

# Numerical Analysis of Nozzle Hole Shape to the Spray Characteristics from Premix Injector in Burner System: A Review

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## Abstract.

The fuel-air mixing during burning process provides significant effects to the fuel atomization and flame development thus predominantly influences to the behavior of particulate matter (PM) and NO<sub>x</sub> production. The variant in fuel injection characteristics are widely used in the field of burner system nowadays. Spray nozzles having various operating conditions depended on the design of nozzle and it was precision components designed to perform very specific spray characteristics under specific conditions. This review paper focuses on spray characteristics, effects of geometry of injector, influence of fuel and hole shaped nozzle with cylindrical and conical holes on spray characteristics. The parameters are discussed based on an overview of the research in the field of simulations with nozzle shaped injectors. Massive researchers had reported that conical nozzle hole is better than cylindrical nozzle due to it contributed suppression of cavitation in nozzle hole, slowed down primary breakup process and thus produced larger spray droplets, high spray penetration.

## Introduction

Alternatives source of fuel is receiving a lot attention especially the application of renewable energy such as bio-diesel fuel (BDF). However, the introduction of alternative fuel into combustion field thus provides significant additional benefits to the fuel atomization and predominantly influences to the lower flame temperature. These behaviors associated with the reduction of particulate matter (PM) and leading to the decreasing of NO<sub>x</sub> production [1-4]. In this review paper, Jatropha oil is an important product which can be produced from the plant for cooking and lighting purpose of the rural population. It is used in boiler fuel for industrial purpose and as an appropriate substitution for diesel. One-third of the energy can be extracted as oil from the fruit of Jatropha that has a similar energy value to diesel fuel. The maximum oil content in Jatropha seeds has been found about 47%. However, there is only accepted average 40%. Nevertheless, the fraction extracted from Jatropha seeds is taken around 91% [5].

The physical properties of density, cloud point, kinematic viscosity (40°C), flash point and pour point of Jatropha oil had been found higher than diesel as shown in the Table 1. The flash and fire points of Jatropha oil was higher compared to diesel fuel. Hence, Jatropha oil is extremely safe to storage [5-6]. Lower sulphur content in Jatropha oil results in lower sulphur oxides, (SO<sub>x</sub>) emissions. Jatropha oil has fraction of approximately 90% calorific value compared to diesel. Other than that, different of nitrogen content of the Jatropha oil and diesel fuel also affect the NO<sub>x</sub> emissions [7].

## Spray characteristics

Spray nozzles having various operating conditions depended on the design of nozzle. The spray characteristics always been considered for selecting a suitable nozzle are spray pattern, capacity, spray impact, spray angle and droplets size. Spray nozzles are precision components designed to perform very specific spray characteristics under specific conditions. Spray characteristics can be

influenced by parameters of seat angle, streamwise velocity or tangential velocity and nozzle exit diameter. In order to obtain an acceptable spray quality for a particular use, those operating parameters must be optimized [8]. Besides, the major factors still focus on viscosity, density, surface tension and physical properties which showed some significant effects on the spray characteristics [9].

Table 1: The physical and chemical properties of mineral diesel, Jatropha biodiesel and Jatropha oil [7]

Property	Mineral diesel	Jatropha biodiesel	Jatropha oil
Density [ $\text{kgm}^{-3}$ ]	840 $\pm$ 1.732	879	917 $\pm$ 1
Kinematic viscosity at 40 °C [cst]	2.44 $\pm$ 0.27	4.84	35.98 $\pm$ 1.3
Pour point [°C]	6 $\pm$ 1	3 $\pm$ 1	4 $\pm$ 1
Flash point [°C]	71 $\pm$ 3	191	229 $\pm$ 4
Conradson carbon residue [w/w%]	0.1 $\pm$ 0.0	0.01	0.8 $\pm$ 0.1
Ash content [w/w%]	0.01 $\pm$ 0.0	0.013	0.03 $\pm$ 0.0
Calorific value [ $\text{MJkg}^{-1}$ ]	45.343	38.5	39.071
Sulphur [% w/w]	0.25	<0.001	0
Cetane number	48-56	51-52	23-41
Carbon [w/w%]	86.83	77.1	76.11
Hydrogen [w/w%]	12.72	11.81	10.52
Oxygen [w/w%]	1.19	10.97	11.06

## Cavitation

Cavitation has been resulted as one of the important parameters which can affects fuel spray atomization. However, cavitation has positive effects to the development of the fuel sprays for diesel fuel injectors. There are many researchers concentrated about using both the experimental and numerical methods to gain a better knowledge of this phenomenon and its relation on the durability and performance of diesel fuel injection. According to the geometric-induced cavitation and string cavitation from experimental, it found that the spray angle increased significantly with the existence of string cavitation while it appear in the nozzle [10]. Gavaises[11] concluded that the cavitation will damage the areas of bubble collapse, while the engine exhaust emissions increased with the association of string cavitation structure inside nozzle. However, limited research was conducted in reporting the cavitation within the conical diesel sprays.

## Nozzle geometries of the injector

There are two common nozzle shapes used to determine the injection behavior of fuel, fuel-air mixing or fuel-air-water mixing. The two common nozzle shapes are conical and cylindrical nozzle orifices. Comparison was made for two of these different nozzle orifices to investigate the cavitation, flow efficiency (discharge coefficient) and exit velocity, spray characteristics, mass flow rate, etc. An experimental study was conducted by Benajes *et al.*[12] to analyze the effects of conical and cylindrical nozzle orifices to the injection rate behavior of a common-rail fuel injection system with maximum needle lift on a cavitation test. The observation of the experiment was taken to compare a cylindrical orifice and a conical orifice in order to increase flow efficiency (discharge coefficient), cavitation reduction, and exit velocity. However, the fuel injection rate is minimized due to the smaller exit area. Payriet *al.*[13] observed that the mass flow rate of conical nozzles was relative to the square root of pressure drop referential absence of cavitation at the nozzle exit while smothery conditions for the cylindrical nozzles. Other than that, Payri *et al.* also found that was an increasing in injection velocity due to the existence of vapor at orifice exit for the cylindrical nozzle. Furthermore, Han *et al.* [14] found that the primary breakup region is relatively influenced by nozzle geometry when compared to the conical and cylindrical nozzles. Besides, Han *et al.* also examined the effects of different nozzle orifice geometry on spray penetration, liquid length, and cone angle [15].

## Influences of the hole shaped nozzles

Two nozzles with cylindrical and conical holes always been chosen for studied and discussed their behaviors in relation to fuel properties and spray characteristics. Biodiesel has a slightly higher mass flow in a cavitating nozzle. Therefore, by using hole shaped nozzles the cavitation of the diesel can be reduced provides similar or slightly higher mass flow. Som *et al.*[15] conducted numerically and experimentally about the effects of hole shape and hydrogrinding on biodiesel sprays. They found that cavitation and turbulence levels inside the nozzle orifice have significantly reduces by conicity. Besides, they found also conicity could slowing down primary breakup process and thus produces larger spray droplets, then penetration and smaller cone angle are increased. Hountalas *et al.*[16] had conducted an experimental on three different nozzle hole types such as a standard, a convergent and a divergent one to investigate the influence of nozzle hole conical shape on engine performance and emissions. According to the experimental result found, soot was increased while NOx decreased for the divergent nozzle hole compared to the other two nozzles.

## Effects between conical and cylindrical hole shaped to the properties of fuels

Higher flow rates are achieved by using the conical nozzle to reduce the strong cavitation. M. Battistoniet *al.* [17] had conducted simulation by CFD for different fuels of diesel and biodiesel and found both fuels achieved similar values with the cylindrical (cavitating) hole, meanwhile diesel slightly prevails when the nozzle's hole is conical. M. Battistoni *et al.* believed that the concurrent phenomena taken into account of higher density causes higher mass flow, therefore biodiesel is more suitable, lower viscosity which causes an increase of the discharge coefficient and then the exit velocity. Diesel is benefited for this condition and this can be appreciated in Figure 1 (c). Lastly is the cavitation can reduce the effective area, the result found that biodiesel is slightly less cavitating which can be appreciated in Figure 1 (b).

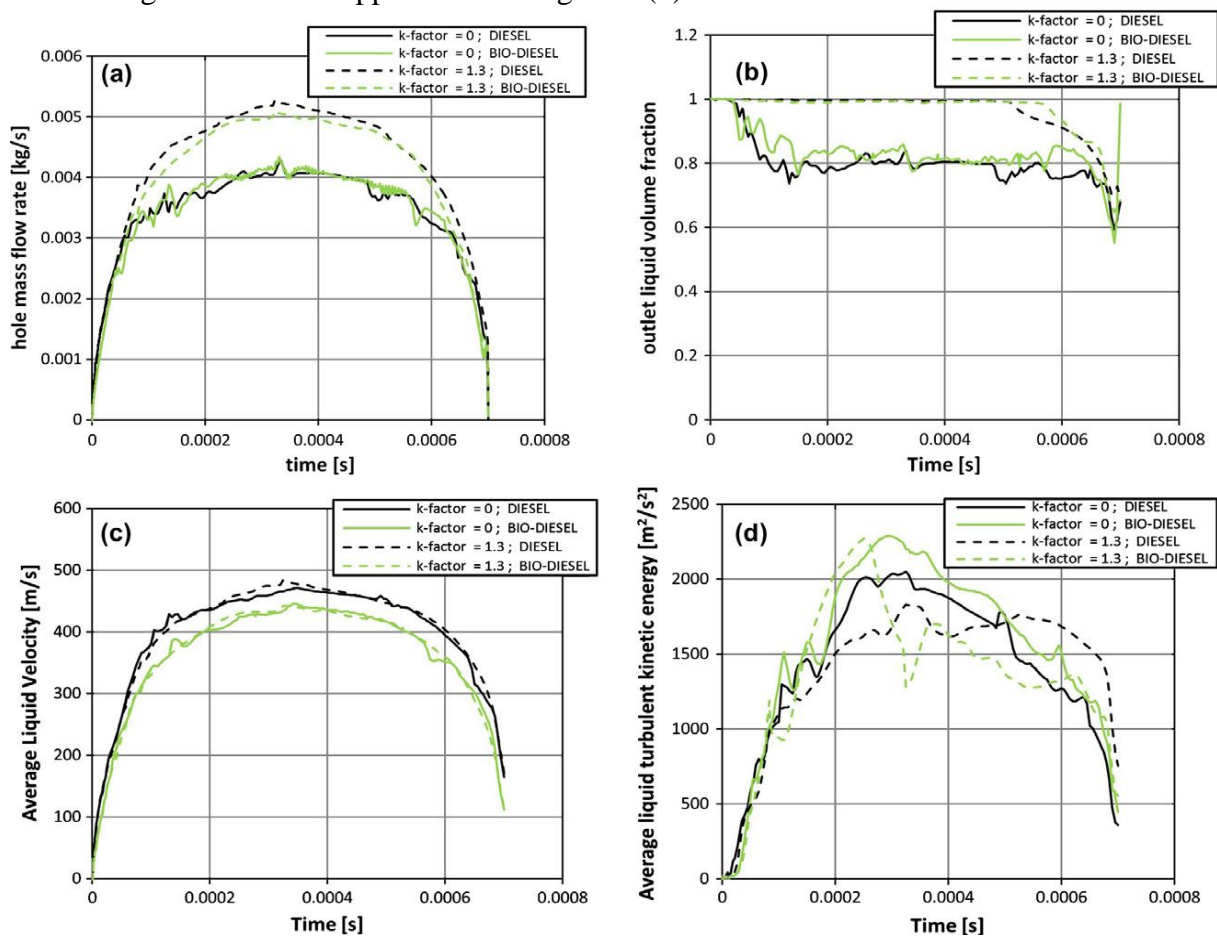


Figure 1: The graph of (a) mass flow rate, (b) area occupied by liquid fuel, (c) mass-averaged liquid velocity, (d) mass-averaged liquid turbulent kinetic energy[17]

In the conical hole, both diesel and biodiesel fuels exploited the full cross section, even though diesel has lower density but it still has a significant higher outlet velocity, while it gives a higher mass flow rate. Furthermore, outlet effective sections are reduced in cavitating conditions, where mass flow is pretty similar. In addition, biodiesel produces a slightly lower cavitating area.

### Spray simulations for both conical and cylindrical hope shaped

Numerical analysis was done by using biodiesel and diesel as comparison. From the result of simulation, biodiesel behaved similarly for both conical and cylindrical hole shapes, whereas diesel fuel showed very different breakup characteristics as it was more sensitive to the different hole shape. Diesel produced a faster and denser spray which remains compact for long time with conical hole, meanwhile diesel enhances spray breakup at cavitating hole.

Penetration for both diesel and biodiesel for both different hole shaped can also be compared and shown in Figure 2. Diesel spray injected from the conical hole with a higher liquid penetration, whereas diesel spray injected from the cylindrical hole and both biodiesel sprays shows lower and similar penetration trends versus time [17].

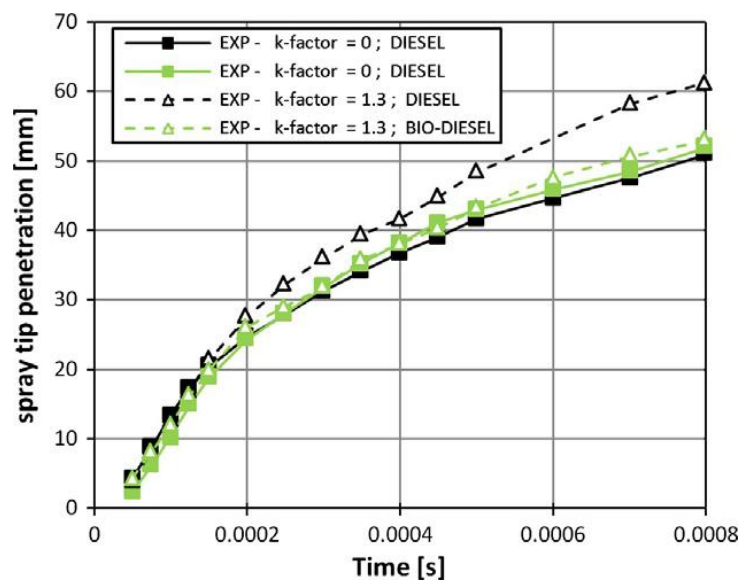


Figure 2: The graph of spray tip penetration against time [17]

### Conclusion

Review on the effect of nozzle hole shape to the spray characteristics revealed that the nozzle geometry has significant effects to the spray characteristics and performances. Two types of different hole shapes, cylindrical and conical shaped are reviewed. Therefore, the results are summarized as follows;

- i. Cylindrical hole shaped will inject the fluid at the condition of highly cavitating.
- ii. Conical hole shaped has the potential to reduce the cavitation characteristics.
- iii. Conical nozzle is better than cylindrical nozzle hole shape.

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