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Droplet Evaporation Characteristics of Diesel and Biodiesel Blends on Hot Surface

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1 Abstract

The worldwide drive to move towards renewable energy sources has made biodiesels an attractive proposition for development in replacement of diesel as a fossil fuel for the internal combustion engine. This study explores droplet evaporation characteristics for both diesel and three biodiesels: namely, sunflower-, corn- and palm-oil derived fuels; when tested on hot stainless steel and aluminium surfaces. Experimental work was carried out across a surface temperature spectrum of between 100 and 460 °C and with droplets of between 100 and 500 μm in diameter, and assessed the impact of type of surface, droplet size and fuel used upon time to evaporation and change between evaporation regime. The distinctive evaporation regimes recorded were film evaporation, nucleate boiling, transition boiling, and the spheroidal or Leidenfrost evaporation, with each presenting a different interaction mode between droplets and surfaces. Regime mapping was conducted in relation to surface temperature, and the results point to an extended evaporation time for biodiesels in comparison with diesel, based on their greater boiling point and more viscous nature. The longest evaporation time was identified for palm biodiesel, with sunflower biodiesel evaporating comparatively more quickly than the other biodiesels. A significant impact was observed from surface material, with droplets evaporating in a shorter time than on the more thermally conductive aluminium compared to stainless steel. The findings also show that decreased droplet size shortened time to reaching a critical regime and shorter overall evaporation time. Initiation of spheroidal evaporation differed by fuel, with biodiesels in general reaching this stage at a higher temperature. The results, contribute to detailed understandings of thermal properties and regime-change behaviours among biodiesels, and can be used to inform efforts to reduce emissions, increase efficiency in spray combustion, and optimize heat transfer in biodiesel applications.

List of Symbols

Tb boiling temperature, ◦C

Tc critical temperature, ◦C

TL Leidenfrost temperature, ◦C

Ts initial surface temperature of the hot surface, ◦C

2 Introduction

In the context of depleting oil reserves alongside rising petroleum demands across different areas of industry and transport, the potential for development of novel renewable fuels is significant. A major renewable alternative diesel-type fuel source is presented by plant-oil based biodiesel blends. Biodiesels offer the following benefits compared with fossil-fuel diesel; when combusted, biodiesels emit less carbon dioxide (CO_2), with a reduced impact on climate changes compared to diesel. Moreover, biodiesels are suitable for diesel engine use, and do not necessitate these engines to be modified [1]. Finally, compared with diesel, the increased flashpoints of biodiesels, their greater lubricity, improved safety profile and lesser environmental impact have attracted significant interest [2].

Spray combustion forms the main combustion type in the diesel engine, and involves the evaporation and ignition of multiple fuel droplets within the combustion chamber. The evaporation of droplets is therefore crucial to delaying ignition, to the mixing of air and fuel, to efficient combustion and to the creation of pollutants. Experimental work by Abu-Zaid [3] explored petrol and diesel droplet evaporation in contact with a hot surface, and showed that evaporation times respond strongly to the surface's temperature and the surface material's thermal characteristics. Moreover, Azami and Savill's [4] modelling of spray evaporation and penetration across alternate fuel types including ethanol, methanol, kerosene, and different biodiesels revealed the impact of thermo-physical characteristics of different fuels on spray and evaporation behaviours in conditions comparable to engines.

Zare et al. [5] compared evaporation behaviours for droplets across diesel, castor biodiesel and canola biodiesel fuels for two hot surfaces: steel and aluminium. They report the highly significant role of thermal conduction of the surface material as combined with the viscosity and dynamic nature of the fuel for droplets' evaporative lifespan. Further, high-speed imaging was employed by Ashikhmin et al. [6] in investigating secondary atomisation regime in micro-emulsions from biodiesels striking heated walls, and determined critical transitions from films forming to, breaking up and rebounding in relation to surface temperatures and the characteristics of fuels.

While acknowledging previous work, further research is required to systematically compare evaporation dynamics across diesel and different types of biodiesel, including those produced from palm, corn, and sunflower oils for widely-used metal surfaces such as stainless steel and aluminium. Significant differences have been established in the heat transfer and thermally conductive behaviours of these surface materials, and these impact upon evaporative processes like nucleate boiling, film boiling, and Leidenfrost behaviour [7, 8]. This work presents experimental work exploring evaporation features for diesel and three biodiesel fuels, on heated surfaces. The study's objectives are as follows:

- Produce evaporation time curves for varied droplet sizes of diesel and three biodiesels: palm-, corn- and sunflower-based fuels.
- Determine distinct evaporation phases: film evaporation, boiling, transition, and spheroidal evaporation.
- Determine optimal evaporative conditions with respect to the size of droplets, surface materials and biodiesel formulation.
- Identify critical surface temperature for the biodiesels and diesel fuels investigated.

3 MATERIALS AND METHODS

3.1. Materials

Biodiesels for this study were produced from palm, corn and sunflower oils bought commercially**.** The diesel investigated was purchased as diesel fuel at a commercial petrol station.

3.2. Testing equipment

Figure 1 illustrates schematically the equipment set-up used in the droplet evaporation experiments. The heated surfaces consisted of a flat, raised-edge plate which prevented droplets from bouncing out. The plate materials were aluminium alloy 7075 and steel 1.5920.

3.3. Experimental apparatus

As shown in Figure 1, the apparatus used for the experiment can be divided into several subunits, as follows:

Heating unit: this apparatus is capable of raising the temperature of the plates to reach 460 ◦C. This unit was positioned within the spiral groove of a ceramic block, before covering with a strongly thermally conductive mica sheet. Surface temperatures were controlled using Variace.

Heating surface: The surfaces for testing formed round discs, one of stainless steel and one aluminium, with a 7.5 cm diameter, and each being 0.8 cm thick. Their slight concave shape was designed to stop droplets from sliding off. Centrally positioned in a groove on the test discs' surface was a Chrome-Alum. thermocouple of 0.076 mm diameter, with the groove being marginally wider. Omega high-temperature thermocouple adhesive was used to secure the thermocouple. The thermocouple's sheath was worn nearly bare through surface polishing. Temperatures were measured for the test surfaces using a multi-meter.

Droplet generation system An 11-gage stainless-steel needle was used with a good quality glass medical syringe holding 20 CC in combination with a Razil pump, and this apparatus produced droplets. After filing the tip of the needle to smoothen and flatten it, it was bent to 90◦ from the original.

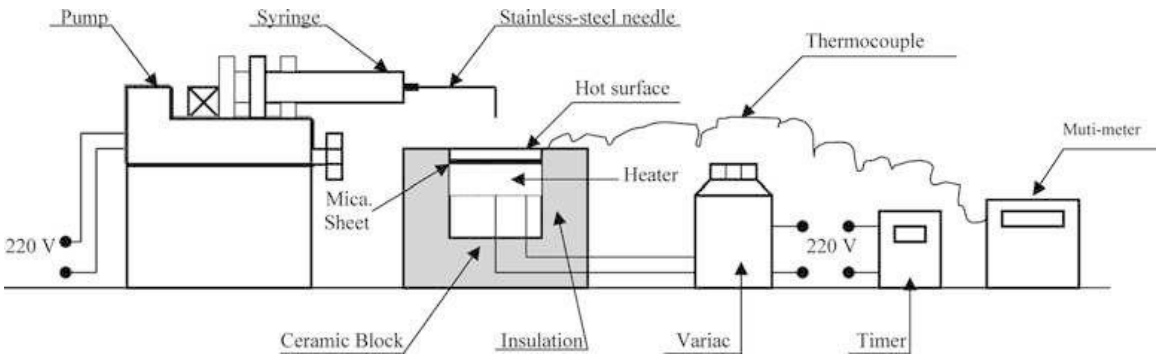


Fig. 1. Experimental set-up: schematic diagram

3.4. Procedures

Multiple experiments were conducted for a series of initial temperatures of between 100 and 460 ◦C. Surface temperatures were left to stabilise at the intended point prior to moving the droplet generator into position with the needle tip central and at 1 cm above the heated surface. The pump was then applied until the formed droplet's weight caused it to detatch from the needle for gentle deposition on the surface. Initial droplet temperature was approximately 25 ◦C. Measurement of time to evaporation (disappearance of droplets) was conducted with an IRWIN crystal timer at 0.01 seconds' resolution.

4 Results and discussion

The drive to develop novel sources of renewable energy is an important current research focus, as the global oil reserve continues to deplete. Diesel is a major fuel source underpinning industry and transport, and a major derivative of crude oil. However, it is also a significant contributor to the emission of greenhouse gases, in particular emitting carbon dioxide (CO_2), which is significant in driving climate change [9, 10]. Biodiesels

present potential alternate fuel sources to diesel, and form a renewable and biodegradable resource, being based upon animal fat or vegetable-based oils. These fuels are suitable for use in current diesel engines, with no major alterations required: moreover, they emit less CO_2 and particulate matter compared with combustion of fossil fuel diesel [11, 12]. Thus, biodiesels offer both lesser impact on the environment and the possibility of decreased fossil fuel dependence and increased energy diversification, and they hence have attracted significant interest within the context of energy transitions for sustainability [13].

Researchers have examined biodiesel droplet evaporation when in contact with a heated surface, measuring the evaporative lifespan of such droplets. Figures 2, 3, 4 and 5 present findings from evaporation experiments showing respective evaporation times as related to initial surface temperature (Ts) for diesel and biodiesel on aluminium and stainless steel surfaces. The values are averaged across five experiments with identical conditions. In qualitative terms, curves produced for biodiesel closely resemble those for diesel, displaying 4 phases: evaporation, nucleate boiling, transition boiling and film boiling (Leidenfrost phenomena). In the evaporation phase ($Ts < Tb$) the heated surface and the droplets come into contact, with heat transfer occurring predominantly through conduction, and droplets evaporating on their upper and side surfaces. During this stage, evaporation time is reduced with extended Ts, due to the increased heat transfer from the surface over time.

During the nucleate boiling phase ($Tb < Ts < Tc$), bubbles of vapour can be observed forming on the heated surface. At higher Ts surface heat transfer increases, as the bubbles form mor dynamically, causing the liquid to mix further close to the surface and reducing evaporation time. Figures 2–5 show that diesel droplets have a significantly shorter evaporation time over evaporation and nucleate phases compared with biodiesels at identical surface temperatures. This difference occurs as the boiling point and heat capacity of droplets influence boiling times, and each fuel has a different boiling temperature range: 180-360 ◦C for diesel; 340–360 ◦C for palm biodiesel, 330–355 ◦C for corn and 330-360 ◦C for sunflower. Therefore, diesel, with the lowest boiling range, evaporates most rapidly under the same conditions. Moreover, from Figures 2-5, biodiesels evaporate more slowly than diesel at identical temperatures, and therefore, the more thermally conductive aluminium surface causes the diesel droplets to evaporate at a greater rate compared with stainless steel.

Critical surface temperature (Tc) is defined as that which allows droplets to evaporate most rapidly, and forms an essential parameter in achieving evaporation efficiency [14]. Tc is identified from Figures 2–5, and presented in Table 2. At critical temperature, droplets rapidly disappear following onset of significant boiling, with evaporation time moving towards its lowest duration and heat transfer reaching its peak. Diesel's critical temperature

appears lower than the biodiesels tested, due to the significance of heating time at Tc, with fast boiling at biodiesel interfaces distorting droplets and eventually causing them to disintegrate. For biodiesel, heating time is a function of boiling temperature as well as heat capacity, as earlier stated. With increase in Ts, heat transfer rate is reduced, due to the shrinking direct interface of fuel with surface, in addition to the vapour's reduced conductivity in comparison with liquid. Thus, at a higher Ts, evaporation time is also higher. For the film boiling stage (Ts > TL), a vapour layer occurs on the surface, separating surface and droplet. With greater As, heat transfer rates increase, with thermal radiation forming the main engine for heat to be transferred from heated surface to the liquid. Therefore, evaporation times are reduced at higher Ts. Furthermore, biodiesel droplets exhibit longer evaporation times than do diesel droplets, with palm-based biodiesel taking longest to evaporate, then corn, and then sunflower. These findings can mainly be explained by the fuels' different molecular and physical characteristics, as palm biodiesel is made up to a larger extent of saturated fatty acid methyl esters such as methyl palmitate, making it more viscous and giving a higher boiling point, which renders it less volatile and slower to evaporate [11, 13]. Compared to palm, sunflower biodiesel contains more unsaturated esters (e.g., methyl linoleate), and is thereby less viscous with a lower boiling point, thus evaporating more rapidly [12]. Corn biodiesel represents a saturated – to unsaturated ester composition between those of palm and sunflower, leading to its evaporation behaviours falling between the two [15]. This pattern of findings for the three fuels persists across the range of surface temperatures applied, emphasising the importance of fuel characteristics at molecular level for evaporation behaviours.

Significant differences are seen between biodiesels and diesel and between surface materials in terms of evaporation. At every surface temperature applied (between 100 and 450 °C) and on both stainless steel and aluminium surfaces, diesel evaporated most rapidly, as the most volatile fuel tested, with the lowest boiling temperature and lightest molecular weight based on its hydrocarbon structure [11]. The comparatively greater evaporation time shown by each of the biodiesel fuels tested ca be explained by the higher molecular weight of these fuels and the higher boiling temperatures as based on their fatty acid methyl ester composition [13]. On a consistent basis, and in particular with the stainless steel surface, the palm biodiesel took longest to evaporate, as attributable to the greater proportion of saturated esters such as methyl palmitate it contains, and its more viscous nature. This contrasts with the high unsaturated ester content of the sunflower biofuel leading it to evaporate more quickly than the other two biodiesel types, and to approach the performance of diesel where the surface temperature was hotter, and in particular with a more thermally conductive aluminium surface. The corn-based biodiesel findings were intermediate between the other biodiesels. Moreover, more rapid evaporation was seen for every fuel tested with an aluminium surface compared to stainless steel, as the former is more thermally conductive, with heat more efficiently transferring between surface and

droplets. The findings suggest the significant impacts of both the molecular composition of fuels and the thermal characteristics of surfaces for droplets' evaporative behaviours.

Analysis of different fuel types in terms of combustion characteristics and droplet evaporation could lead to more efficient approaches to combustion and progression in related technology [17]. Across each fuel assessed, larger droplets led to significant increases in evaporation time. Referring to Figures 6-9, surface material was also significant for evaporation times, as all droplet types evaporated more rapidly on aluminium in comparison with stainless steel. The underlying reason for this finding is likely the greater thermal conductivity of aluminium, at ≈237 W/m·K, in comparison with ≈16 W/m·K for stainless steel. Thus, more heat is transferred from aluminium to droplets, accelerating phase change [8, 13]. For diesel, which is strongly volatile, evaporation time was lower for aluminium than stainless steel at any droplet diameter. The biodiesels showed a similar pattern, evaporating more slowly with stainless steel. This pattern was strongest in palm biodiesel, as it is more viscous and contains a higher proportion of saturated esters [8, 16]. However, evaporation times by surface material were closer with increased droplet diameter, probably reflecting the stronger internal heat resistance against thermal conduction. The closest evaporation times across surface types was demonstrated by sunflower biodiesel, which, being less viscous and having more unsaturated fatty acid methyl ester content, showed more rapid evaporation regardless of surface thermal conductivity. The results shown suggest that surface materials impact evaporation dynamics via both thermal conductivity and interactions with fuels' distinct thermos-physical characteristics, and this is crucial in design for combustion chamber and thermal spray system optimisation.

For the stainless steel surface, both diesel and biodiesels showed clear transitions over different surface temperatures, in line with accepted evaporation phases. Figure 10 shows the four phases observed in the study: film evaporation at between 100 and 180 °C, nucleate boiling between 180 and 300 °C, transition boiling at 300–380 °C, and the spheroidal phase at temperatures over 380 °C. Within the film evaporation region, conduction was the main method of heat transfer, extending the lifespan of droplets [3]. At greater surface temperatures, droplets transitioned to nucleate boiling, with strong bubble generation and greater internal convection, and thus more rapid evaporation of droplets [17].

Within the transitional boiling phase, the findings reveal rapidly fluctuating surface contact and boiling intensity, with increase and less stable evaporation behaviours. For temperatures of over around 380 °C, the spheroidal/Leidenfrost phase was initiated, with droplets levitating, being separated by a vapour film from the surface: this made heat transfer less efficient and increased time to evaporation, notwithstanding the higher temperature of the surfaces [18, 19].

Palm biodiesel presented the greatest evaporation time for the majority of temperatures used, as the more viscous fuel with the highest boiling temperature [12]. The more volatile and lower molecular weight corn- and sunflower-based fuels showed earlier transitions to boiling phase, as well as more rapid evaporation, and this difference was greatest with the aluminium surfaces (not shown here). This is supported by earlier work pointing to combination effects from fuel composition, size of droplets, and surface materials' thermal characteristics upon evaporation behaviours [5, 6].

5 Conclusion

The results of the study form the basis for the following conclusions:

1. The temperature of surfaces, surface type and fuel used each influenced droplet evaporation time both individually and as interacting parameters.
2. For the stainless steel surface, droplets of biodiesel , and in particular, palm-based fuel, evaporated more slowly than diesel, based on their greater viscosity and elevated boiling point. For aluminium, palm biodiesel also evaporated most slowly: then corn; then sunflower; and finally, diesel, with the shortest evaporation period.
3. At a surface temperature in excess of 400 °C, the effect of surface type on the lifespan of droplets was reduced, which suggests that the impact of surface materials is reduced as the thermal conditions grow closer to critical.
4. Diesel's critical thermal evaporation point is estimated at about 450 °C regardless of surface type, and when temperature increased beyond this, a <1 second evaporation lifespan was recorded, with droplets considered to then rapidly transition to either explosive or film evaporation.
5. Evaporation of droplets of sunflower oil took around 1.6 seconds to evaporate for the aluminium and 2.1 seconds for the stainless steel surface at 400 °C. In the same conditions, the palm-based fuel evaporated significantly more slowly, at 2.8 and 3.5 seconds respectively for aluminium and stainless steel.
6. Palm biodiesel exhibited a lower critical temperature for aluminium than for stainless steel, at 440 °C and 460 °C respectively, which points to the influence of thermal conductivity of surface material on initiation of fast evaporation phases in ore viscous fuel types.
7. The aluminium surface decreased evaporation times over stainless steel across all fuel types, based on the material's greater thermal conductivity. This difference was particularly prominent at smaller droplet sizes, in which the evaporative process largely depends on surface heat transfer. Evaporation times for the biodiesels were slowed more significantly by stainless steel, with palm biofuel evaporation showing the greatest difference from aluminium, while sunflower biodiesel evaporated more consistently across surface type. The results emphasise the significance of selecting appropriate surface materials for thermal systems in which fuels are atomised and evaporate.

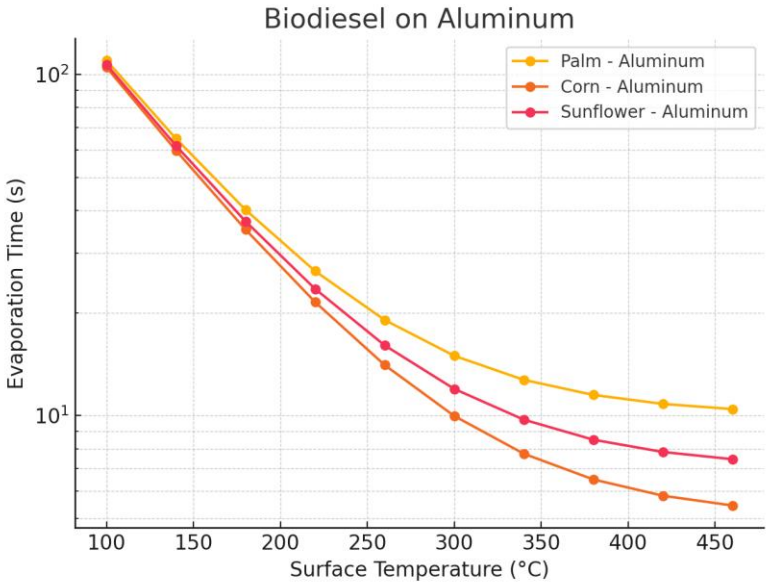


Fig. 2. Evaporation time plotted against initial surface temperatures for three biodiesels on aluminium

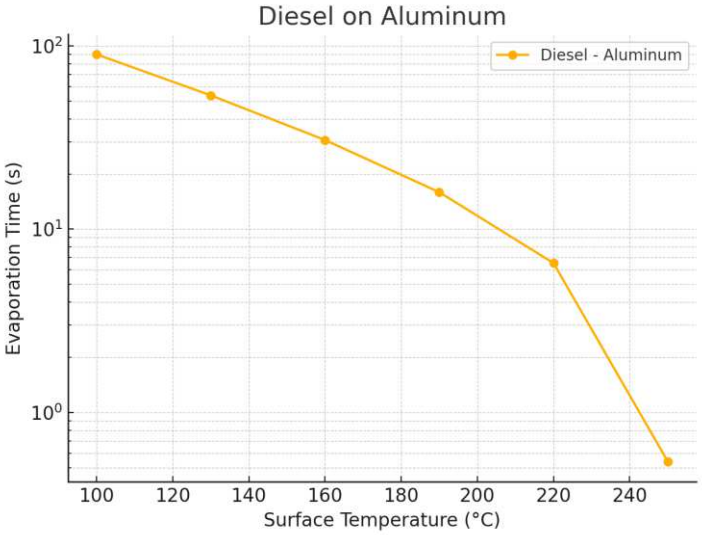


Fig. 3. Evaporation time against starting surface temperature for diesel on aluminium

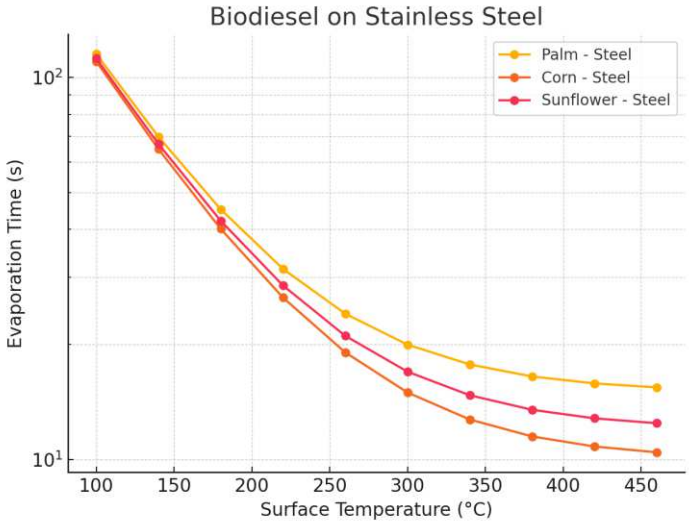


Fig. 4. Evaporation times against starting surface temperature for biodiesel droplets on stainless steel

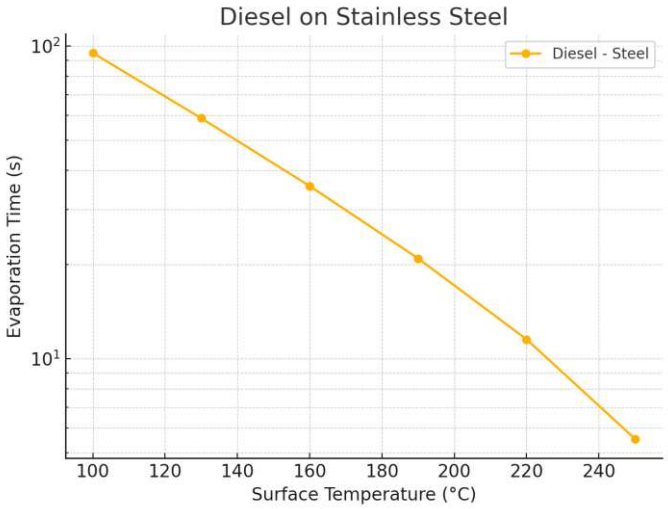


Fig. 5. Evaporation time against starting surface temperature for diesel droplets on stainless steel

Table 2, Diesel and various biodiesels: thermal characteristics

Fuel	Initial Surface Temp (Ts)	Boiling Point (Tb)	Critical Temp (Tc)
Diesel	100–450 °C	~180–360 °C	~450–540 °C
Palm Biodiesel	100–450 °C	~340–360 °C	~625–635 °C
Corn Biodiesel	100–450 °C	~330–355 °C	~620–630 °C
Sunflower Biodiesel	100–450 °C	~330–360 °C	~625–640 °C

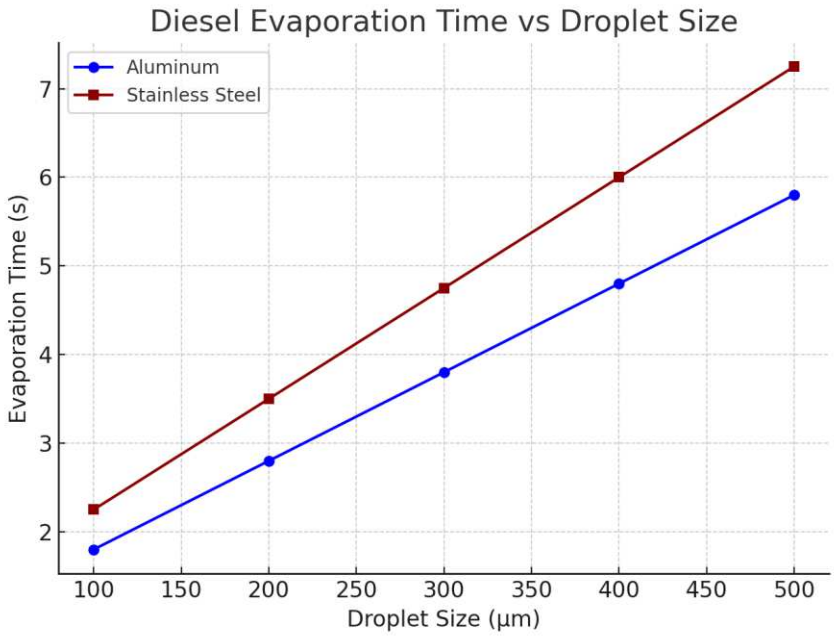


Fig. 6. Evaporation times against droplet size for diesel on stainless steel and aluminium

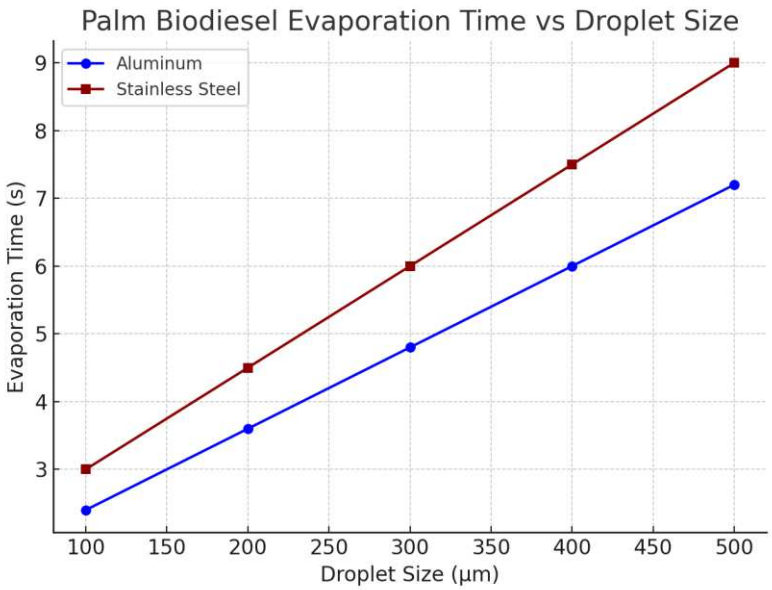


Fig. 7. Evaporation times against droplet size for palm oil on stainless steel and aluminium

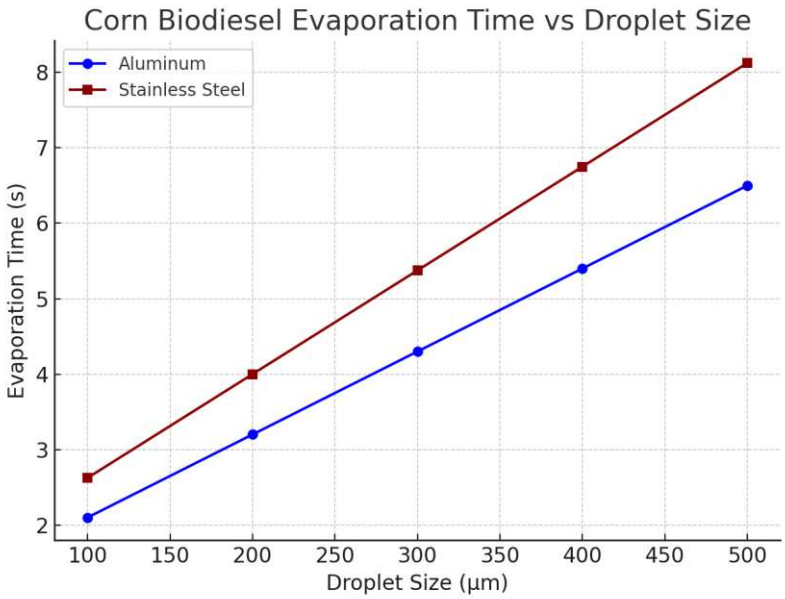


Fig. 8. Evaporation times against droplet size for corn oil on stainless steel and aluminium

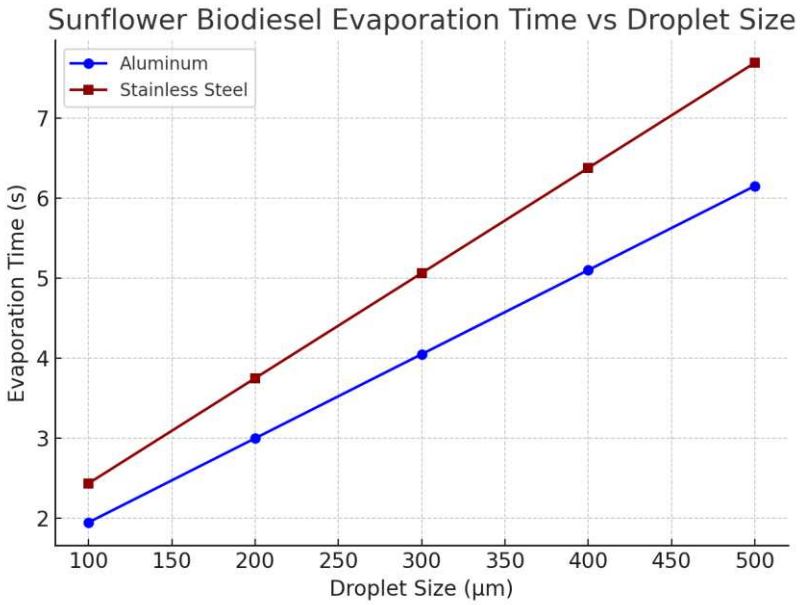


Fig. 9. Evaporation times against droplet size for sunflower oil on stainless steel and aluminium

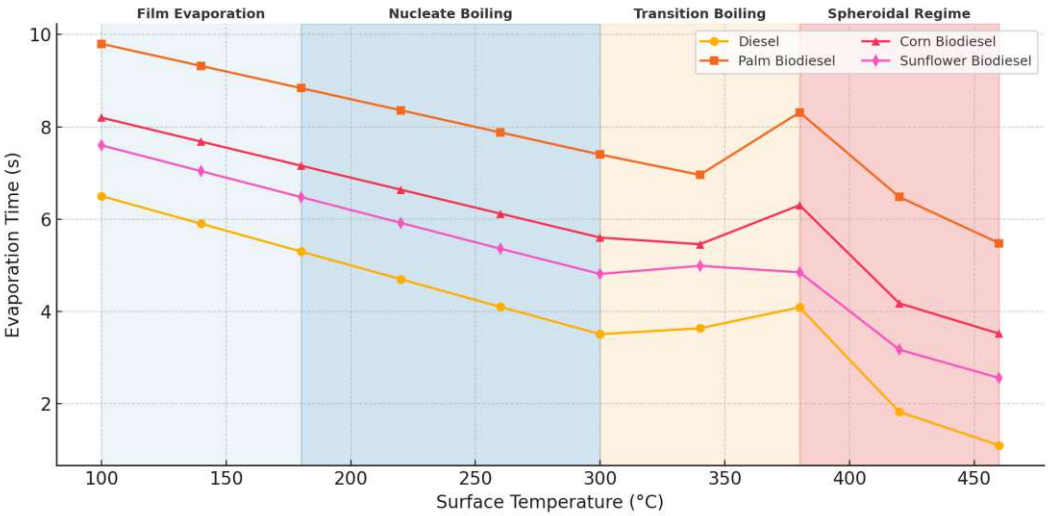


Figure 10**.** Evaporation times for droplets of diesel and biodiesels (palm, corn, and sunflower) on a stainless steel surface in relation to surface temperature. Different coloured regions relate to different dominant evaporation regimes: film evaporation; nucleate boiling; transition boiling; and spheroidal (Leidenfrost) regime.

6 References

1. kuo-Long Pau, Je-Wei Li, Chien-Pie Chen, Ching-Hua Wang, “On droplet combustion of biodiesel fuel mixed with diesel/alkanes in microgravity conditions”, Combustion and Flame, 156 (10), pp. 1926-1936, (2009).
2. Agarwal, A. K. (2007). Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. *Progress in Energy and Combustion Science*, 33(3), 233–271.
3. Abu-Zaid, M., “An experimental study of the evaporation of gasoline and diesel droplets on hot surfaces”, Int. Comm. In heat and Mass Transfer Journal, Vol. 21, 2, pp. 314-322, (1994).
4. Azami, M. and Savill, M., “Modeling of spray evaporation and penetration for alternative fuels”, Fuel, Vol. 180, pp. 514-520, (2016).
5. Zare, M., Ghobadian, B., Hassan-Beygi, S. and Najafi, G., “Evaporation characteristics of diesel and biodiesel fuel droplets on hot surfaces”, Journal of Renewable energy and environment, Vol. 7, 2, pp. 1-7, (2020).
6. Ashikhmin, A., khomutov, N., Piskunov, M., and Yanouvsky, V., “Secondary atomization of a biodiesel micro-emulsion fuel droplets colliding with a heated wall”, Applied Sciences, 10, 2, pp. 685, (2020).
7. Sirignano, W. A. (1999). *Fluid Dynamics and Transport of Droplets and Sprays*. Cambridge University Press.
8. Marek, R., & Straub, J. (2001). Analysis of the evaporation and condensation heat transfer processes. *International Journal of Heat and Mass Transfer*, 44(1), 39–5
9. Demirbas, A. (2007). Importance of biodiesel as transportation fuel. *Energy Policy*, 35(9), 4661–4670. https://doi.org/10.1016/j.enpol.2007.04.003
10. IEA (International Energy Agency). (2023). *World Energy Outlook 2023*. Paris: IEA. https://www.iea.org/reports/world-energy-outlook-2023
11. Knothe, G. (2005). Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. *Fuel Processing Technology*, 86(10), 1059–1070. https://doi.org/10.1016/j.fuproc.2004.11.002
12. Atabani, A. E., Silitonga, A. S., Badruddin, I. A., et al. (2012). A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renewable and Sustainable Energy Reviews*, 16(4), 2070–2093. https://doi.org/10.1016/j.rser.2012.01.003
13. Hoekman, S. K., Broch, A., Robbins, C., Ceniceros, E., & Natarajan, M. (2012). Review of biodiesel composition, properties, and specifications. *Renewable and Sustainable Energy Reviews*, 16(1), 143–169.
14. Khuong, L.S., Hashimoto, N., Konno, Y., Suganuma, Y., Nomura, H. and Fujita, O., 2024. Droplet evaporation characteristics of hydrotreated vegetable oil (HVO) under high temperature and pressure conditions. *Fuel*, *368*, p.131604.

15. Qi, D. H., Geng, L. M., Chen, H., Bian, Y. Z., Liu, J., & Ren, X. C. (2010). Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. *Renewable Energy*, 35(6), 1437–1443.
16. Özarslan, S. and Sarıkoç, S., 2025. Droplet Evaporation and Combustion Characteristics of Fuels: A Review.
17. Bai, B., & Gosman, A. D. (1995). Mathematical modeling of wall films formed by impinging sprays. *SAE Transactions*, 104, 162–176.
18. Bernardin, J. D., & Mudawar, I. (1999). The Leidenfrost point: Experimental study and assessment of existing models. *Journal of Heat Transfer*, 121(4), 894–903.
19. Yao, S. C., & Chang, R. K. (1983). Drop impact on solid surfaces. *Annual Review of Fluid Mechanics*, 16(1), 397–429.