Review of Optical Diagnostic Technique for Diesel Spray

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***Abstract*—To enhance the fuel efficiency and reduce both NOX and soot emissions in diesel engine, it is essential to understand the mixture formation and the combustion process in the cylinder. The injection parameters such as pressure, mass and multiple approaches as well as the impingement play an important role in mixture formation, combustion process and emissions. Previous works have addressed various optical diagnostic techniques. This review describes those factors mentioned above systematically to clarify the diesel spray in the compression ignition engine. Therefore, a diesel vehicle with better fuel economy and low emission that meets the stringent regulation across the world could be realized.**

***Index Terms*— diesel spray, performance, combustion, emission, compression ignition engine**

I. Introduction

To sustain a pollution-free environment, the government agencies around the world issue the emission regulations that are revised regularly and have become stricter in the last two decades [1, 2]. The standards have been raised significantly especially for heavy-duty diesel engine due to its complicated combustion processes, causing large volumes of NOx and soot emissions [3, 4]. In a direct injection diesel engine, an injector is placed on the cylinder head to insert the fuel into the combustion chamber [5-7]. Fuel spray is then formed irregularly in high-pressure and high-momentum environment that creates high-turbulence spray resulting in a good mixture between fuel and air in the chamber [8-12]. Typical diesel engine is illustrated in Figure 1.

Diesel spray formation starts with the spray atomization processes followed by the mixing between fuel spray and air. Firstly, liquid fuel should be rapidly atomized into spray. To form good droplet spray, rapid vaporization is preferred. In addition, the fuel jet has to be short in break-up length and wide in spray angle to distribute well in the chamber. Local mixing inside the spray is also favored and can be achieved from turbulence phenomena induced by bulk flows such as swirl and squish.

Swirl flow is caused by an intake air. This flow affects the bulk movement of spray and control the air utilization in the chamber. Squish flow, on the other hand, is caused by the piston motion. It stirs the mixture of fuel and air around the lip

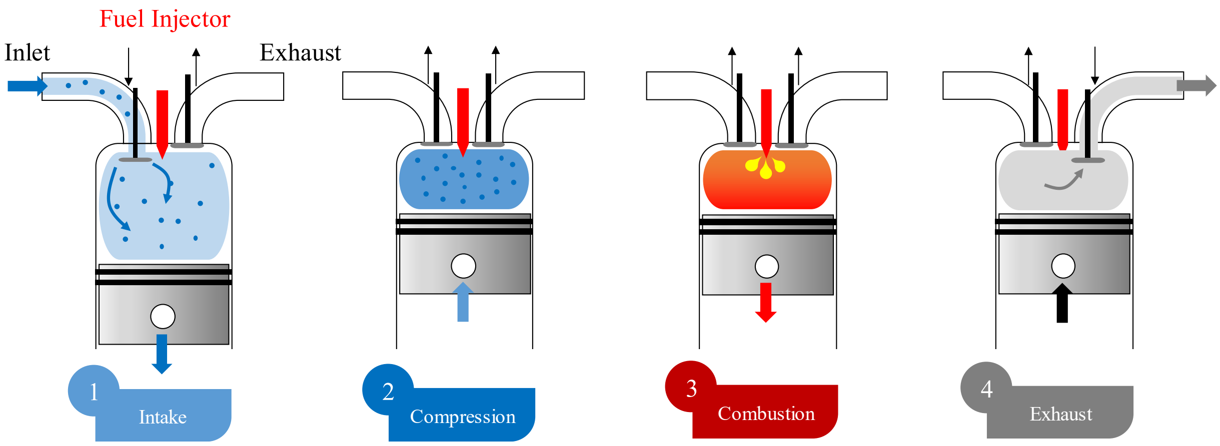

Fig. 1. Diesel Engine 4-Strokes Process

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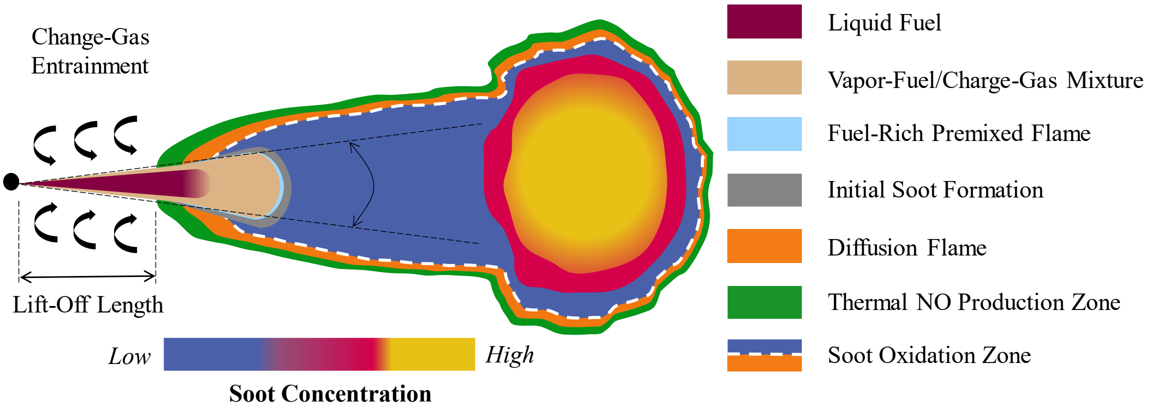

Fig. 2. Direct Injection Diesel Combustion Model, Adapted from [13].

of the cavity. Both swirl and squish flow known as in-spray local mixing contributes to better atomization of Diesel fuel in the chamber. The characteristic of injection diesel combustion is shown in Fig. .

The development of Diesel spray has improved significantly owing to hydrodynamics considerations. Cavitation phenomenon for instance, by investigating its effects on a nozzle entrance, a break-up mechanism of high-speed liquid jet can be understood sufficiently. However, there are still unknown elements in Diesel spray which have not yet been identified. This paper tries to provide a complete review on Diesel spray behavior from liquid breakup, spray penetration, spray volume, velocity distribution, to air entrainment effects. Several new approaches for future works were proposed at the end of this study.

II. Investigating Technique

To have a better understanding on diesel spray, its mixture formation and combustion, several optical diagnostic techniques have been greatly applied. Table 1 summarized those methods comprehensively and are shown briefly in the following table.

TABLE I.
OPTICAL DIAGNOSTICS TECHNIQUES FOR IN-CYLINDER MIXTURE FORMATION MEASUREMENT

No.	Technique	Application	Advantage	Disadvantage
1.	Mie Scattering	Liquid fuel distribution	Simple setup	Sensitive to large droplets
2.	Schlieren and Shadowgraph	Comprehensive spray observation	Simple setup	Sensitive to liquid and vapor phase
3.	LRS	Density measurement and vapor concentration	Simple setup, trong signal, 2-D imaging	Interference from Mie and false scattering, Limited to gaseous fuel
4.	SRS	A/F ratio and residual gas fraction	Multi-species and multi-point detection, the most accurate A/F reading, unaffected by windows fouling	Weak signal
5.	LIF	Fuel concentration	Strong red shifted signal 2-D imaging	Quenching at high pressures Difficult to calibrate
6.	FARLIF	A/F ratio	Direct A/F measurements 2-D imaging	Careful calibration needed High pressure operation
7.	LIEF	Fuel vaporization and atomization	2-D imaging Simultaneous detection of vapor and liquid	Quenching by oxygen
8.	LEA (LAS)	Fuel vaporization and atomization	Quantitative concentration measurements	Poor spatial resolution

Mie Scattering technique has been widely used due to its simplicity and explicitness by applying the Lorenz-Mie theory. Its application is mainly to detect the liquid phase of the spray. This is due to the intensity produced by this technique is not very accurate to determine the droplet diameter and its concentration. Therefore, Mie Scattering method is usually used to identify liquid phase penetration [Siebers, 1998] and the spray structure [Gulder et al., 1992].

Unlike Mie Scattering that can only detect the liquid phase, Schlieren and Shadowgraphy offers both; liquid and vapor phase of the spray. Furthermore, this method can also roughly estimate the interface between liquid and vapor phase through the intensity gradient. This method can be used to identify spray boundary under evaporating conditions. Yet, Schlieren and Shadowgraphy technique has the same limitations as Mie Scattering in that they both measure the spray structure because of the limitation in quantitative analysis.

Laser technique, considered as monochromatic illuminant, allows the elastic scattering method to be effectively adopted in vapor-phase measurement of Diesel spray. When passing through the gas mixture, a beam light will scatter a small amount of light energy. If this scattered light consists of the incident wavelength, the phenomenon is known as Rayleigh scattering, whereas if the scattered light is far from the incident wavelength is referred as Raman scattering.

Direct Imaging is a diagnostic method that is commonly used in internal combustion engine. Such method employs high-speed camera such as CCD and CMOS camera to capture the spray evolution in a certain time interval. To distinguish the spray and its background, the illumination technique using laser flashlight is employed. An initial photo is generally taken as the background. It is then taken away during the image process using computer software to obtain better images quality.

While Direct Image technique is used to observe the spray evolution, Schlieren technique is used to investigate the fuel concentration by detecting the refractive-index variation caused by density variation. Schlieren technique can detect two phases of the fuel: liquid and gaseous phases.

The source, a laser, passes through a lens (the first lens) which diverges the laser into light beams. After passing the Test Section, the light beams are then converged by the second lens before finally appear on the screen. During this process, due to changes in fluid density, several light beams are deflected so that they take a different route compared to the light beams which are not affected by the density variation. Some of these unaffected light beams must be blocked using a knife edge placed at the focus of the second lens. As a result, better liquid concentration can be visualized on the screen.

Laser Rayleigh Scatering (LRS) is able to analyze the vapor-phase concentration of Diesel spray because its scattered light intensity is proportional to the density number of gas molecules. Moreover, under low gas density, this technique can also be applied to measure the vapor concentration due to the larger scattering cross section.

Regardless of its phase whether liquid or vapor, LIF can be used to visualize the spray in internal combustion engines. Such technique applies the basic principle that molecules are excited from ground (lower) to higher state when they are illuminated by a homogeneous light. The fluorescence signal can then be obtained when those molecules return to their initial state. When the molecules are illuminated by the light, the electrons are excited to upper energy orbital because several lights are absorbed at this stage. Energy is then released leading to the detection of the fluorescence signal.

III. Conclusion

The optical diagnostic method is widely applied to investigate the spray in internal combustion engine as they are non-intrusive. This method is normally divided into two types: photography and non-photography. Photography technique aims to observe the macroscopic characteristics such as fuel distribution, spray length and angle, whereas non-photographic technique aims to study the microscopic characteristics.

References

[1] M. F. Roslan, I. Veza, and M. F. M. Said, "Predictive simulation of single cylinder n-butanol HCCI engine," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 884, no. 1, p. 012099: IOP Publishing.

[2] I. Veza, M. F. M. Said, Z. A. Latiff, M. F. Hasan, R. I. A. Jalal, and N. M. I. N. Ibrahim, "Simulation of predictive kinetic combustion of single cylinder HCCI engine," in *AIP Conference Proceedings*, Pahang, Malaysia, 2019, vol. 2059, no. 1, pp. (020017-1)-(020017-9): AIP Publishing.

[3] M. Rusli *et al.*, "Performance and Emission Measurement of a Single Cylinder Diesel Engine Fueled with Palm Oil Biodiesel Fuel Blends," in *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1068, no. 1, p. 012020: IOP Publishing.

[4] I. Veza, V. Muhammad, R. Oktavian, D. W. Djamari, and M. F. M. Said, "Effect of COVID-19 on biodiesel industry: A case study in Indonesia and Malaysia," *International Journal of Automotive and Mechanical Engineering,* vol. 18, no. 2, pp. 8637-8646, 2021.

[5] I. Veza, M. F. Muhamad Said, Z. Abdul Latiff, and M. A. Abas, "Application of Elman and Cascade neural network (ENN and CNN) in comparison with adaptive neuro fuzzy inference system (ANFIS) to predict key fuel properties of ABE-diesel blends," *International Journal of Green Energy,* pp. 1-13, 2021.

[6] I. Veza, M. F. Roslan, M. F. Muhamad Said, Z. Abdul Latiff, and M. A. Abas, "Cetane index prediction of ABE-diesel blends using empirical and artificial neural network models," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* pp. 1-18, 2020.

[7] A. Katijan, M. F. A. Latif, Q. F. Zahmani, S. Zaman, K. A. Kadir, and I. Veza, "An Experimental Study for Emission of Four Stroke Carbureted and Fuel Injection Motorcycle Engine," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,* vol. 62, no. 2, pp. 256-264, 2019.

[8] P. M. de Oliveira *et al.*, "Soot-free low-no x aeronautical combustor concept: The lean azimuthal flame for kerosene sprays," *Energy & Fuels,* vol. 35, no. 9, pp. 7092-7106, 2021.

[9] H. Kurji, "Fuel Flexibility with low emissions for gas turbine engines," Cardiff University, 2017.

[10] N. Zeoli, "Multiphase modelling of the characteristics of close coupled gas atomization," Aston University, 2011.

[11] J. Dai, N. Yu, and G. Cai, "Investigation of non-premixed flame combustion characters in GO2/GH2 shear coaxial injectors using non-intrusive optical diagnostics," *SCIENCE CHINA Physics, Mechanics & Astronomy,* vol. 58, no. 12, pp. 1-13, 2015.

[12] G. Subbuswamy, *Numerical and experimental study of film cooling with backward injection angle*. Lamar University-Beaumont, 2012.

[13] J. E. Dec, "A conceptual model of DL diesel combustion based on laser-sheet imaging," *SAE transactions,* pp. 1319-1348, 1997.

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