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Evaporation and Puffing of Diesel-Biodiesel-Ethanol Blend Droplets Under Convective Conditions

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Abstract

With increased use of blended fuels, understanding spray combustion at droplet level helps in using fuels efficiently and reduce harmful emissions. Puffing and micro explosion are the phenomenon observed in the spray combustion of the blended fuels with components having different volatility. Most of the previous studies primarily focused on the puffing and micro explosion under quiescent conditions. In the present study an attempt has been made to study puffing and micro explosion of diesel, biodiesel (RME) and ethanol blends under convective conditions by introducing droplet in to high temperature air stream. High speed back light imaging technique was sued to capture the time evolution of the droplets and analyzed for change in size with time. Effect of temperature on the droplet evaporation is studied by varying air stream temperature from 400°C to 600°C while the effect of volatile phase was studied by varying the ethanol content between 10 to 30 % by mass in the blend. Results indicate that mixing small amount of ethanol in the ternary blend increase puffing and micro explosion potential. Gas temperature was found to be critical for creating micro explosion in droplets with 10% ethanol while this effect seems to nullified with increase in the ethanol content. Increasing the ethanol content improved the micro explosion potential and reduced the time for micro explosion. Changes inside the droplet during the heating phase is found to be critical for creating micro explosion and its intensity.

Keywords

Micro explosion, puffing, diesel-biodiesel-ethanol blend, high speed imaging.

Introduction:

Europe is striving to achieve net-zero greenhouse gas emissions by 2050 and the strategies are focused towards reducing the utilisation of fossil fuels. Biodiesel and bioethanol produced from renewable sources serve as potential alternatives to partially replace fossil diesel, particularly in marine engines that are difficult to decarbonise. Ethanol cannot be directly utilised in existing diesel engines due to its thermo-physical and chemical properties. However, it can be effectively utilised by designing emulsion consisting of ethanol, diesel and biodiesel. The biodiesel, present in the ternary blend acts as a surfactant to form a micro-emulsion, with diesel as a continuous phase and ethanol as a dispersed phase [1].

When the droplets of this emulsion are introduced into high temperature environment, due to high volatility of ethanol compared to diesel, droplets tend to undergo puffing and micro explosion [2,3]. Puffing and micro explosion improves the atomization and enhances the evaporation and mixing insides the combustion chamber. Most of the puffing and droplet explosion studies in the literature either used placing droplets on thermocouple/glass fibres

[2,4] or used free falling droplets introduced into heated chamber [6] and were limited to studying droplet explosion in the quiescent environment. Computational works in the literature were also primarily focused on micro explosion in the quiescent environment [6]. A few researchers in the recent times turned their attention on studying multi-component fuel blends evaporation under convective conditions [7,8]. Antonov et al studied explosive disintegration of oil and water droplets under conductive, convective and radiative modes of heating and found that concentration of the components and rate of heat flux supplied to the droplet have strong influence on the droplet disintegration. Meng et al conducted experiments on micro explosion of biodiesel and ethanol blends under hot co-flow conditions and found that air temperature and co-flow rate influences the intensity of micro explosion. In the present study, evaporation, puffing and micro explosion of ternary blends of diesel, rapeseed methyl ester (RME) biodiesel and ethanol under co-flow conditions has been studied. Effect of temperature and concentration of different components on the puffing and micro explosion and dynamics of droplets during the process is presented in the paper.

Methodology:

The experimental setup used for this consists of tubular air heater, temperature controller, thermocouple to place a droplet and a flow meter. A schematic of the experimental setup used for this study is shown in Fig 1. Compressed air from the tank was made to flow through the tubular heater of diameter 10 mm to heat it to the desired temperature at the exit of the heater. A thermocouple placed at the exit of the heater was connected to the temperature controller to maintain temperature of the air stream at ±15°C of the set value. The flow rate of the gas was controlled using a needle valve to maintain a constant air velocity of about 3 m/s at the exit of the tube. Once the desired air stream temperature was reached, droplet suspended on a 75 µm gauge thermocouple was introduced into the air stream rapidly and the dynamics of droplet was recorded using high speed backlight imaging technique. Droplet images were taken at a frame rate of 2000 frames per second and analysed for variation in shape and diameter to identify evaporation, puffing and micro explosion using an in-house developed Matlab algorithm. The resolution of the camera was set at 50µm per pixel in this study. Another set of images were taken at 100K fps to understand the dynamics of micro explosion process.

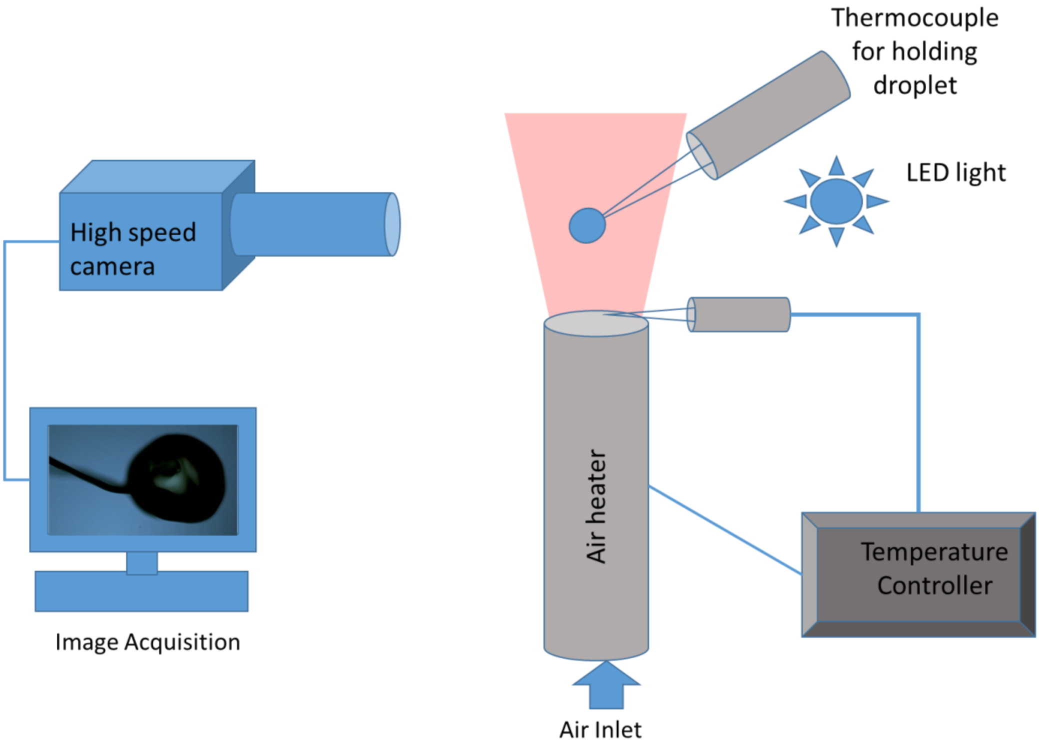

Figure 1: A schematic of the experimental setup used for this study

Results and discussion:

Experiments were conducted at three different air temperatures *viz.* 400°C, 500°C and 600°C for different compositions of diesel, RME and ethanol. In the nomenclature of blends, 'D' represents diesel, 'BD' represents RME bio-diesel and 'E' represents ethanol. Number subsequent to the corresponding alphabet indicates the percentage by mass of that fuel in the blend. Example D80BD10E10 has a composition of 80% Diesel, 10% RME and 10% ethanol. Images of the droplets introduced into the high temperature air stream were captured and processed using our in-house developed Matlab image processing algorithms. Evolution of the normalised droplet area with normalised time for 400°C and 600°C are shown in figure 2. Plots showed that having no ethanol in the blend (D50BD50) didn't induce any micro explosion even at 600°C. Introducing small amount of ethanol (10%) to the blend facilitated droplet evaporation, along with puffing and micro explosion observed at 400°C and 600°C respectively. Increasing the ethanol content in the blends led to an increase in micro explosion potential at both temperatures. The puffing of the droplets prior to micro explosion was observed to be stronger for higher ethanol content in fuel blend and it also increased with an increase in temperature.

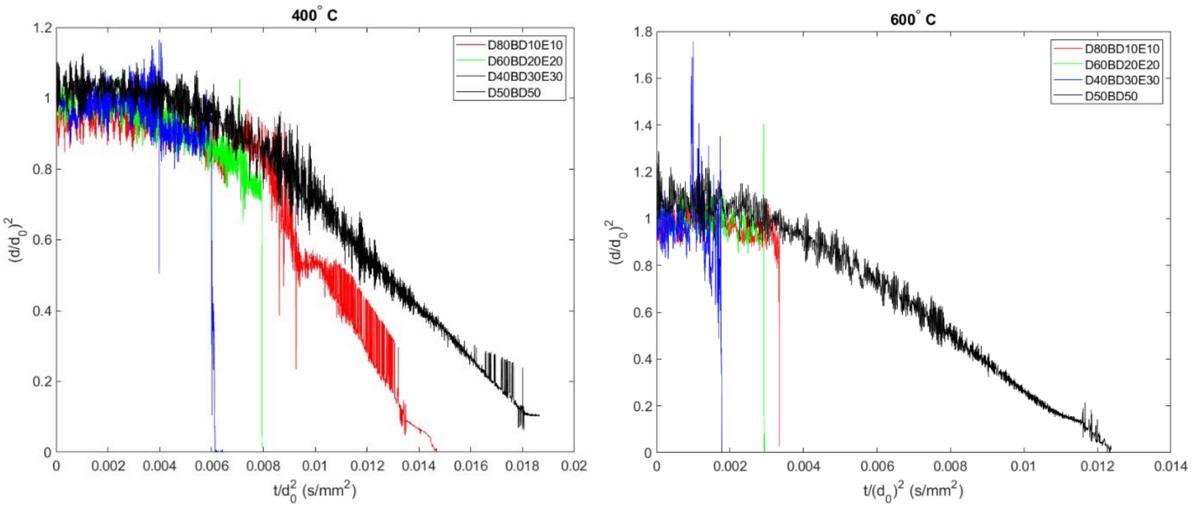

Figure 2: Effect of temperature on the evaporation and micro explosion of the blends. The sharps oscillations in the droplet diameter are due to oscillations of droplets in the air flow.

Effect of temperature on micro explosion for blends of D60BD20E20 and D40BD30E30 are shown in figure 3. It was observed that by increasing the temperature, the time required for the occurrence of micro explosion also decreased for both blends. It can also be seen from the images that blends with 30% ethanol content experienced micro explosion relatively earlier with respect to time compared to the blends with 20% ethanol. The blend that contained 30% ethanol also experienced intense puffing before the occurrence of micro explosion at 600°C compared to the other blend. This could be due to local evaporation of ethanol inside the droplet at higher temperature.

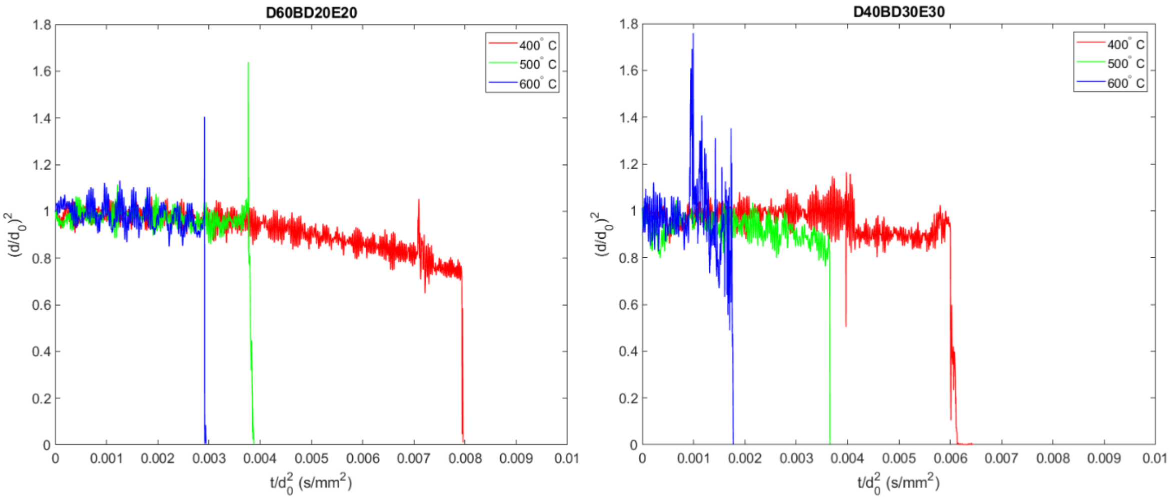

Figure 3: Effect of temperature on the micro explosion of D60BD20E20 and D40BD30E30 blends

A closer look at the droplet images revealed some noticeable changes inside the droplets during the heating process. A typical image of the droplet transformation before micro explosion are shown in figure 4. When introduced into the high temperature air stream, phase separation started in the droplet with time. As the time elapsed, the separated phase (ethanol) kernels started coalesce into a large internal drop. If the local kernel evaporates before merging to the larger one, it creates puffing. In case of ethanol coalescing into larger internal droplet, it created micro explosion. It was observed that intensity of puffing and micro explosion depends strongly on the size of the dispersed phase inside the diesel. Larger the size of separated phase, stronger the puffing and micro-explosion. A similar change inside the droplet i.e separation and coalescence were reported by the authors in their previous work on micro explosion of droplets under quiescent environment [9].

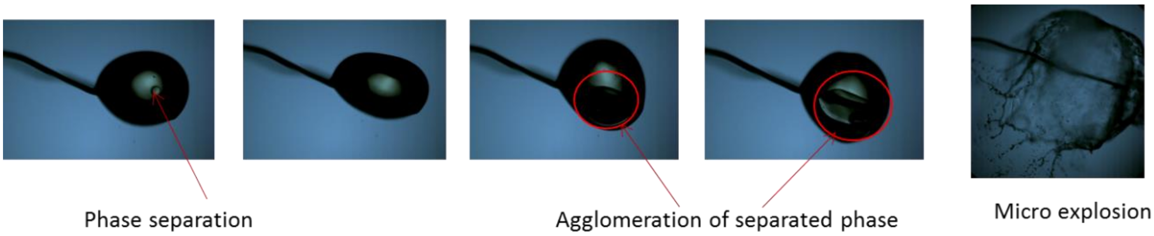

Figure 4: Separation and agglomeration of dispersed phase before the micro explosion

Ultra high speed images were taken at a framerate of 100K frames per second to capture the transients of micro explosion observed for D40BD30E30 at 600°C, as shown in figure 5. From the images it can be seen that primary droplet explosion leads to the formation of a number of larger size droplets, which further undergoes puffing and micro explosion, if they are spatially located in the co-flow of hot airstream. It was also observed that puffing and micro explosion occurs even for smaller size droplets, the intensity of these events were dependant on the amount of the volatile phase present in those smaller size child droplets that were formed after the explosion of primary droplet.

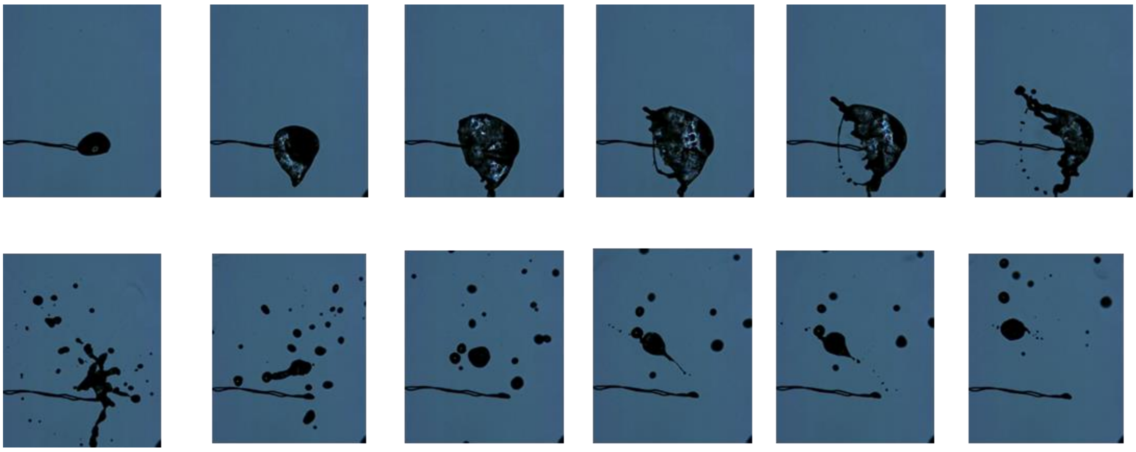

Figure 5: Primary and secondary droplet undergoing micro explosion

Summary:

Evaporation of multicomponent fuel blend droplets composed of diesel, RME and ethanol under convective conditions were experimentally studied using high speed backlight imaging. Results showed that blending a small amount of ethanol in diesel, RME mixtures can accelerate droplet evaporation and puffing at temperatures in the range of 400°C. Under high temperature conditions of about 500° C and 600°C, micro explosion was observed with 10% addition of ethanol to the blend. Blends with 20 % and 30 % ethanol showed micro explosion behavior at all the temperatures studied. It was observed that increasing the gas stream temperature or increasing the ethanol content in the blend reduces the time for micro explosion. The close-up images indicated that coalescence of the volatile phase i.e. ethanol in the present case is critical for micro explosion of the droplet, while the ultra-high speed images showed that puffing and micro explosion occurred in child droplets of varying size ranges.

Acknowledgments

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References:

[1] Fernando, S., Hanna, M., 2004, Energy and Fuels, 18 (6), pp. 1695–1703

[2] Avulapati, M.M., Ganippa, L.C., Xia, J., Magaritis, A., 2016, Fuel, 166, pp. 59-66.

[3] Shinjo, J., Xia, J., Ganippa, L.C. Megaritis, A., 2014, Physics of Fluids, 26, 103302-1.

[4] Yi, P., Li, T., Fu, Y., Xie, S., 2021, Fuel, 284, 118892.

[5] Botero, M.L., Haung, Y., Zhu, D.L., Molina, A., Law, C.K., 2012, Fuel, 94, pp. 342-347.

[6] Shinjo, J., Xia, J., Megaritis, A., Ganippa L.C., 2016, Journal of Fluid Mechanics, 793, pp. 444-476.

[7] Antonov, D.V., Piskunov, M.V., Strizhak, P.A., 2019, Applied Thermal Engineering, 152, pp. 409-419.

[8] Meng, K., Wu, Y., Lin, Q., shan. F., Fu, W., Zhou, K., Liu, T., Song, L., Li, F., 2019, Journal of the Energy Institute, 92 (5), pp. 1527-1536.

[9] Avulapati, M.M., Magaritis, A., Xia, J., Ganippa, L.C., 2019, Fuel, 239, pp. 1284-1292.