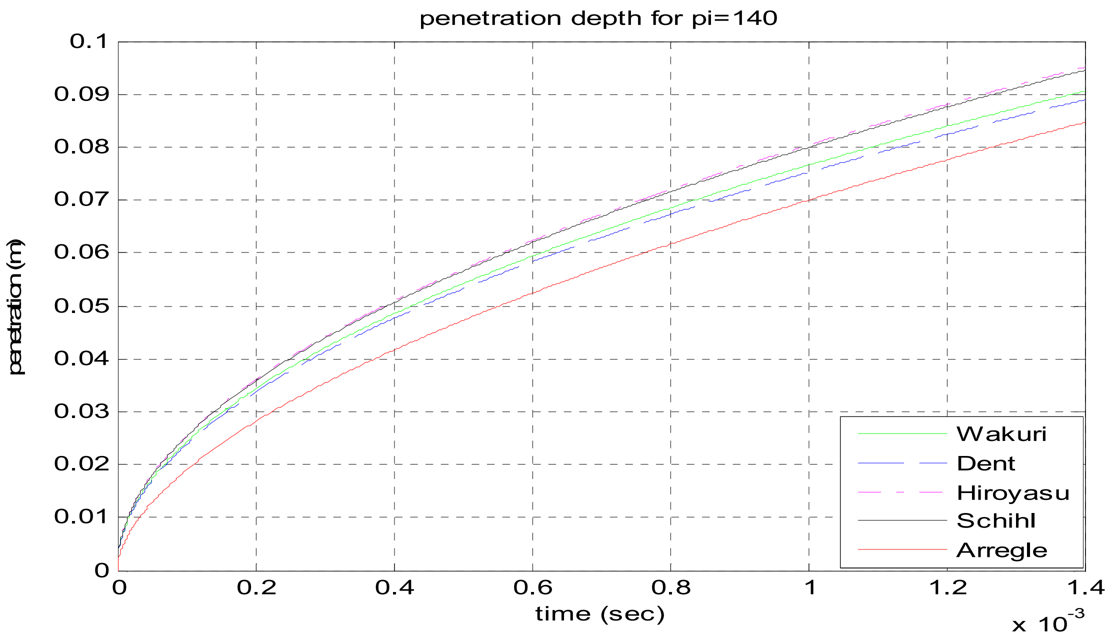

Fig.1. Validation of results.

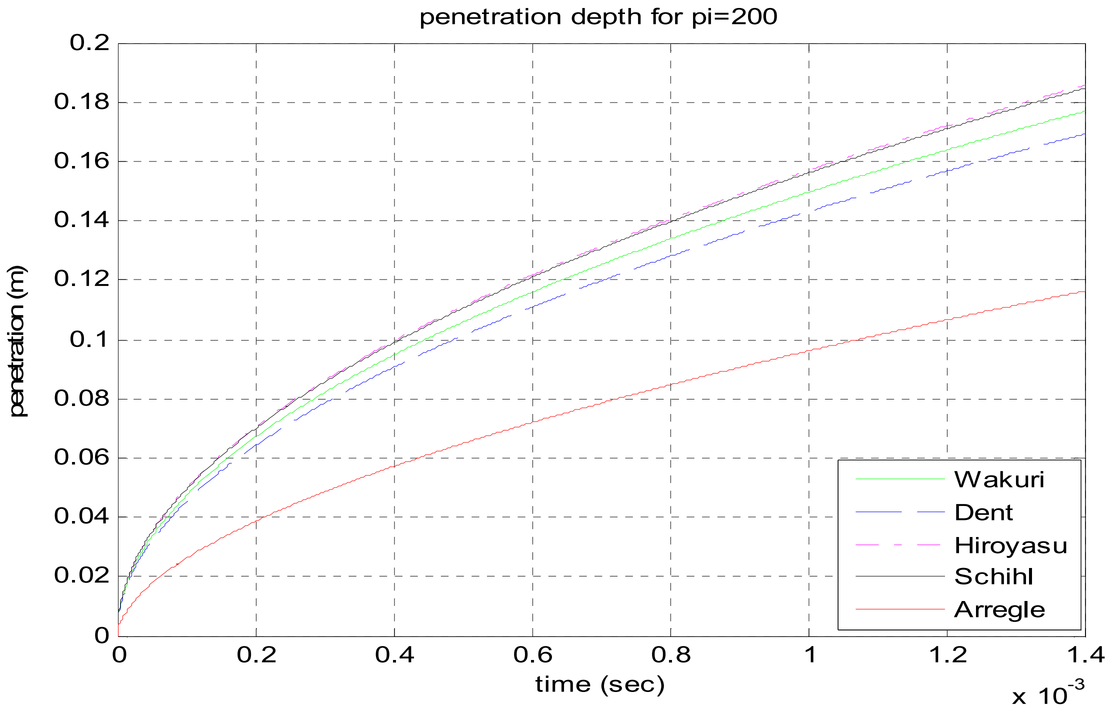

Fig.2. Effect of injected pressure pi=200 MPa on penetration depth for different spray models.

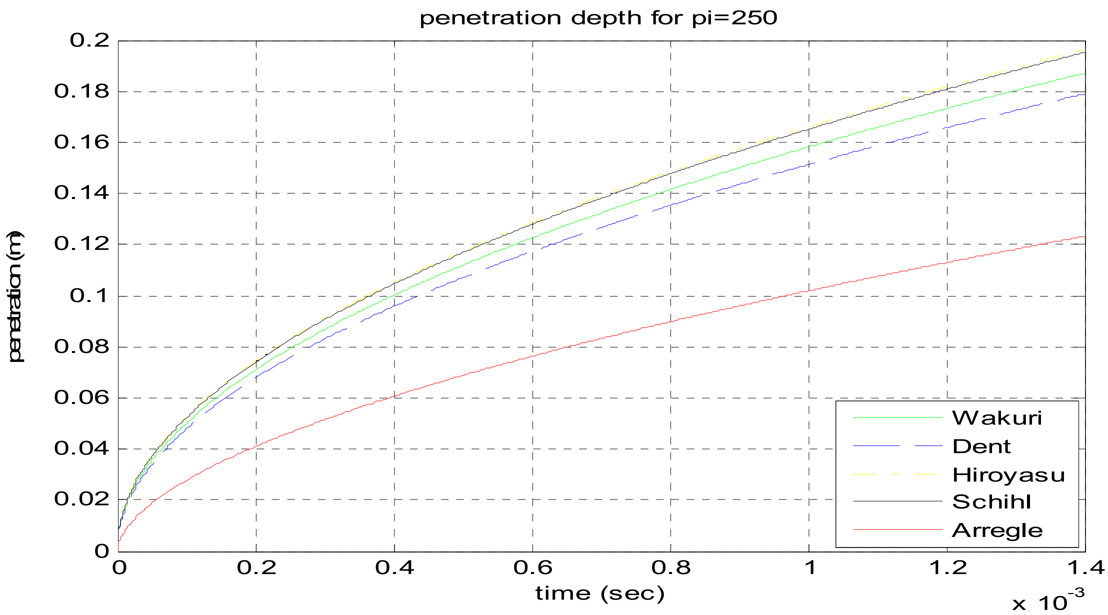

Fig.3. Effect of injected pressure pi=250 MPa on penetration depth for different spray models.

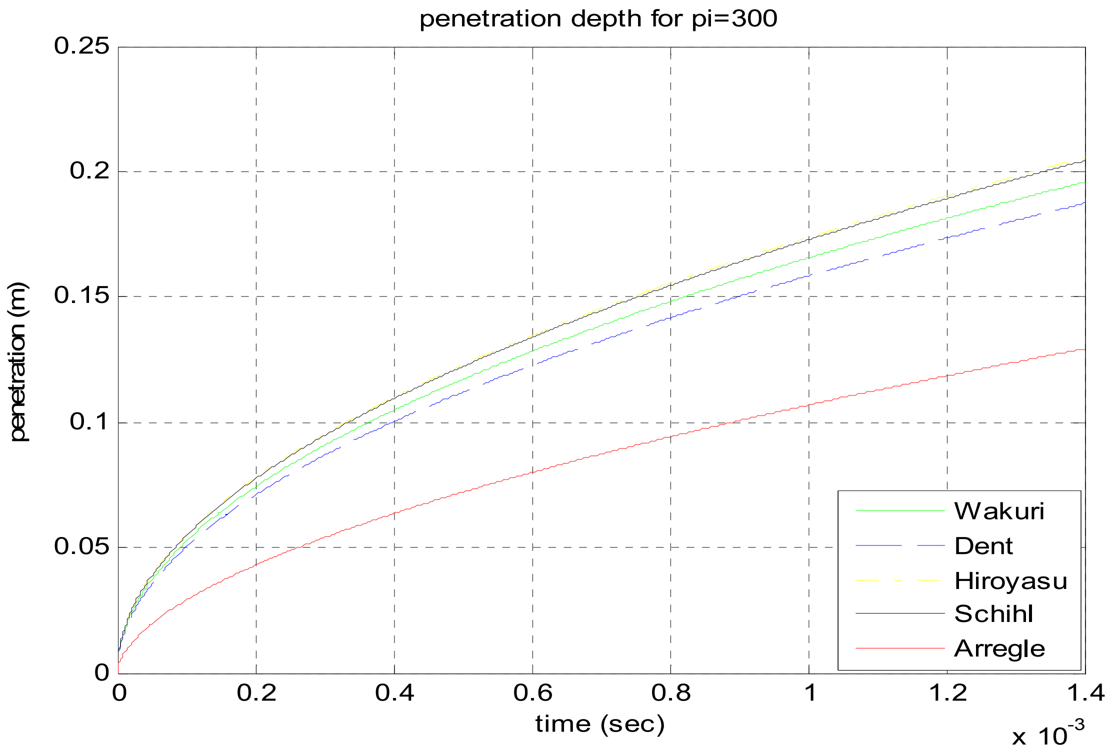

Fig.4. Effect of injected pressure pi=300 MPa on penetration depth for different spray models.

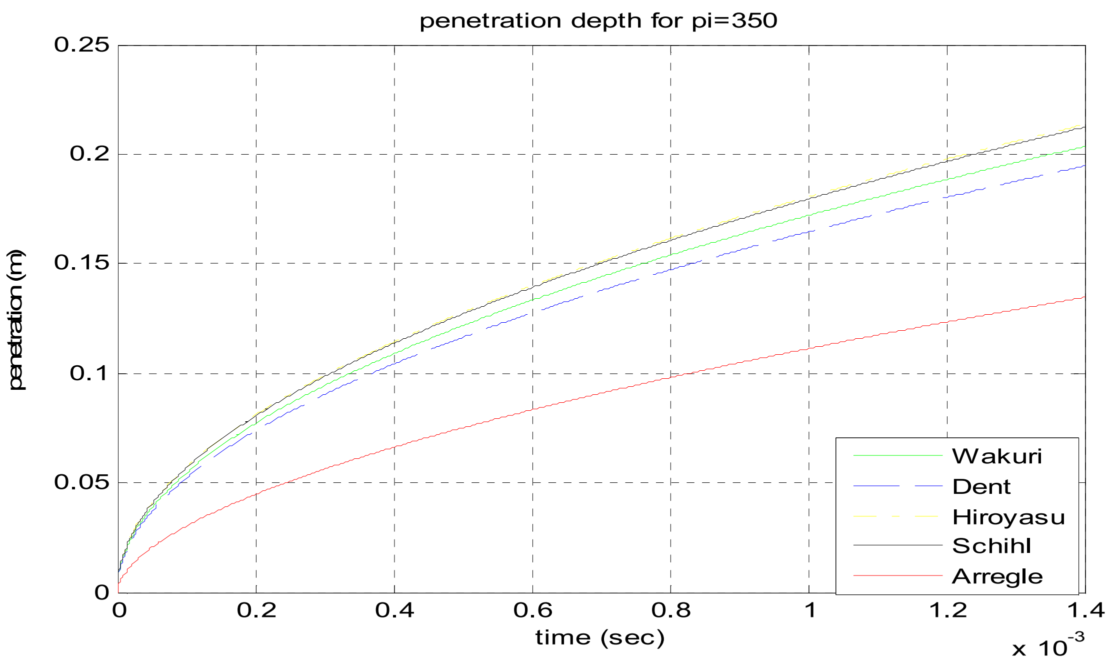

Fig.5. Effect of injected pressure pi=350 MPa on penetration depth for different spray models.

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Table 1. Parameter for validation (Lustgarten, 1973)

Parameter	Value
Ambient gas density (Kg/m^3)	14.8
Ambient gas temperature (K)	450
Injected Pressure (MPa)	140
Nozzle Diameter (mm)	0.241
Density of fuel (Kg/m^3)	699

Table 2. Shows the range of parameters of the present study.

Parameter	values
Ambient gas density (Kg/m^3)	25
Ambient gas temperature (K)	500
Injected Pressure (MPa)	200 , 250, 300, 350
Nozzle Diameter (mm)	1
Density of fuel (Kg/m^3)	878