

TRANSIENT PROCESSES IN LIQUID DROPLET COMBUSTION

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Hubbard et al [1] have recently presented a study of the problem of spherical droplet vaporisation under transient conditions, a problem which was studied earlier by Kotake and Okazaki [2]. The results of Ref. 2 show that there is no quasi-steady trend during any part of the process of vaporisation (this implies that a plot of the square of diameter (d_s^2) with time (t) will not be linear). Further, the numerically computed flame temperatures in a corresponding combustion problem (combustion of the spherical fuel droplet in an oxidising atmosphere) of this reference [2] appear to be smaller than the adiabatic flame temperatures.

The study of Ref. 1 shows that the gas phase transients are unimportant and that the liquid phase unsteadiness remains for a short time. Consequently the plot of d_s^2 vs. t shows a linear decay for the major part of the evaporation process. Based on the d_s^2 vs. t results, obtained by numerical computation of the vaporisation process and on the fact that the flame temperatures obtained by Kotake and Okazaki [2] are significantly lower than measured flame temperatures Hubbard et al. [1] suggest that the results of Kotake and Okazaki are erroneous. The present note is also intended to show that the solutions of the combustion problem in Ref. 2 are also probably incorrect and to provide more direct supporting arguments.

The slope of d_s^2 vs. t curve as suggested by the theoretical work of Ref. 2 (shown in Fig. 1) rapidly decays initially and attains a constant value of smaller magnitude after a significant period. The experimental results of Refs. 4 and 5 show a smaller initial slope and quick attainment of a constant value. The fact that the duration of small slope is short compared to the life time of the droplet, confirm that the well known d^2 law is valid over most of the combustion period. Qualitative arguments also suggest that the initial slope should be small; the heat flux from the flame to the surface must

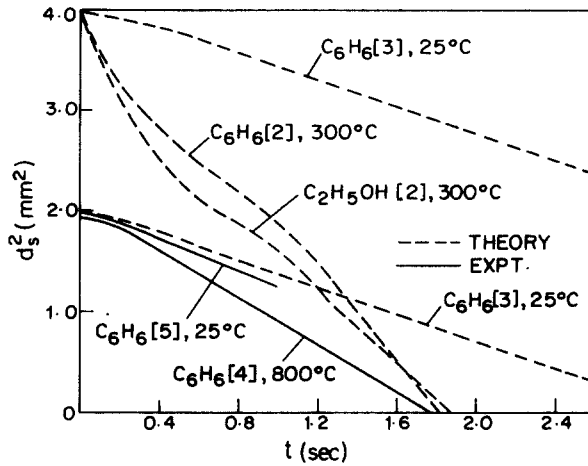
FIG. 1. COMPARISON OF d_s^2 Vs t CURVES

FIG. 1

Comparison of d_s^2 vs. t curves

initially heat the droplet as well as providing the heat of vaporisation thus reducing the mass rate of vaporisation initially. This implies that the slope of the d_s^2 vs. t curve should be small initially, as observed in the experiments. The experimental data shown in Fig. 1 demonstrate this feature. The data presented in the Fig. 1 do not correspond exactly to the conditions of the analytical results but correspond to temperatures greater and smaller than the calculations. The analytical investigations of Ref. 3 also demonstrate that unsteady periods of gas phase and condensed phase are small compared to the life period of a burning droplet as can be seen in Fig. 1.

The combustion time (t_b) from the plots of d_s^2 vs. t of Ref. 2 is 1.8 secs. for a 2 mm diameter benzene droplet burning in air at 300°C . A calculation, using a quasi-steady expression for the burning time ($= d_s^{0^2}/K$, d_s^0 = initial diameter, K = burning constant $\sim 0.9 \text{ mm}^2/\text{sec}$. at 300°K) shows that t_b at 300°C (573°K) should be about 4 secs. The plots of Kobayasi [4] show that at as high a temperature as 800°C , a smaller droplet ($d_s^0 = 1.4 \text{ mm}$) of benzene takes 1.8 secs. to burn out completely. Thus it is observed that the burning time predicted by Kotake and Okazaki is less than half the actual combustion times. Thus the correct prediction of burning time is not achieved with the theory of Kotake and Okazaki.

Kotake and Okazaki also conclude that the combustion process approaches a quasi-steady state, based on the d_s^2 vs. t curve. But the plot of flame to

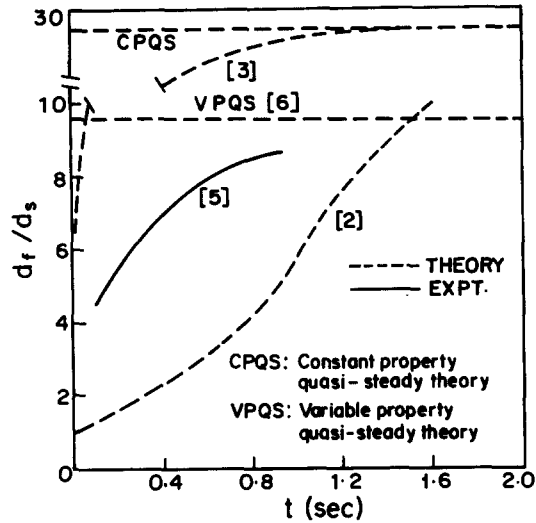


FIG. 2. COMPARISON OF d_f/d_s Vs t CURVES FOR BENZENE.

FIG. 2

Comparison of d_f/d_s vs. t curves for benzene

droplet diameter ratio (d_f/d_s) with time shows a continuous increase till the end (see Fig. 2). The results of Ref. 3 presented in Fig. 2, however, show that the quasi-steady value is attained soon. Further the results of Ref. 2 show that the flame temperature keeps increasing till the end of combustion and the maximum value is much lower than adiabatic flame temperature even though thin-flame approximation has been used. The primary reason for these discrepancies probably lies in errors of numerical integration of the partial differential equations.

The value of d_f/d_s predicted by Ref. 2 appears to be in the same range as is experimentally observed ones (see Fig. 2). This feature, though interesting, does not necessarily support the accuracy of predictions. A number of studies have obtained values of d_f/d_s in the same range as experimentally observed, based on entirely different grounds - on unsteadiness in the gas phase [6], unsteadiness in both the phases [2], variable thermodynamic properties [7] and natural convection [8]. As can be expected, all these view points cannot be correct as discussed at length in Ref. 3.

In conclusion, it can be said that the unsteadiness in the combustion of liquid droplets lasts only through a fraction of the total burning time. This disputes the numerical results in Ref. 2. The theoretical results of [1,3] in agreement with the experimental results of [4,5] emphasise the importance of

quasi-steady process in droplet evaporation and combustion. Hence, it is necessary to improve the quasi-steady predictions, particularly in regard to d_f/d_s . Ref. 3 describes a successful attempt in this direction.

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