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EFFECTS OF AMBIENT DENSITY ON FLOW CHARACTERISTICS OF BIODIESEL SPRAY INJECTION USING COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

Efficiency of combustions engine is highly dependent on the formation of the air-fuel mixture prior to ignition. Both the homogeneity of the combustion process and the ignition process are largely dependent on the mixture properties. This study focuses on determining the spray characteristics of biodiesel blend in rapid compressions machine (RCM) by using simulation of ANSYS version 15.0 Fluent. The parameters investigated including spray angle, spray penetration, spray velocity, size diameter of particle, formations of spray, turbulence kinetics energy and spray area. The simulation was performed on three types of biodiesel blend which are B5, B10 and B15 at different ambient pressure and ambient density. Result shows that when in high ambient pressure, the spray of biodiesel angle decreased. The results also indicated that, the spray penetration length and spray area decreased with the increasing in the ambient density. The spray velocity also decreases as the ambient density increases. This study concludes that the ambient pressure and density strongly affected the characteristics of fuel spray.

Keywords: simulations, spray, density, pressure.

INTRODUCTION

Fuel injection is a system for admitting fuel into an internal combustion engine. It has become the primary fuel delivery system and provides the fuel spray into the engine's combustion chamber. The spray of the fuel plays an important role in showing the combustion and emission characteristics of a fuel because it affects the air fuel mixture formation directly [1]. The spray characteristic mainly depends on fuel injection pressure, fuel density, fuel viscosity, ambient pressure and temperature [2]. Among all of this these parameters, the effect of fuel density and fuel viscosity is very important parameter which affecting the spray cone angle. This study investigates the effect of ambient pressure on flow characteristics of biodiesel blend spray characteristics such as spray tip penetration, cone angle, the liquid length and spray area in a constant volume chamber. This simulation study used computational fluid dynamics (CFD); ANSYS version 15.0 Fluent software in order to study the spray characteristics.

Diesel engine is an internal combustion engine that uses the heat of compression to initiate ignition and burn the fuel that has been injected into the combustion chamber and its combustion progresses by natural heterogeneous [3]. Spray penetration is of prime importance in diesel engine and most significantly affected by the fuel density, viscosity and surface tension. Over penetration of spray leads to impingement of fuel on the combustion chamber walls. This is acceptable if the walls are hot and considerable air swirl present [4]. Beside that if the spray penetration is inadequate; fuel-air mixing is unsatisfactory. Optimum engine performance is obtained when the spray penetration is matched to the size and geometry of the combustion chamber. The characteristics of the fuel spray are strongly affected by the behavior of the fuel flow in the injector and determination of the fuel proportion at the outlet of the nozzle provides initial conditions for determination of the spray characteristics in the combustion chamber [5]. The cavitation phenomenon affects the spray evaporation [6]. Increasing of fuel evaporation leads to improvement of the combustion and as a result leads to decrease in fuel consumption and emissions and decrease in performance and torque of the engine. The optical spray pattern analysis is by comparing their spray shapes contours, spray patterns recorded with high speed camera and give the information about the spray shape, spray pattern symmetry, and spray development at the start and end of injection and to shot-to-shot variations.

The mixture formation during ignition delay period is important process because ignition is controlled by physical process caused by multi-hole injection and air motion and chemical process of fuel decomposition and oxidation [7]. In particular, mixture formation of biodiesel during early stage of burning is important process because ignition is controlled by physical process caused by multi-hole injection, air motion, chemical process of fuel decomposition and oxidation [8-9].Atomization is defined as a process whereby a volume of liquid is disintegrated into a multiplicity of small drops. Usually the atomization quality is described in terms of mean drops this is because the physical process involved in atomization are not well known understood. The function of the atomizer is not merely to disintegrate a bulk liquid into small drops but also to discharge these drops into the surrounding gas in the form of a symmetrical uniform spray.

During the time of injection the internal structure of the liquid jet is very important because it will affects the process of jet atomization and evaporation characteristics. Besides that, for estimating the engine performance and

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exhaust emission an understanding of the process of spray break up is also important [10]. By reducing the fuel droplet size coupled with the strong spray dynamics will have some positive effect on enhancing the mixing process through better atomization and evaporation [10]. Moreover, an effective solution to make improvement the mixing process is by reducing the diameter of nozzle orifice and increasing the injection pressure [6].

In addition, velocities components act on the nozzle outlet plane are significant and appreciated since it contributes to the disintegration of the mixing fluids into droplets [11]. Implosions of cavitation bubbles inside the nozzle holes increase when the turbulence kinetic energy increases and contributes to the further break-up of the spray [12-13]. Consequently, the purpose of this work is to study the characteristics of area injection, the angle of spray cone, spray drop particles, turbulences kinetics energy and the spray tip penetration in rapid compression machine under high ambient and injection pressure of biodiesel in which using the Computational fluid dynamics software.

SIMULATION SETUP

Generally, the simulation in ANSYS FLUENT 15.0 involves three main stages which are pre-processing, solving and post-processing.

The injector and rapid compression machine was modeled by using Solid Work. In this study, the combustion chamber is a space where the spray formation occurs. The model of the injector only considered the tip of the nozzle. Figure 1 shows the 3D model of internal combustion chamber in RCM while Figure-2 shows the 3D model of the cross sectional area of the injector tip.

Figure-3 shows the section geometry of the combustion chamber. It is 1/6 section from the overall geometry because there are 6 nozzles in the actual RCM and only 1/6 is adequate and considered sufficient for the simulations analysis. The assigned boundary condition was served as the initiation and direct to the motion of the flow. Table 1 show the boundary condition for case study and Table 2 shows the solver setup. These simulations were carried out by using a multiphase volume of fluid (VOF) using a constant mass flow rate of air and biodiesel at 0.05 kg/s and 0.042 kg/s, respectively. The parameters that have to the determined include spray angle, spray penetration, spray velocity, size diameter of particle, formations of spray, turbulence kinetics energy and spray area.

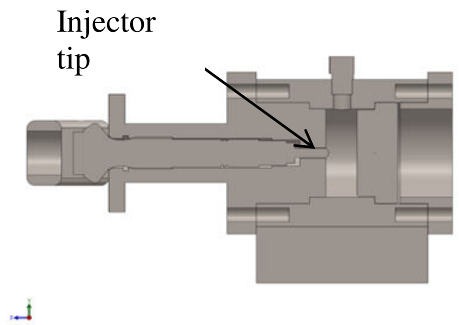

Figure-1. 3D model of cross section in internal combustion chamber in RCM.

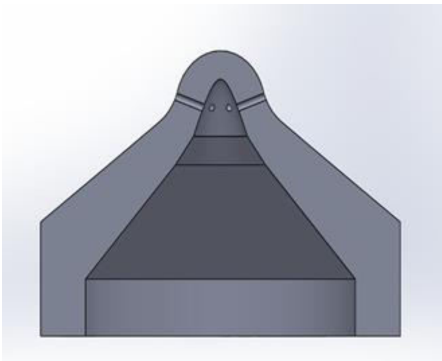

Figure-2. 3D model of the cross sectional area of the injector tip.

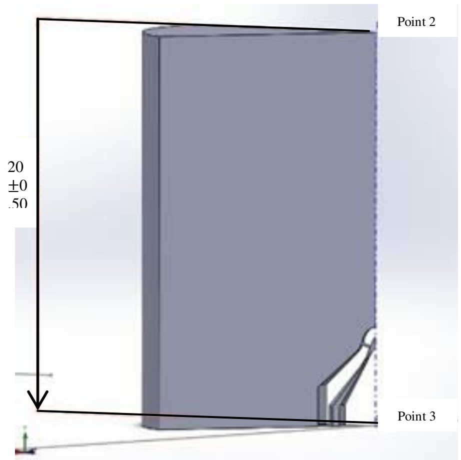

Figure-3. Section geometry of the combustion chamber.

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Table-1. The boundary condition.

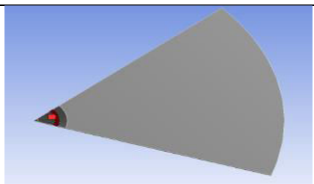
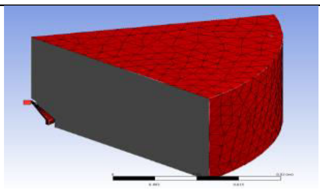
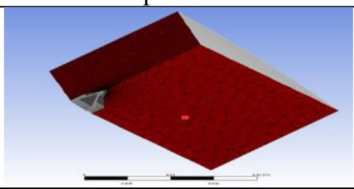
<table>
<tr><th>Boundary Conditions</th><th></th></tr>
<tr><td>Inlet</td><td>
Pressure inlet = 100 MPa</td></tr>
<tr><td>Wall</td><td>
No slip conditions</td></tr>
<tr><td>Periodic</td><td></td></tr>
<tr><td>Fluid Properties</td><td>
<table>
<tr><th rowspan="2">Biodiesel</th><th colspan="2">Properties test</th></tr>
<tr><th>Density (kg/m^3)</th><th>Viscosity (kg/ms^{-1})</th></tr>
<tr><td>B5</td><td>844.5</td><td>0.00278</td></tr>
<tr><td>B10</td><td>852.2</td><td>0.00280</td></tr>
<tr><td>B15</td><td>854.2</td><td>0.00283</td></tr>
</table>
</td></tr>
</table>

Table-2. Solver setup.

Options	Type
Multiphase model	**Volume of Fluid** (VOF)
Solver choice	Pressure-Based Solver
Time	Transient
Velocity Formulations	Absolute
Energy	On
Models	Viscous Model k-epsilon (2eqn)
K-epsilon Model	Realizable
Material	B5, B10 and B15
Boundary conditions	Injection Pressure = 100 MPa
	Temperature inlet = 300 K
	Temperature periodic= 850 K
Scheme	Simple
Pressure	PRESTO!
Momentum	Second Order Upwind
Turbulence Kinetic Energy	Second Order Upwind
Initialization Methods	Hybrid Initialization
Number of iterations	4000

RESULTS AND DISCUSSIONS

The simulation was performed at different ambient pressures which are 4MPa, 6MPa and 8MPa corresponds to ambient density 16.6 kg/m^3, 25.0 kg/m^3 and 33.3 kg/m^3. The others parameters were kept at constant value where the ambient temperature was set at 850 K, injector temperature at 300 K and the injection pressure was set at 100MPa. The fuel was injected by six holes injector with hole diameter of 0.645 mm.

Table-3 displays the characteristic for each biodiesel which are B5, B10 and B15. From the figure we can see that the highest density among this three biodiesel is B15 which is 854.2 kg/m^3. Meanwhile the lowest density is biodiesel B5 which is 844.5 kg/m^3. The value of density for each biodiesel is not in a very big range. This happen is due to poor mixture formation results of the low volatility and density of biodiesel. From this result, it shows a small drop of the velocity value. This is due to differences of the ambient pressure and ambient density. The higher the pressure and ambient density the lower the velocity spray at the injector nozzle. This may be attributes to the fact that the relative higher density and bulk module of the ambient properties decrease the velocity of the fluid exiting the nozzle.

Table-3. Properties of biodiesel.

Biodiesel	Properties test	
	Density (kg/m^3)	**Viscosity** (kg/ms^{-1})
B5	844.5	0.00278
B10	852.2	0.00280
B15	854.2	0.00283

Figure-4 shows the graph of spray velocity against the distance of the spray from the injector for all the parameters. Most of the trend of the spray is the same which the velocity is higher at the nozzle and gradually decrease when the spray are distant from the injector nozzle. This is due to the drag force between the biodiesel with the gas ambient. Besides, there is an ambient pressure in the chamber which can influence the decreasing of the velocity spray. Furthermore, the graph shows that between distances from 0 m to 0.004 m the velocity is rapidly decreased. This is due to the difference between the injection pressure and ambient pressure. When the spray is penetrate from the nozzle it was resisted with the pressure and cause the spray velocity rapidly decrease.

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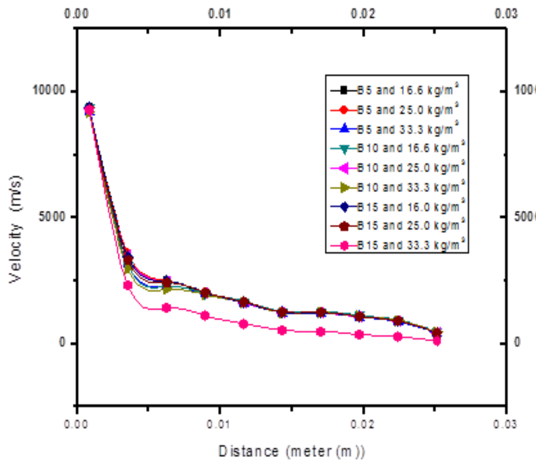

Figure-4. The graph of velocity of spray against the distance of the spray from the injector for all the parameters.

Figure 5 to 7 illustrate the turbulence kinetic energy of mixing fluid from the injector nozzle for each biodiesel. The higher turbulence kinetics energy was located at the outlet of the nozzle which is the first place where the biodiesel fluid reacted with the ambient. This is due to the higher of velocity and lower the eddies or swirl at this locations. The turbulence kinetics energy is gradually decreased until at the middle of the spray projection, this is because the velocity spray was decreased by the effects of the drag force from the ambient. At the end of the spray projections, it shows that the turbulence kinetic energy is increase. From this situations the changes in turbulence kinetics energy are found to be strongly dependent on the swirl ratio, injection pressure and measurement locations. From the results, it show that the swirl activities is higher at the middle rather than at the end of the spray projections.

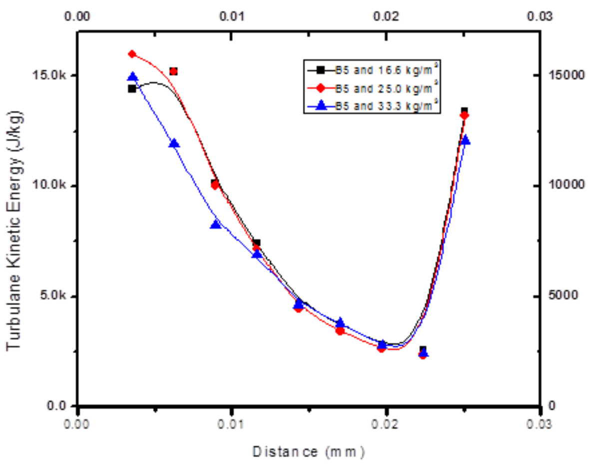

Figure-5. Graph of turbulence kinetics energy against Distance from the nozzle injector for biodiesel B5.

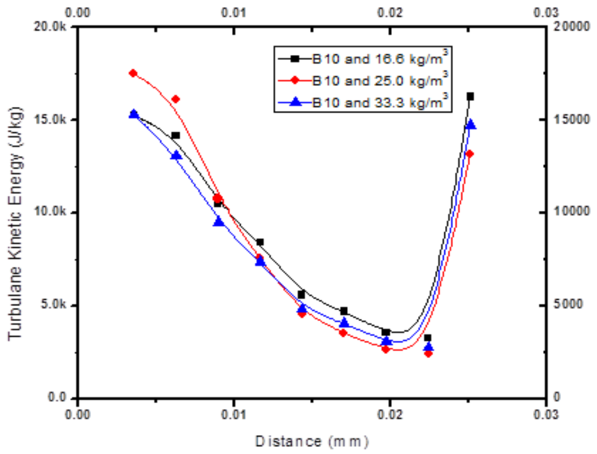

Figure-6. Graph of turbulence kinetics energy against Distance from the nozzle injector for biodiesel B10.

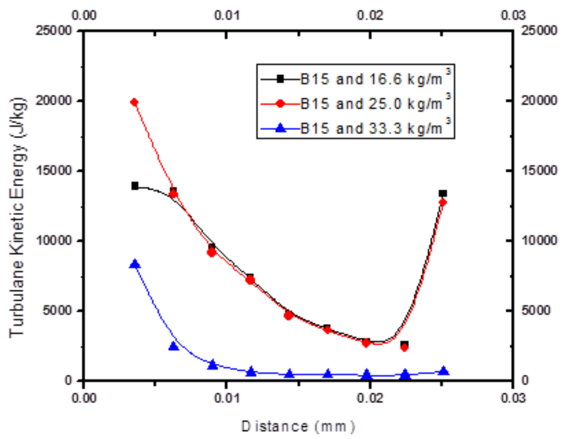

Figure-7. Graph of turbulence kinetics energy against Distance from the nozzle injector for biodiesel B15.

Figure-8 shows the results of mixture velocity in contour of iso-surface format. The red area in the contour represented as the maximum velocity while the blue area represented as the lower velocity. From this contour at near wall of the chamber shows that the spray velocity is slow and at the the velocity of the spray is 0 m/s at the exactlty at wall. This is due to the the boundary condition of the wall which is no-slip conditions. The no-slip conditions which states that for a fluid in contact with a solid wall, the velocity of the fluid must equal that of thw wall. In other woeds, as it name implies, there is no "slip" between the fluid and the wall. Fluid particles adjacent to the wall adhere to the surface of the wall and move at same velocity as the wall. Beside that, the velocity is nearly to zero at wall is also due to the effect of the viscosity and the wall shear.

From the simulations, the spray development were full develop at time elapse of 0.0003 seconds. From the Figure-9 and 10, it shows that at biodiesel B5. 33.33 kg/m^3 and biodiesel B15 ,33.3 3 $kg/m^3$with different spray contour at 0.0001 seconds. The Figure shows that at time

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elapse of 0.0001 seconds the biodiesel B5, 33.33 kg/m^3, the spray contour does not reach at wall, while at biodiesel B15, 33.3kg/m^{3}the spray contour have reach at the wall. The diffrences between for both parameter is the biodiesel material which are B5 and B15. The differences between this material is the density and viscosity. Morever, biodiesel B15 from the different pressure and density ambient which are 6 MPa, 25.0 3 kg/m^3. and 8 MPa, 33.33 kg/m^3. It shows that at 0.0001 seconds and pressure ambient 6 MPa the spray behavior is more shorter than at pressure ambient 8 MPa. From this cases, it shows that the pressure ambient also give influence to the spray development. The finding also show that at time elapse 0.0003 seconds the spray development were fully develop for all parameters.

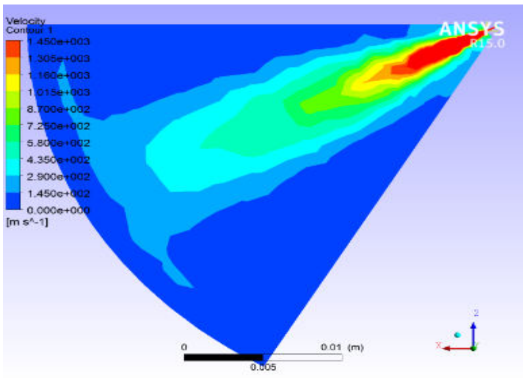

Figure-8. Figure for velocity contour for biodiesel.

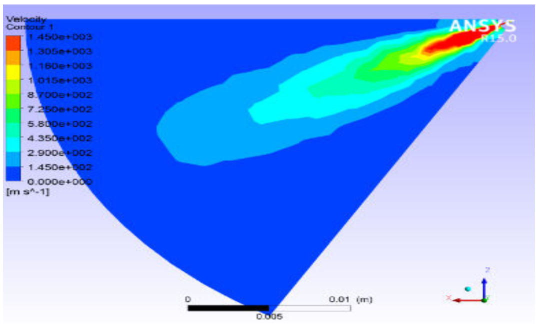

Figure-9. Figure formation of spray for biodiesel B5 and 33.3 kg/m^3 at 1 m/s.

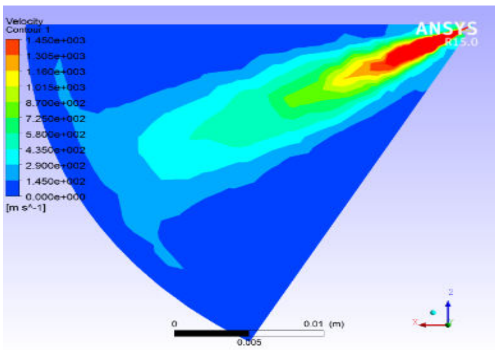

Figure-10. Figure formation of spray for biodiesel B15 and 33.3 kg/m^3 at 1 m/s.

The distribution of droplet size diameter and spray is a crucial parameter needed for fundamental analysis of practical spray systems. Detailed information regarding droplet diameter and velocity distributions in spray is of ultimate importance for the design, operation and optimization of spray systems. The size of diameter of particle is usually independent of the velocity distribution and the constraint on momentum and kinetic energy. From the Figure-11, it shows that the particle diameter of the spray is uniform from the outlet of the nozzle until to the walls. Besides, the size of the particle diameter is dependent on the pressure and density ambient.

Figure-12 shows the changes of the spray penetration length, the angle of spray and spray area according to pressure and density ambient. From the results, it shows that the pressure and density ambient give an influence to the spray penetration length, angle of spray and spray area. This due to differences between theinjector pressure which is 100MPa to the pressure ambient which are 4MPa, 6MPa and 8MPa. The lower the differences of pressure between pressure injector and pressure ambient the shorter the spray penetration, the angle of spray and the area of spray. This is because the spray was resisted with the ambient pressure.

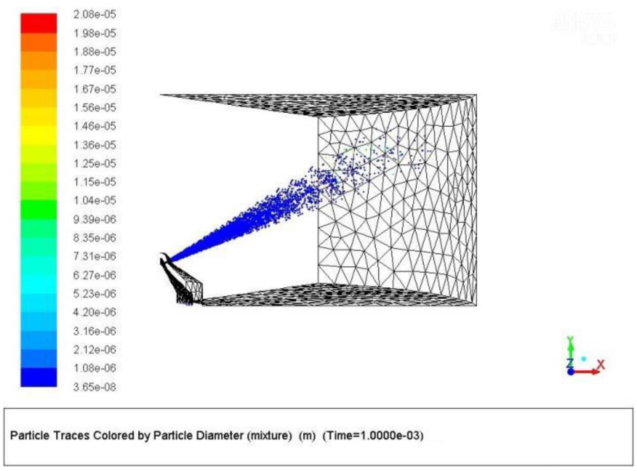

Figure-11. Spray structure produced by single nozzle (4 MPa and 16.6 kg/m^3) with color scale which represents the droplet diameter.

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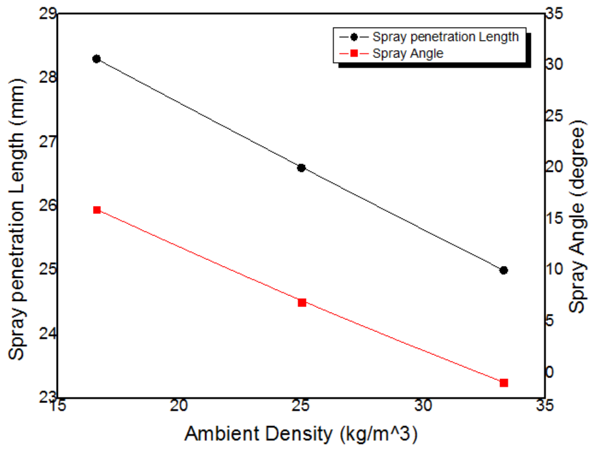

Figure-12. The effect of ambient density to spray penetrations length and spray angle for biodiesel B10.

CONCLUSIONS

The simulations show that ambient density, ambient pressure and biodiesel properties just give a small influence to the velocity spray. In terms of turbulence kinetic energy, the higher turbulence kinetics energy was located at the outlet of the nozzle which in the first place when the biodiesel fluid react the ambient. This due to the higher of velocity and lower in eddies or swirl. The turbulence kinetics energy is gradually decreases until at the middle of the spray projection; as the velocity of the spray is decreases. From this situation, it shows that the swirl activities is higher at the middle rather than at the end of the spray projections.

The spray formation shows the type of fuel, ambient pressure and ambient density give influence to the time taken for completion of the spray formation. From the results, it shows the ambient pressure and ambient density give an influence to the spray penetration length, spray angle and spray area. This due to differences between the injection pressure which is 100MPa to the pressure ambient which are 4MPa, 6MPa and 8MPa. The lower the difference of pressure between pressure injector and pressure ambient the shorter the spray penetration, the angle of spray and the area of spray as the spray were resisted with the pressure ambient.

From this study, it is found that the type of fuel, pressure ambient and density ambient give influence to the pattern spray flow in the internal combustions systems.

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