Investigation of temperature effects on bio-oil sprays issued from a pressure swirl atomizer

Yongyingsakthavorn P[1]*, Vallikul P[1], and Dumouchel C[2]

[1] King Mongkut's University of Technology North Bangkok (KMUTNB), 1518 Pracharat Sai 1 Road, Wongsawang, Bangsue, Bangkok, 10800, Thailand

[2] UMR 6614 - CORIA – Université et INSA de Rouen, Rouen, France

*Corresponding Author: pisity@kmutnb.ac.th, Tel. +66-2587-0026 ext. 409

Abstract

This work experimentally investigates the effects of temperature on spray characteristics of diesel, biodiesel and palm olien injected from a widely-used pressure swirl injector. The spray characteristic considered is the local volume concentration. The laser-diffraction technique is employed for path measurement of scattered light intensities and transmissions. The measured transmissions are converted to extinction coefficients before applying a deconvolution process. The local scattered light intensities and local extinction coefficients are then determined by applying a previously developed maximum entropy deconvolution technique. Lastly, the local drop-size distributions and local volume concentrations are determined. In measurement, the fuels are vertically injected at pressure of 12 bar into ambient pressure of 1 bar. Their temperature is varied by an electrical heater. Measurements are conducted on the 7-cm plane away from the injector. Scanning of laser beam with 1-cm diameter is performed throughout the half of the axisymmetrical spray section from the center to the edge with the step of 1 cm. The results show that the temperature influences the spray structure as shown by the local volume concentrations. The higher temperature tends to provide less concentration at the center core and higher concentration at the outer region.

Keywords: *biodesel, solid-cone spray, local volume concentration, maximum entropy, deconvolution*

1. Introduction

Owing to the fact that fossil fuels are decreasing rapidly and being more expensive, there are many researches on alternative fuels to investigate their potentials and performances. In Thailand, oil palm is the most appropriate candidate for production of biodiesels because of its high production yield (kg/rai) and low cost of oil extraction [1].

For spray combustion process, atomization into small drops is required to have high rate mixing and shorter drop lifetimes [2]. In this process, viscosity is one of the important properties influencing atomization performance. Even though the viscosity of biodiesel is much lower than that of palm oil after transesterification process, it can be twice or as high as that of diesel fuel [3]. This difference can lead to undesired spray characteristics affecting combustion performance. Prior fuel heating is useful process, particularly for very high viscosity vegetable oil like palm olien. Viscosity inversely varies with temperature. The higher the temperature, the lower the viscosity.

Pressure swirl atomizer is popular as industrial burner for many reasons. The conical sheet is created through centrifugal force from swirl flow inside the injector. Small drops are obtained from breakup of the sheet. If the viscosity of the injected fuel differs, flow condition inside the nozzle will change and provide different sheet. Generally, lower viscosity leads to a thinner sheet and then a finer spray [4]. Spray patterns, such as spray angle and local volume concentration, are also affected. The effects of viscosity on spray patterns should be investigated so that the optimized combustion performance can be obtained.

This work aims to investigate the effects of temperature on the local spray volume concentration of palm oil based biodiesel and palm olien. The plam olien is also used because its viscosity is quite high and can be varied in a wider range. Measurements are conducted by using laser diffraction technique and then the developed maximum entropy tomographic reconstruction is applied to the measured line-of-sight data to determine the local volume concentration [5-6].

2. Experimental Setup

The fuel injection system comprises a compressed nitrogen tank, a pressure vessel, a flow control valve, a pressure gauge, an electrical heater with a temperature control, and a solid-cone pressure swirl atomizer. The fuel filled in the pressure vessel is pressurized and vertically injected by using the compressed nitrogen gas into ambient still-air.

The fuels used are diesel, palm oil based biodiesel and palm olien and their injection temperatures are controlled by the heater with the temperature control. The test temperatures are at 30 and 40 °C for biodiesel and diesel sprays, and at 90, 120, and 140°C for palm olien. Kinematic viscosities of biodiesel and diesel are shown in Table 1. For palm olien, its viscosity is measured at 40, 60, 80 and 100°C as shown in Fig. 1.

Table 1 Kinematic viscosities of biodiesel and diesel

Fuel type	T (°C)	ν (mm^2/s)
Diesel	30	3.45
	40	3.23
Biodiesel	30	9.23
	40	7.04

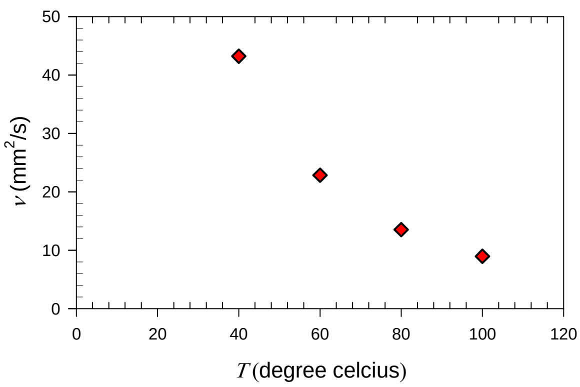


Fig. 1 Kinematic viscosity of palm olien as a function of temperature

The commercial laser diffraction instrument, named Malvern Spraytec, is employed to measure line-of-sight scattered light intensity and transmission. These measured data are required to calculate the line-of-sight drop-size distribution and line-of-sight volume concentration of a spray by using Mie's theory and transmittance theory, respectively.

Fig. 2 shows the measurement positions of the Malvern Spraytec with a laser-beam diameter of 10 mm. Measurements are carried out at the 7-cm cross-section and injection pressure is 12 bar.

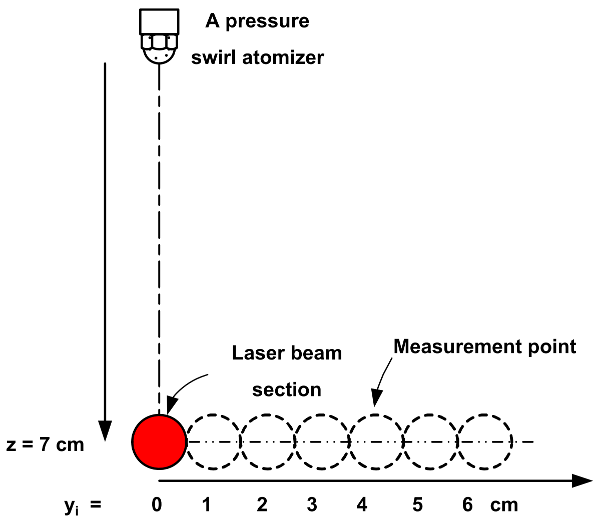


Fig. 2 The spray measurement diagram

3. The ME Deconvolution Approach

To reconstruct the local volume concentration from light-of-sight data, reconstruction for the local drop size distribution is also required. This is due to the fact that the local Sauter mean diameter is also needed for the calculation of the local volume concentration. In this paper, the developed maximum entropy tomographic reconstruction technique [5-6] is conclusively described.

For the local drop size distributions, the tomographic reconstruction is applied to the light-of-sight scattered light intensities. The spray from the pressure swirl atomizer is assumed to be axisymmetrical. Therefore, the spray cross-section is divided into *N*-1 annular rings and a center core as shown in Fig. 3, where δ is the laser diameter and N the number of measurement position along the *y* axis.

The relationship between the light-of-sight light intensities, $\bar{I}_j(y_i)$, and the local light intensities, , $I_j(r_k)$, of any diode *j* is:

$$\bar{I}_j(y_i) = 2\sum_{k=1}^{i} L_{ik} I_j(r_k), \quad i = 1 \text{ to } N \quad (1)$$

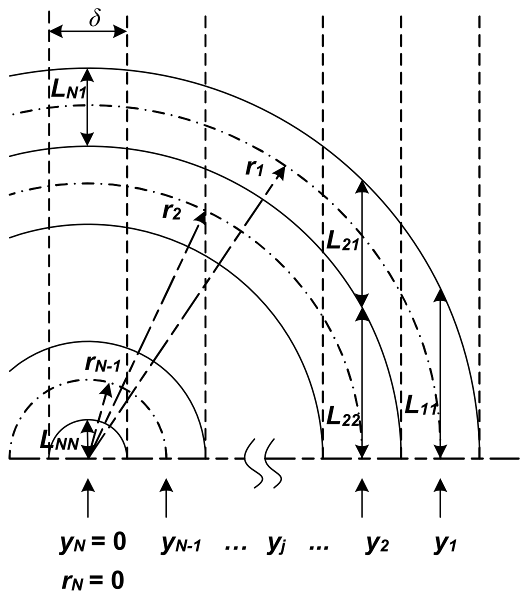


Fig. 3 Division of the axisymmtrical spray

where L_{ik} is the path length given by

$$L_{ik} = \sqrt{\left(r_k + \frac{\delta}{2}\right)^2 - r_i^2} - \sum_{m=k+1}^{i} L_{im} \quad (2)$$

Eq. (1) is solved for $I(r_k)$ using the technique of Maximum Entropy (ME) as described in previous work [5]. Local intensities onto all diodes are then used to determine the local drop size distribution in the annular region defined by r_k.

To determine the local volume concentration, the same deconvolution procedure is carried out but the tomographic reconstruction is applied on the line-of-sight extinction coefficient instead of the scattered light intensities. However, the Malvern Spraytec provides the transmission, which is calculated from the measured intensities of the undiffracted light I_L and the incident light I_0:

$$T = \frac{I_L}{I_0} \tag{3}$$

From Beer-Lambert law,

$$I_L = I_0 e^{-\int_L K(s)ds} \tag{4}$$

where $K(s)$ is the extinction (or attenuation) coefficient per unit path length, s is the curvilinear coordinate along the laser beam, and L is the optical path length. From Eqs. (3) and (4), the transmission is then related to the extinction coefficient $K(s)$ as:

$$-\ln T = -\ln\left(\frac{I_L}{I_0}\right) = \int_L K(s)ds = KL = \overline{K} \tag{5}$$

Therefore, each measurement in Fig. 2 can report line-of-sight extinction coefficients. The reconstruction is applied on these N coefficients. They are calculated from the measured line-of-sight transmissions T by using Eq. (5). The relationship between the path-integrated and local extinction coefficients is:

$$\overline{K}(y_j) = 2\sum_{k=1}^{j} L_{jk} K(r_k), \quad j = 1 \text{ to } N \tag{6}$$

where L_{jk} is the path length (see Eq. (2)). Eq. (6) is solved for $K(r_k)$ using the technique of Maximum Entropy (ME) as described in previous work [6].

When the local extinction coefficients $K(r_k)$ are obtained, the local volume concentrations, $C_{v,k}$, are determined with:

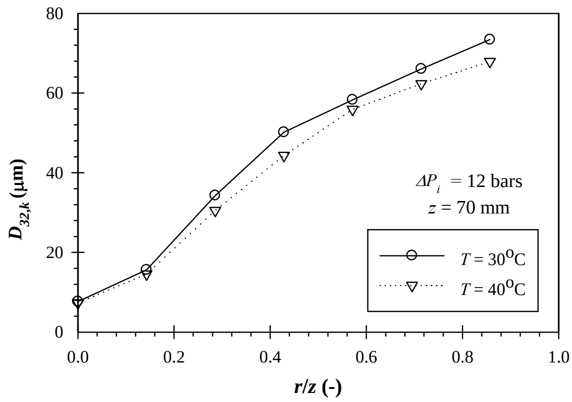
$$C_{v,k} = \frac{2D_{32,k}K(r_k)}{3\overline{Q}_k} \tag{7}$$

where $D_{32,k}$ is the local Sauter mean diameter, $\overline{Q}$ is the mean scattering coefficient, which is already mentioned in previous work [6].

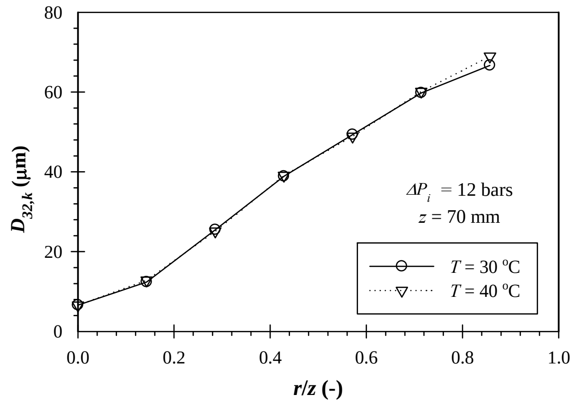
4. Results and Discussion

4.1 The local mean drop sizes

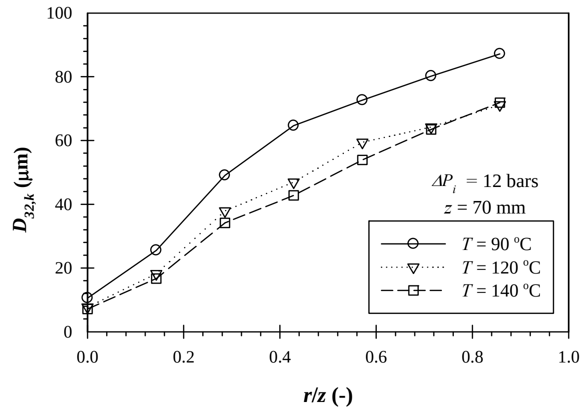
Fig. 4 shows the local mean drop sizes ($D_{32,k}$) on the 7-cm cross-section at ΔP_i = 12 bar for biodiesel, diesel and palm olien. The selected temperature levels are 30 and 40°C in the case of biodiesel and diesel, and are 90, 120, and 140°C in the case of palm olien. All results show that the smallest $D_{32,k}$ are obtained at the center of the spray while the largest $D_{32,k}$ are at the edge of the spray. When temperature is increased, the mean drop size of the spray tends to be smaller for all regions except at the center one where the drops are very small at the order of 10 μm. In the cases of biodiesel and palm olien, a decrease of $D_{32,k}$ is clearly seen (Fig. 4(a) and (c)).



(a) Biodiesel



(b) Diesel



(c) Palm olien

Fig. 4 Local Sauter mean diameters as a function of the liquid temperature

The obvious decrease of $D_{32,k}$ is not found in the case of diesel (Fig. 3(b)) because its viscosity does not vary much (for T = 30 to 40 °C).

The local $D_{32,k}$ shown in Fig. 4 are subsequently used in calculation of the local volume concentration.

4.2 The local extinction coefficients

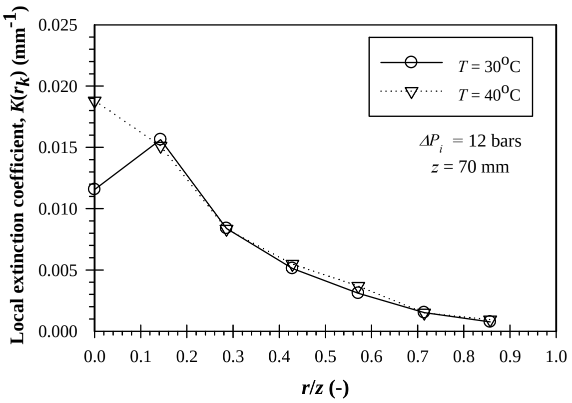
Prior to determine the local concentration, deconvolution of the extinction coefficients is required. Fig. 5 shows the reconstructed results of the extinction coefficients of biodiesel, diesel and palm olien. The results show that the extinction coefficient is the highest at the spray center and decreases from the center to the outer, except only in the case of biodiesel where the maximum extinction coefficient is at r_k = 10 mm. An increase of the liquid temperature increases the local extinction coefficient in the outer local positions implying that the amount of liquid is more spread outwards. This is particularly visible for palm olien (Fig. 4(c)). The effects of temperature on the extinction coefficient are not significant for biodiesel and diesel (Figs. 4(a) and (b)).

These local $K(r_k)$ are further applied to determine the local volume concentration.

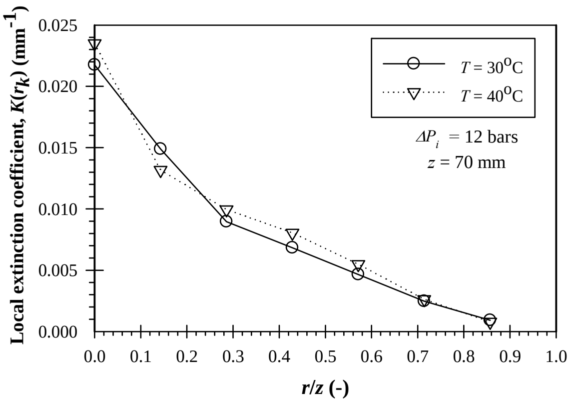
4.3 The local volume concentrations

The local volume concentration is finally calculated from the local Sauter mean diameter and the local extinction coefficients by using Eq. (7). The results are shown in Fig. 6. The peak or maximum volume concentration appears at the region between the center core and the edge of the spray. This is due to the fact that the pressure swirl atomizer provides conical-sheet breakup. When the fuel is heated, the peak point tends to be decreased at the inner region and moves outwards for all cases. This is clearly seen in the cases of biodiesel and palm olien (Figs. 6(a) and (c)) but not in the case of diesel (Figs.

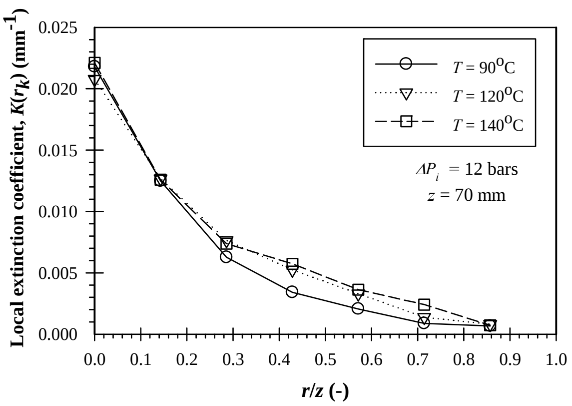
6(b)). The outward shift of the local concentration can be explained by the higher swirl flow inside the nozzle when the viscosity is reduced, which leads to higher radial velocity of drops.



(a) Biodiesel



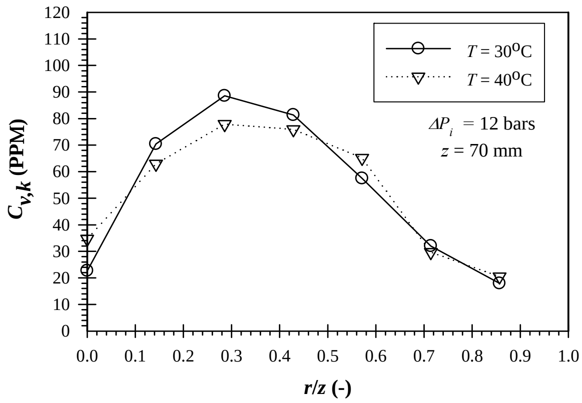
(b) Diesel



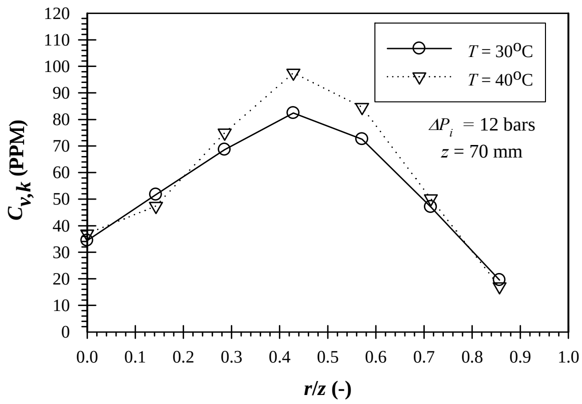
(c) Palm olien

Fig. 5 Influence of the temperature on the local extinction coefficient

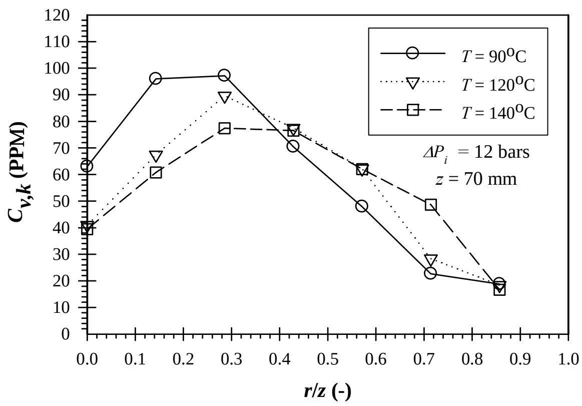
This means that the concentration is reduced at the inner region and is raised at the outer region.



(a) Biodiesel



(b) Diesel



(c) Palm olien

Fig. 5 The local volume concentration at different temperatures

5. Conclusions

This work presents the spray characteristics of the bio-oil fuels in term of the local Sauter mean diameter and the local volume concentration, affected by the temperature.

From the results, it can be concluded that

1. The mean drop size decreases at all local positions as temperature increases.
2. The local volume concentration tends to be reduced at the center core of the spray while increased at the outer region when temperature increases. This is clearly seen in the case that viscosity changes notably as in the case of biodiesel and palm olien.

6. Acknowledgement

This research is co-financially supported by the Engineering faculty of the King Mongkut's University of Technology North Bangkok (KMUTNB). Research facilities are provided by the Department of Mechanical Engineering of KMUTNB and by the Joint Graduate School of Energy and Environment (JGSEE) of the King Mongkut's University of Technology Thonburi (KMUTT). Lastly, the authors would like to give a thank to Mr. Teerapun Sangjun for some help.

7. References

[1] MA, A. N. and Ong, A. S.H. (1986), Biomass energy from palm oil industry, *Proceeding ASEAN Conference on Energy from Biomass*, pp. 13-21.

[2] Law, C. K. and Williams, F. A. (1972), Kinetics and convention in the combustion of alkane droplets, *Combustion and Flame*, Vol. 19(3), pp. 393-406.

[3] Sriroth, K. (2002), Palm oil: the biodiesel hope of Thailand, *28th Congress on Science and Technology of Thailand on 24-26 October 2002 at Queen Sirikit National Convention Center*, Bangkok, Thailand.

[4] Lefebvre, A. H. (1989), *Atomization and Sprays*, Hemisphere Publishing Corp.

[5] P. Yongyingsakthavorn, C. Dumouchel, P. Vallikul, and B. Fungtammasan (2009), Deconvolution with Maximum Entropy Solution to Determine Local Extinction Coefficient and Local Volume Concentration from Laser Diffraction Data, *Part. Part. Syst. Charact.*, 26, 187-198.

[6] P. Yongyingsakthavorn, P. Vallikul, B. Fungtammasan, and C. Dumouchel (2007), Application of the maximum entropy technique in tomographic reconstruction from laser diffraction data to determine local spray drop size distribution, *Experiments in Fluids*, 42, (3), 471 – 481.