On Evaporation Constants of Biodiesel-Diesel Blends: The Effects of Blending Ratios

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Abstract

This paper presents the measurement results on the evaporation constants of droplets of biodiesel-diesel blends within controlled-temperature environment at atmospheric pressure. Series of shadow images of the fuel droplet evaporating at different times have been taken. Analyses of the time series images led to the determination of the evaporation constant via the classical D^2-law. It has been found that blending of biodiesel with mineral diesel affects the evaporation constant significantly. Substitution of only five percent by volume of biodiesel in mineral diesel causes up to 20% reduction in the value of the evaporation constant.

Key word: Evaporation, Droplet, Biodiesel

Introduction

Classical works on the theory of one dimensional evaporation of liquid in the form of a single droplet, heated under elevated ambient temperature were studied for the cases with and without combustion. (1-2) The studies reported both measurement and validation results of the evaporation constant of different liquid droplets. The results obtained from the theory were within sufficient accuracy and adequate for many engineering design purposes. (1) In the study of Morin, et al. (3) the concept of using the fibre-suspended droplet technique to experimentally determine the evaporation constant of vegetable oil derived biofuels was advanced at high elevated temperature. It was shown in their work that the evaporation constant of the biofuels – namely rapeseed and sunflower methyl esters - depends on the chemical compositions of the oils and their esters.

In Thailand, the use of palm oil based biodiesel-diesel blend at 2% (B2) as transport fuel has been mandatory since 2007 and B5 have also been available commercially as an option for consumers. Although the subject of engine performance and emission characteristics of biodiesel has been studied widely and some studies have been conducted on the characteristics of biodiesel spray Tantivoranukul, et al. (4) fundamental information on the evaporation behavior of a single droplet of biodiesel-diesel blend is lacking. This reports the results of a study on the evaporation of droplets of palm oil based biodiesel blended with diesel at different volume ratios.

Theoretical Background

The diffusion heat and mass transfer models govern the evaporating process of a quasi-steady ideal gas phase evaporation from completely spherical drop was advanced rendering mass flux at the surface of the droplet as

\[ \rho v = D_{\text{gas}} \ln(1 + B_M) = \alpha \ln(1 + B_T) \]  

where \( B_M \) and \( B_T \) are mass and heat transfer numbers. (1) The properties appearing in the above equations are for a gaseous mixture, being evaluated at the surface temperature. The mass flux term that appears on the left hand side of Equation (1) can be related to the time rate of change of the diameter of the liquid drop through the conservation of liquid and gas at the interface such that Equation (1) can be written in terms of the droplet diameter evolving with time as

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$D^2 = D_0^2 - \beta t$ , \hspace{1cm} (2)

where the evaporation constant

$$\beta = \frac{\rho D_{45}}{\rho_1} \ln(1 + B_D) = -\frac{\rho_1 \alpha_T}{\rho_1} \ln(1 + B_T) . \hspace{1cm} (3)$$

The value of $\beta$ can either be determined experimentally by fitting Equation (2) to the experimental data or predicted by Equation (3) using the gaseous properties at the interfacial surfaces of the gas and liquid.

**Materials and Experimental Procedures**

The fibre-suspended droplet technique Morin, et al.\textsuperscript{(3)} has been advanced in this work. The droplet, suspended from the tip of a 0.2 mm diameter-wire, is heated in a slide-able (or movable) cylindrical heating chamber pre-set at a designed temperature (140-200°C) and at atmospheric pressure. A high speed CCD camera, 640×480 pixels in 4.7 ms (Keyence CV-H035M), is used to capture the images of the evaporating drop.

The measurement procedures have been verified by measuring the evaporation constant of water drops at different controlled ambient temperature and atmospheric pressure. The time series of shadow images of the drops are as shown in Figure 1.

Figure 2 compares the evaporation constants obtained from the curve-fitting of $D^2$-model, Equation (2), with those obtained from direct calculation using one dimensional model, Equation (3). Error-bars appearing on the curve-fitting represent deviation of measured evaporation constants from their mean values.

The results show good agreement between the experiment and calculated evaporation constants; verifying the proposed experimental setup and calculation procedures.

**Results and Discussion**

In applying the measurement procedures to determine the evaporation constant of liquid drops of biodiesel-diesel blends, the plot of dimensionless $D^2/D_0^2$ versus $t/D_0^2$ for diesel and biodiesel is shown in Figure 3. The ambient condition was at atmospheric pressure and 200°C controlled temperature. A decrease in evaporation constant has been found even at low biodiesel-diesel mixture ratios. It can be observed from the experimental results that the biodiesel drop swells at the beginning of the heating process. This effect is less obvious or cannot be detected for the fuel mixture or for diesel fuel alone.

![Figure 2](image2.png)

**Figure 2.** The measured evaporation constant of water drops compared with the evaporation constant calculated from one dimensional model.

![Figure 3](image3.png)

**Figure 3.** The linear plot of $D^2/D_0^2$ versus $t/D_0^2$ at atmospheric pressure and 200°C ambient temperature, dotted and solid lines represent measured data and its linear fit, respectively.
The variations of the experimental results from the D\textsuperscript{2}-model can be observed in the case of diesel fuel. This is due to the fact that the fuel is a multi-component liquid of different evaporation constants. The curve deflects when different portions of volatile substances evaporated. When blending diesel with biodiesel, which is of lower volatility, the evaporation of the less volatile component dominates and the D\textsuperscript{2} curve becomes more linear, and the evaporation rate also decreases. On the other hand for pure biodiesel, an initial drop size larger than that of diesel has to be generated so that the interfacial surface between the drop and the wire can be minimized. This results in the initial evaporation of a non-spherical drop and in the deviation of the experimental data from the model.

**Conclusions**

Considerably lower evaporation constant for biodiesel as compared to diesel has been found. The difference can be as much as 20% with only 5% addition of biodiesel in diesel. This could have significant bearing on the combustion characteristics of a biodiesel and diesel blend. The D\textsuperscript{2}-law may not be appropriate for describing the evaporation rate of neither pure diesel nor pure biodiesel except for the case where there is a right mixing ratio between the two. Therefore care should be taken when applying the D\textsuperscript{2}-law to biodiesel blends when they are used in an energy-conversion equipment originally designed for diesel fuel.

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