Assessment of Experimental Artifacts in Evaporation Tests on Isolated, Suspended Droplets

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Summary

The suspended droplet framework is commonly used to study liquid fuel evaporation and combustion. However, measurements at this facility can be affected by artifacts. This study examines their impact on butanol droplet evaporation. Thermal radiation and fiber conduction effects are specifically addressed. Results show that heat conduction through the fiber can significantly affect droplet evaporation, even causing internal bubbling in some cases.

Body

Although the suspended droplet framework offers many advantages in droplet evaporation study, such as simplicity and the possibility of controlling many relevant parameters (e.g., environment temperature, gas velocity, etc.), it may also have some drawbacks. For example, the suspension fibers (e.g., quartz) used to hold the fuel droplet in a hot environment can artificially increase heat conduction to the droplet and eventually enhance the droplet evaporation rate [1]. In addition, using relatively big droplets in this kind of facility can introduce some other experimental artifacts, such as the absorption of radiative heat due to the proximity to hot gas/walls [2]. Hence, this study intends to assess these effects on the evaporation of butanol droplet at higher temperatures by both modeling and experimental approaches. Two types of isolated droplet facilities are considered in this study, DCF [3] and SDF [4], to measure droplet evaporation parameters. An ellipsoidal radiometer probe is used to measure the radiative flux received by the droplet at both facilities. To estimate the evaporation rates of isolated fuel droplets and to assess the effects of different experimental artifacts on the droplet evaporation, a 1D evaporation model has been developed and successfully validated against experimental data obtained at DCF conditions for different alcohols, including butanol. To emulate the actual droplet evaporation conditions at the SDF, the fiber conduction and radiation absorption sub-models are added to the modeling tool.

As shown in Figure 1, the effect of the suspension medium is very relevant for the evaporation behavior, with significantly higher evaporation rates and shorter droplet consumption times for tests with thicker fiber arrangements. The average evaporation rate of butanol droplets suspended at 2x1, 2x3 and 2x6 SiC arrangements are calculated as 0.403 mm^2/s, 0.482 mm^2/s and 0.659 mm^2/s, respectively.

Figure 2 shows the deviation of the steady evaporation rate (k) estimated for each case, as from the canonical evaporation rate (k_c) where the effects of all artifacts are ignored. For each experimental artifact, two situations are assessed, namely: the nominal SDF test conditions (solid line), and an additional case of interest (dashed line) which aims to evaluate the magnitude of these artifacts under a widely different set of conditions (i.e., increasing v_{gas} from 0.1 to 1 m/s, the radiative heat flux (Q_r) from 24 to 150 kW/m^2 and decreasing the gas temperature (T_g) from 1336 to 700 K). The results confirm that the impact of fiber conduction on k decreases with d_0, since the heat absorbed from the suspension fibers reduces its relative importance when compared gas-liquid heat transfer for a larger droplet. Moreover, even if two thin (15 µm) SiC fibers were used for this assessment, the conduction of heat through the fibers is clearly affecting the k when using the SDF test conditions (solid lines in Figure 2). On the contrary, the relevance of both radiative heating and forced convection clearly increases with d_0. For the latter, this enhancement is related to the aforementioned increase in Re for larger droplets which, for SDF conditions, shifts the ratio k/k_c from 1.028 to 1.052 when the droplet size increases from 400 µm to 800 µm. A larger gas velocity would also increase the Reynolds (and therefore Nusselt) numbers, as it can be assessed from the results calculated for v_{gas}=1 m/s. In this case, evaporation rate can be significantly enhanced, since the ratio k/k_c varies between 1.23 and 1.38 for 400 µm and 800 µm droplets, respectively. If the gas temperature is reduced to 700 K, the effect of this evaporation rate enhancement is found to increase slightly. Moreover, the mechanism with a larger potential impact on the evaporation results (for the range of conditions explored in Figure 2) is the absorption of thermal radiation. This effect is quite reduced for the conditions used in the SDF tests, mainly due to the small radiative heat flux measured in this facility. However, a radiative heat flux of 150 kW/m^2 would completely modify the droplet evaporation behaviors, practically doubling the evaporation rate for 800 µm droplets. Such a thermal radiative flux can be perfectly reached in furnaces (e.g., hot walls at 1400 K behaving as a grey-body with $\varepsilon = 0.7$). Therefore, a careful assessment of this effect should be considered when extracting droplet evaporation characteristics under high-temperature conditions, mainly when using big droplets.

Conclusion

Two types of experimental setups (drop tube and suspended droplet facilities) and a droplet evaporation model have been employed to assess the effect of experimental artifacts that can affect the isolated droplet evaporation process. A wide range of experimental conditions (modifying the number and material of the suspension fibers, etc.) were tested for high-temperature conditions. The conduction of heat through the suspension fiber has been found to be quite relevant, since this mechanism can significantly enhance the evaporation rate leading even to the onset of internal bubbling and puffing events for cases where platinum filaments were used. For a given suspension element, the impact of this mechanism was found to be reduced for larger droplets, suggesting that the relevant parameter for assessing the relevance of this artifact is the ratio d_f/d_0. However, the potential impact of radiative heating can be much more significant for setups where the droplet is surrounded by highly-emissive hot surfaces, particularly for cases where big droplets are to be tested. Overall, it is observed that these artifacts can significantly modify the droplet evaporation behaviors. Hence, they should be carefully considered when analyzing results obtained under the suspended droplet configuration.

References

[1]. WANG, J, HUANG, X, QIAO, X, JU, Dehao and SUN, C, 2020. Experimental study on effect of support fiber on fuel droplet vaporization at high temperatures. May 2020. http://dx.doi.org/10.1016/j.fuel.2020.117407.

[2]. GHASSEMI, H., BAEK, S.W., and KHAN, Q.S, 2006. Experimental Study on Binary Droplet Evaporation at Elevated Pressures and Temperatures. June 2006. http://dx.doi.org/10.1080/00102200500296697.

[3]. MUELAS, Á., REMACHA, P., and BALLESTER, J, 2019. Droplet Combustion and Sooting Characteristics of UCO Biodiesel, Heating Oil and Their Mixtures Under Realistic Conditions. May 2019. http://dx.doi.org/10.1016/j.combustflame.2019.02.014

[4]. Asrardel, M., Poonawala, T., Muelas, Á., Ballester, J. Assessment of Experimental Artifacts in Evaporation Tests on Isolated Suspended Droplets. 11th European Combustion Meeting 2023; Rouen, France.

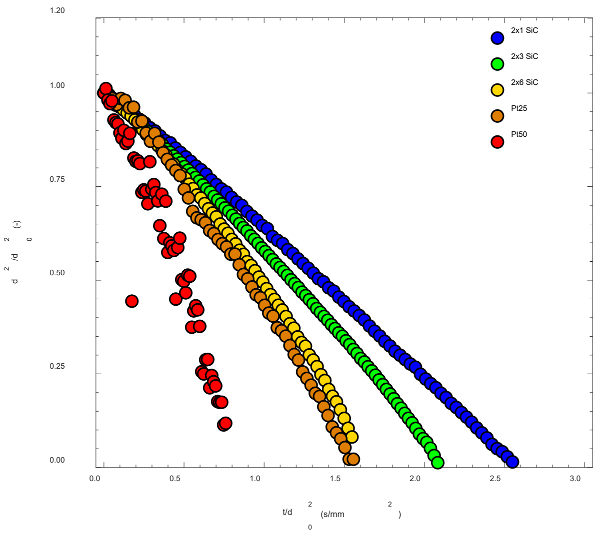

Figure 1, Experimental evaporation curves for d0≈450 µm butanol droplets suspended at 2x1 SiC, 2x3 SiC, 2x6 SiC, Pt25, and Pt50.

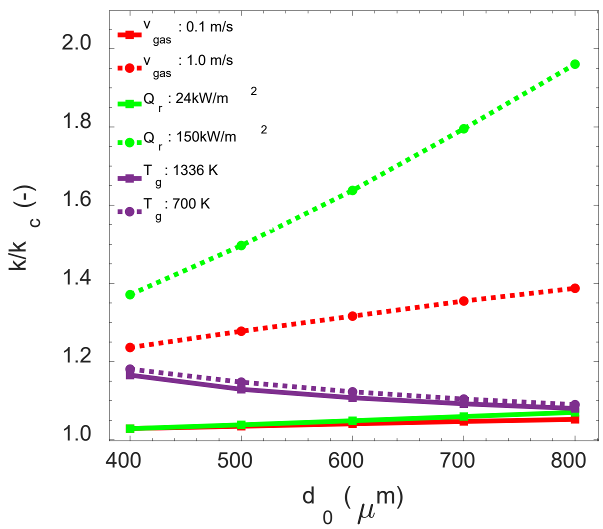

Figure 2, k/k$_c$ ratio estimated for butanol droplet evaporation anchored on 2x1 SiC fibers by including one artifact at a time: forced convection (red), radiation absorption (green) and conduction of heat through the fiber (purple).