

On The Thin Layer Boilover

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ABSTRACT

The burning of a thin fuel-layer floating on water is a problem of interest in unwanted fires. Heat losses to the water below may cause its boiling and induce an eruptive vaporization of explosive and violent character referred to as thin-layer boilover.

A few years ago the present authors began a systematic and comprehensive study of this complex phenomenon. The results emphasized the importance of heat transfer in the direction normal to the fuel and sublayer surfaces. They corroborated that boilover is due to the heterogeneous boiling nucleation at the fuel/water interface, in sublayer water that has been superheated.

A wide range of boiling points fuels were tested including a crude-oil, a heating oil, and five single-component fuels. Some of the parameters of the process were varied to observe their effect on the boilover characteristics and, through them, some of the controlling mechanisms were inferred. The influence of the major parameters of the problem, specifically the initial fuel-layer thickness, the pool diameter, and fuel boiling point, on the temperature history of the fuel and water and time to the start of boilover, was studied.

A simple, one dimensional, quasi-steady, heat conduction model helps to understand how these different problem parameters affect boilover. However due to its limitations, there was a need to develop a more elaborated model, unsteady and including in-depth radiation absorption.

INTRODUCTION

The burning of a liquid fuel floating on water is an important potential hazard in unwanted fires. Although the fuel burning itself is similar to that of a single fuel, the presence of the water introduces effects that are caused by the transfer of heat from the fuel to the water underneath. This heat transferred in depth may induce water boiling and splashing, a phenomenon referred to as boilover.

This phenomenon is often encountered with fires involving large storage tanks containing multicomponent fuels (particularly crude oils or other heavy oils), leading to explosive vaporization of the water often present on the bottom of the tank. However, boilover can also occur with the burning of thin layers of these liquids floating on water. Studies specifically concerning thin-layer boilover of pure or multicomponent fuels are, on the whole, scarce and rather recent ([1] to [5]). Most of these studies have been conducted on small or medium-scale fires in a laboratory. Although test pans of finite diameter cannot perfectly model real situations, they ensure calm external conditions, stable flames and nearly uniform heat transfer through the fuel and the fuel/water interface which help the onset of nearly uniform boiling at the interface. This facilitates the experiments and, in turn, the results should give a better understanding of the boilover process. Despite some overlaps, these studies are often quite different and comparative analysis is not always obvious. In fact, it appears that a complete understanding of boilover is still lacking, most likely because of the complexity of the mechanisms involved. For this reason, the present authors, a few years ago, began a systematic and comprehensive study of the thin-layer boilover phenomena [6] [7]. The work was concerned primarily with the influence of three main parameters that affect strongly boilover: initial fuel layer thickness, pool diameter, and fuel boiling point, on the burning rate, time to the start of boilover, burned mass ratio, boilover intensity and temperature history of the liquid phase. On the basis of these results, the mechanisms leading to boilover, and its intensity, were discussed. Heat transfer modeling was also proposed and applied to predict the temperature histories in the fuel and water layers and the time for boilover to occur.

EXPERIMENT

Stainless-steel pans 6-cm deep and of inner diameters 15, 23, 30 and 50 cm were used in the experiments. The pans were placed on a load cell to measure the consumption of fuel as a function of time. For each pan diameter, different initial fuel layer thicknesses were tested (ranging from 2 to 15 mm). Before each test, water was first poured on the pan, followed by the fuel until it reached 1 mm below the pan lip. During combustion, the location of the fuel/water interface remained fixed. Fuel and water temperature were measured with an array of stainless-steel sheathed chromel-alumel thermocouples of 0.5 mm diameter inserted horizontally through the side wall of the pan, with their junction located along the centerline. After a short period of time from ignition, the burning rate reached steady-state, defined here as the pre-boilover burning rate. At the onset of thin-layer boilover, the burning rate increased significantly with intense splashing of water and fuel.

Fuels used in these experiments are heating oil (components with a narrow range of volatility), a crude oil : Kittiway 63%, Arabian light 33%, Oural 4% (components with large range of volatility) and five single-component fuels : toluene, n-octane, xylene, n-decane and hexadecane.

RESULTS

Burning of a thin fuel-layer spilled on water

An example of the evolution of the surface regression rate as a function of the initial fuel-layer thickness, for the different pool diameters investigated, is shown in Fig 1 for the crude-oil. The burning rate increases first with increasing initial crude-oil-layer thickness and then reaches a constant limiting value that is characteristic of each pan size. This limiting burning rate increases with pool diameter, as is usually observed for this range of pool sizes. The variation of the burning rate with the initial fuel-layer thickness is due to heat losses to the water underneath. When the crude-oil thickness is small, the water acts as an efficient heat sink and the burning rate is reduced. This influence lessens when the thickness is increased and the limiting values are reached for layer thicknesses around 1 cm. The same type of trend is observed for the other fuels used. Note that the pans used are deep enough to insure that there are no depth effects on the experimental results.

Time to the start of boilover

Figure 2 shows the time to the onset of boilover as a function of the initial crude-oil layer thickness. It is seen that the dependence is practically linear. Assuming that thin-layer boilover starts when the temperature at the heating oil/water interface reaches the nucleation temperature of water, then these straight lines can be considered to be representative of a constant, average, apparent thermal penetration rate. The larger the pool size, the higher the penetration rate, which is consistent with the increase of burning rate with the pool size. Similar experiments are reported by Koseki et al. [4] with crude oil and a larger range of pan diameters (0.3-2.7 m). However, as a result of large scatter in their test results, they only deduced an average thermal penetration rate from a linear fit to the data. If the regression rate of the fuel surface is known, then it is possible to deduce, by difference from the fitted slope, the effective thermal penetration rate responsible for boilover.

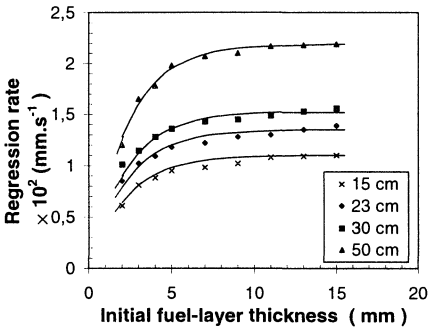


Figure 1. Surface regression rate as a function of fuel-layer thickness for different pool diameters (fuel : crude-oil).

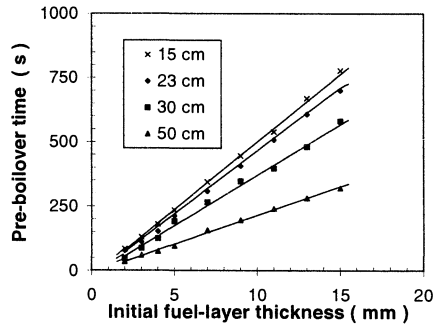


Figure 2. Pre-boilover time as a function of initial fuel-layer thickness for different pool diameters (fuel : crude-oil).

Inspection of Fig. 3 shows that this effective thermal penetration rate increases with the fuel boiling point. In fact, the regression rate and the surface heat flux decrease, on the whole, with an increase of the fuel boiling point. The apparent thermal penetration rate is therefore reduced although less than the regression rate, resulting in an increase of the effective thermal penetration rate. Then, even if the heating rate of the liquid phase is increased, the difference between the fuel surface temperature and the water nucleation temperature is increased, and the amount of time to reach this temperature at the fuel/water interface is relatively larger. This is seen in Fig. 4 where the time to the start of boilover is reported as a function of the fuel boiling point (average vaporization temperature is used for the crude and heating oils). It is worth noting that the time for alkanes is slightly larger than the time for aromatics even though their boiling points are close. This is due to a lower thermal diffusivity of the alkanes when compared with the aromatics. Concerning crude-oil and heating oil, the times are slightly shifted since they contain both alkanes and aromatics. Hexadecane is also shifted. Its thermal diffusivity is close to the decane one but its boiling point is higher. The result is a more pronounced temperature gradient, a higher heating rate, and a shorter time to the start of boilover.

Burned mass ratio

The burned mass ratio can be defined as the ratio between the amount of fuel burnt before occurrence of boilover and the initial amount of fuel. It has been seen above that the thermal wave responsible for boilover moves more rapidly when the boiling temperature of the fuel is high. Therefore, the burned mass ratio decreases when the boiling temperature of the fuel increases. Figure 5 shows the evolution of this ratio when the initial layer thickness exceeds about 1 cm. The values presented are independent of the diameter used and consistent with the values of thermal penetration rates, which are responsible for boilover and the limiting regression rates. The thickness of the fuel layer at the time of boilover increases with the fuel boiling point and consequently the overall intensity of boilover increases.

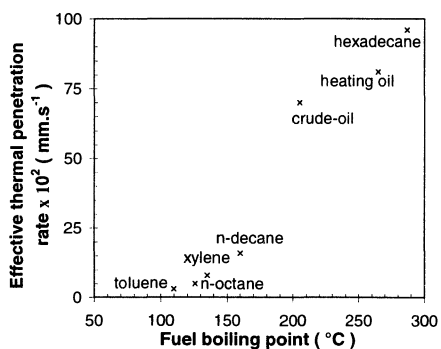


Figure 3. Effective thermal penetration rate as a function of fuel boiling point (initial fuel-layer thickness : 13 mm ; pan diameter : 15 cm).

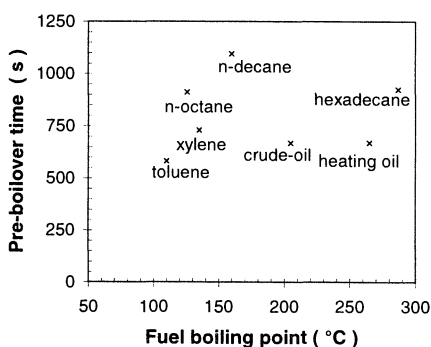


Figure 4. Pre-boilover time as a function of fuel boiling point (initial fuel-layer thickness : 13 mm ; pan diameter : 15 cm).

Liquid temperature history and boilover general characteristics

Temperature histories, particularly at the fuel water interface, provided interesting information about the events taking place during the onset of boilover. An interesting result is that boilover appears to occur, in all cases, when the temperature at this interface reaches a value of approximately 120 °C. Figure 6 shows, for example, the variation of the temperature with the distance from the fuel/water interface, for different times after the ignition, for the case of a heating-oil layer thickness of 11 mm, burning in a pan of 15 cm in diameter (boilover occurs at 630 s).

The experimental observation that the transition from normal pool burning to disruptive burning occurs at an approximately fixed temperature that is above the saturation temperature of the water, indicates that the phenomena may be caused by the boiling nucleation of the water at the water/fuel interface. It is well known that a liquid that is not in contact with a gas phase can be superheated, at constant pressure, to temperatures that are above the liquid saturation temperature [8]. Under these conditions, bubble nucleation will occur within the liquid at a fixed temperature, called the "limit of superheated". It is worth noting that the low value of the level of superheat ($\approx 20^\circ\text{C}$), already mentioned in previous works [1] [4] [5], is smaller than that expected from experiments of the nucleation of water in hydrocarbons [9]. It is plausible to attribute this difference to changes in surface and interfacial tensions due to the adsorption of impurities at the interface between liquids, which may lead to the heterogeneous nucleation of the water rather than to its homogeneous nucleation. Unfortunately, no experimental evidence is available to confirm this statement.

Under these conditions, bubbles in the superheated water could nucleate, most likely heterogeneously, at the fuel/water interface, and grow explosively. The formation of the first bubbles, as well as how the bubbles grow, break away from the interface, rise, and finally reach the free surface, has been analyzed in Ref. [7] from a video recording of the fuel/water interface for hexadecane burning on water. The most important information is the location of the bubbles initiation with respect to the interface and their subsequent development. It is seen that the bubbles are initiated at the interface but grow on the fuel side. Theoretical analysis

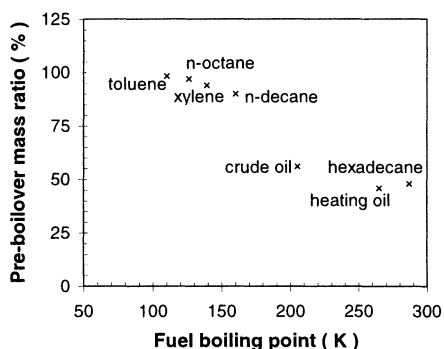


Figure 5. Pre-boilover burned mass ratio as a function of fuel boiling point (initial fuel-layer thickness : 13 mm ; pan diameter : 15 cm).

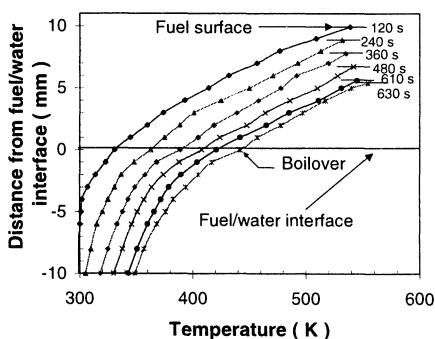


Figure 6. Development of vertical temperature profile (fuel : heating oil ; initial fuel-layer thickness : 11 mm ; pan diameter : 15 cm).

indicate that the characteristics of the bubble growth, when a liquid is superheated in contact with another liquid, depends on the relative magnitude of the interfacial tensions [10]. The present case clearly corresponds to the “bubble blowing” regime; in other words, the surface tension of water is larger than the sum of the surface tension of fuel and the interfacial tension. Although this inequality is difficult to quantify because interfacial tensions of fuels are generally not available, the surface tension of water is large enough to ensure it.

The moment when the nucleation of the first bubble is observed varies during the period that the water is superheated. However, in general, the shorter this period, the more intense the bubble nucleation process is. This period of increasing bubble nucleation intensity is accompanied by a crackling noise. This crackling noise appears to be the result of water droplets, more or less enveloped by a thin layer of fuel, that are projected into the flame zone. These small droplets explode due to the nucleation of the water and cause the characteristic crackling noise. The increase in the crackling noise intensity and frequency is generally the precursor of the boilover, and can be used to characterize its onset. The violent vaporization (i.e., the actual boilover) generally occurs when the rate of bubble nucleation increases so rapidly that bubbles cannot be buoyantly transported toward the fuel surface. The large volume of water vapor generated at the interface suddenly breaks through the fuel layer above, ejecting fuel drops and columns toward the flame. The result is often spectacular, producing a column or ball of fire of very large proportions. The fuel ejection can deplete the fuel in the pan and, consequently, causes the sudden termination of the pool fuel burning. Occasionally, the boilover is not too intense and the disruptive burning can become repetitive.

The simultaneous recording of temperature and fuel mass loss, as the boilover is approached, provided also interesting information about the events taking place during the onset of the phenomenon. This has been addressed properly in Ref. [7]. At this onset, a sudden increase in fuel weight is observed. This apparent change of weight is due to the sudden expansion of water vapor at the nucleation site. The effect is naturally bigger, the higher is the internal pressure. It coincides with significant disturbances of the fuel/water interface, and a corresponding increase in vaporization intensity. It is found that the sudden increase in fuel weight often coincides with a rapid and large temperature increase. It can be observed that the amplitude of this temperature increase at the onset of boilover increases as the difference between the fuel and water boiling point increases, corroborating that the intensity of the boilover process is strongly dependent on the boiling point of the fuel.

Boilover intensity

We have defined the boilover intensity as the ratio between the mass loss rate of fuel during the short boilover period and the maximum fuel burning rate during the pre-boilover period [6]. In fact, the actual time extent of the explosive burning is difficult to determine due to the tumultuous and violent character of the phenomenon. Moreover, this corresponds to fuel burnt during eruptive vaporization but also to burning droplets randomly ejected outside the pan, together with some water. Thus, the estimation of the boilover intensity is approximate and only must be viewed as qualitative. Figure 7 shows the boilover intensity, then estimated, as a function of the initial fuel-layer thickness, for the different pool sizes and for crude-oil as fuel. The data show an increase with the thickness but a strong decrease with the pool size. This last observation was already noted by Koseki and Mulholland [3] and Koseki et al. [4], also using a crude-oil as fuel.

The influence of the fuel type on the boilover intensity is presented in Fig. 8. It is seen that the phenomenon intensity increases as the difference between the fuel and the water boiling points

increases. This is consistent with the results concerning the effect of the fuel type on the pre-boilover mass ratio. The results of Fig. 5 show that the amount of fuel left when the boilover starts increases as the fuel boiling point is increased. Therefore, the quantity of fuel ejected into the flame and the resulting overall intensity of boilover increases with fuel of higher boiling point.

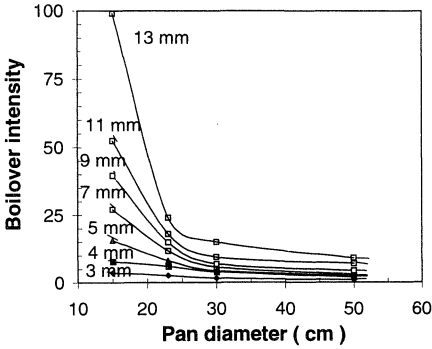


Figure 7. Boilover intensity as a function of initial fuel-layer thickness for different pool diameters (fuel : crude-oil).

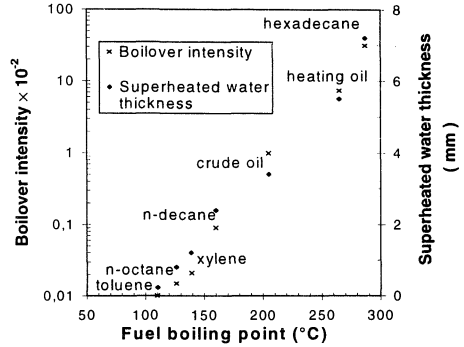


Figure 8. Boilover intensity and superheated water thickness as a function of the difference between fuel and water boiling point (initial fuel-layer thickness : 13 mm ; pan diameter : 15 cm).

MODELING OF FUEL AND WATER HEATING

The above results indicate that the characteristics of the boilover phenomena are determined primarily by the heat transfer through the liquid phase.

In a simple approach, if heat transfer from the fuel surface to the liquid phase is assumed to be limited to conduction, and assuming a constant regression rate and that both the fuel and water have approximately the same thermal diffusivity α , the following, one-dimensional, quasi-steady heat conduction equation may support the description of the spatial evolution of the temperature :

$$\frac{d^2T}{dx^2} = \frac{r}{\alpha} \cdot \frac{dT}{dx} \quad (1)$$

where time has been replaced by x/r (where x is the depth from the fuel surface and r the fuel surface regression rate (assumed to be steady)).

This model, already used by Arai et al. [5], gives the following expression for the temperature distribution in the liquid phase :

$$\frac{T - T_\infty}{T_s - T_\infty} = \exp\left(-\frac{r}{\alpha} x\right) \quad (2)$$

where T is the instantaneous liquid temperature, T_0 the initial liquid temperature, T_b the boiling point of the fuel. From this expression, the influence of the main parameters studied above, as initial fuel layer thickness, pan diameter, and fuel boiling point, on the time to the start of boilover and the boilover intensity, is seen clearly.

The maximum depth of the fuel layer at the onset of boilover, x_{bm} , is obtained by setting the liquid temperature at $T=120^\circ\text{C}$, and solving for x in equation (2). For initial fuel layers thicker than x_{bm} , the fuel will burn as in a normal pool until the surface regresses to a point where the fuel layer thickness equals x_{bm} , at which point boilover will occur with its maximum intensity (thickest fuel layer). For thinner initial fuel layers, the fuel will burn as in a pool until the water temperature reaches 120°C , at which point boilover will occur but with a lesser intensity, depending on the final fuel layer thickness.

A matter of concern is the boilover intensity. It appears that the determining factors are the thickness of the fuel layer at the time that nucleation of the water starts and the thickness of the layer of superheated water (assumed to be where the water is between 100 and approximately 120°C and may gasify). The thicker these layers, the more intense the boilover since a larger mass of evaporated water at boilover contributes to a more intense boilover process by enhancing the expansive effect of the water vapor on the ejection of the fuel toward the flame. These statements appeared verified when studying the influence of the aforementioned three main parameters.

One aspect related to the effect of the initial fuel layer thickness is that boilover intensity increases with the final thickness of fuel when the water reaches the nucleation temperature. Another aspect results from the thermal penetration through the liquid. Since the thicker the initial fuel layer, the longer it takes to reach the critical fuel thickness at the time of nucleation, the deeper the thermal wave penetrates. The result is a thicker layer of superheated water which also results, as indicated above, in a more intense boilover. It should be pointed out that there may be additional effects other than simply the amount of fuel ejected into the flame, as indicated above. A possible additional effect is the delay of the onset of water nucleation due to the increased hydrostatic pressure, mentioned previously, at the fuel/water interface as the fuel thickness increases. A higher pressure will require a higher degree of superheat for the bubble to grow, and therefore, a thicker layer of superheated water. Furthermore, the thicker fuel layer may also initially restrain the expansion of the vaporized water until enough pressure in the vapor is built up to eject the fuel above. In fact, it can be seen that, in general, the fuels with higher viscosity tend to experience a more intense boilover. In those cases, it is observed experimentally that the onset of boilover is characterized by the formation of a vapor film at the fuel/water interface, rather than individual bubbles.

The effect of the pan diameter was shown as resulting from a larger surface heat flux at the fuel surface (pan larger and sootier and more radiative flames). As the pan diameter is increased, the regression rate increases and, according to Eq. (2), the thickness of the superheated water layer decrease and, consequently, the boilover intensity decreases.

As for the effect of the boiling point of the fuel, a higher value results in an increase of the fuel layer thickness at the time of nucleation and in an increase of the superheated water layer thickness. This is likewise clearly shown by Eq. (2) and agrees with the observations. This effect of the fuel boiling point on the thickness of the layer of superheated water (considered to be between 100 and 120°C) at the time of onset of bubble nucleation is shown in Fig. 8. It is seen that the superheated water layer thickness (deduced from temperature measurements) increases as the fuel boiling point increases.

However, if the Eq. (2) helps in understanding how the different problem parameters affect boilover, it presents some limitations. To apply it throughout the whole liquid phase, it is assumed that the thermal diffusivity of the fuel and water are similar. On the other hand,

steady-state is assumed but, in reality, there are transient effects related to the time needed to the regression rate and temperature profiles to become steady. Moreover, in depth-absorption of radiation and possible effects of convection are not accounted for.

Then, it appears that the viability of this simple temperature distribution model is restricted to the thickest initial fuel layers (more than approximately 0,8-1 cm). The model is only really valid for highly viscous fuels, such as multicomponent fuels (crude oils, heating oil, etc.).

The above statement indicate that an accurate model of boilover must be unsteady and include in-depth, radiation absorption. Therefore, a transient, one-dimensional model, including radiation in-depth, has been developed and applied to predict temperature histories in fuel and water layers and time to the onset of boilover [11]. This modeling effort is, in some respect, complementary to the work from others [12] [13] and particularly from Inamura et al. [14], through some improvement and extension.

The governing energy equation :

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + \frac{\partial \dot{q}_r''}{\partial x} \tag{3}$$

is solved with appropriate boundary conditions and using an implicit finite difference discretization method. It is assumed that density ρ , thermal capacity C_p , and thermal conductivity k are constant. The interface fuel/water boundary conditions are handled out by deriving a finite difference energy equation for the fuel and water near the interface and the continuity energy and temperature conditions. The temperature gradients in the fuel and water layers are expanded in Taylor series form and the gradients are used to obtain the diffusion terms.

The radiative heat flux at the fuel surface was obtained by extrapolating the measured heat flux across the liquid phase and a mean average absorption coefficient by applying the classical attenuation law :

$$\dot{q}_r'' = \dot{q}_{r_s}'' \exp(-\mu \cdot x) \tag{4}$$

where \dot{q}_r'' is the radiative flux at a given depth x , \dot{q}_{r_s}'' is the radiative flux at the surface and μ the mean absorption coefficient. These measurements were made by means of water-cooled radiometers, located at different positions along the centerline of the pan. The estimated radiant flux at the surface, together with Eq. (4), was used to calculate a fuel effective average radiation absorption coefficient. It can be observed that absorption in-depth takes logically a much important role in the following order of fuels : fuels with large range of volatility, fuels with narrow range of volatility and single component fuels.

An example of temperature histories along the fuel and water is presented in Fig. 9, for the case of crude oil with an initial layer thickness of 13 mm and a pan of 150 mm in diameter. For comparison purposes, the experimental measurements are also presented in the figure. It is seen that the temperature profiles are predicted reasonably well, particularly away from the fuel surface. The major difference is the prediction of a temperature inversion layer near the fuel surface, whose amplitude increases with time, and that is not experimentally observed. As the onset of boilover is approached, the predicted maximum temperature in the fuel exceeds its boiling temperature by approximately 20°C, this maximum being reached around 2 mm below the fuel surface. It should be noted that Inamura et al. [14] obtained similar trend for a crude-oil but with an excess with respect to boiling temperature of the fuel greater than our value.

This may be attributed to the fact that the boiling temperature used by these authors as surface temperature is a mean temperature.

The prediction of a temperature inversion layer is the result of in-depth radiation effects. These effects are more pronounced when the absorption coefficient and the radiative heat flux at the surface are high, although a sensitivity analysis of their relative importance indicates that the later is dominant. Also, the predicted temperature profiles for single component fuels present the same trend, with the temperature increment varying according to their burning rates (surface heat flux) and their propensity to absorb radiation.

The experimental measurements do not show the temperature inversion layer, but only a less steep temperature profile near the fuel surface. This is due to the onset of convective currents (Rayleigh effect) generated by the radiation absorption near the surface, and that are not considered in the theoretical model. The presence of convective currents is well evidenced by Ito et al. [1] and Inamura et al. [14], who employed a holographic interferometry technique to investigate the temperature field of n-decane burning floating on water. Incorporation in the model of these convective currents is rather complicated and beyond the scope of this work.

The model appears to predict fairly well the dependence on the initial fuel-layer thickness, of the time to the start of boilover. The accuracy depends greatly on the uncertainty in the estimation of the values of heat fluxes supplied by the flame. In contrast change in the burning rate show that any measurement errors in this quantity would have to be large to account for discrepancy in the prediction. As for the influence of the radiation absorption coefficient, it also appears to be relatively small. Some observed discrepancies with experiments could also be explained by aforementioned Rayleigh convection currents generated in the fuel layer that tend to enhance the penetration of the thermal wave and thus to decrease the time to the start of boilover. The thinner the initial layer, the more pronounced this effect is.

The model predicts also well the observed decrease of the time to the start of boilover as the size of the pan is increased. Figure 10 gives an example for a slick of heating oil of 13 mm. The general trend observed is consistent with the well known dependence of the burning rate, and consequently the surface heat flux, on pool diameter. As stated above, as the pan diameter

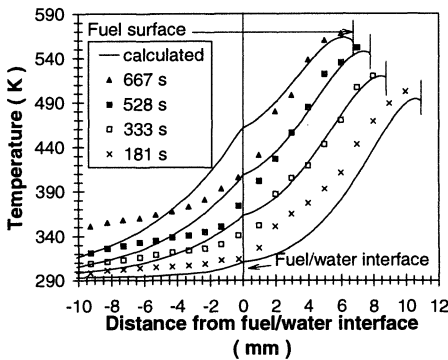


Figure 9. Measured and calculated temperature profiles for crude-oil at four time periods after ignition (initial fuel-layer thickness : 13 mm ; pan diameter : 15 cm).

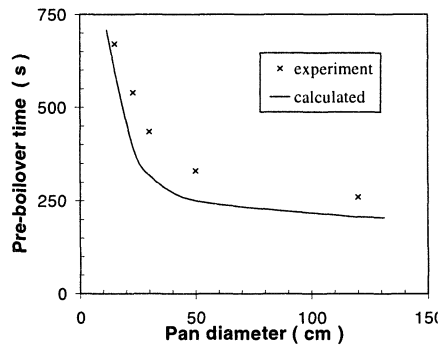


Figure 10. Measured and calculated pre-boilover time as a function of pan diameter for heating oil (initial fuel-layer thickness : 13 mm).

is increased, the surface heat flux increases, the liquid heats up faster, and the water reaches the nucleation temperature sooner. Although physically the relationship between pan size and boilover time is clear, there is an uncertainty problem in the measurements that tends to increase greatly when the pool size becomes large (1 m or more). Indeed the flames in large pans are less structured and stable, and the heat transfer through the liquid loses its uniformity giving rise to sporadic and random eruptive boiling. This, together with the decrease of the phenomenon intensity, causes the reproducibility of the tests to decrease.

Another important factor in the boilover process is the boiling point of the fuel as evidenced by the works of references [5], [7] and [14]. It can be observed that the calculated times to start boilover dependence on the fuel boiling for the different single component fuels, together with crude-oil and heating oil, predict well the general trend of the experimental data.

CONCLUSION

Thin layer boilover is an instability problem that needs to be addressed. It appears well established now that boilover appears to occur at a fairly constant temperature of the fuel/water interface which is $\approx 20^{\circ}\text{C}$ above the saturation temperature of water (all the few recent works dealing with this problem are in agreement). Therefore, the criterion to separate cases without and with boilover is the onset of boiling nucleation in the superheated water near the fuel/water interface. Knowing the temperature liquid history, it is then possible to predict the time to reach this temperature of superheat.

An important part of the work deals with the post boiling period. The influence of the basic parameters : initial fuel-layer thickness, pool diameter, fuel boiling point, on the burning rate, time to the start of boilover, pre-boilover mass ratio and boilover intensity, is studied with different multicomponent and single-component fuels.

This influence is properly inferred with a very simple conduction model which helps in understanding how the different problem parameters affect boilover. However, this model presents some limitations due to its simplifying assumptions. A more elaborated transient, heat transfer model, including in-depth radiation absorption, has been proposed. Beyond a simple comparison between prediction and experimental results, it permits addressing in more depth some important issues : such as the influence of surface radiation heat flux, burning rate, absorption coefficient, fuel boiling point, all which strongly affect the boilover process.

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