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Investigation of hot surface ignition of a flammable mixture

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Experimental and numerical studies are conducted to analyze hot-surface ignition of a flammable mixture. The experimental setup, equipped with temperature diagnostics and schlieren imaging, utilizes a glow plug to initiate ignition in a flammable mixture. The numerical simulation utilizes a tabulated chemistry approach to include detailed reaction kinetics for the fuel including low-temperature reaction pathways. The numerical approach is validated with a test case for a homogenous reactor and simulations of the experimental setup are carried out. Experimental data and simulation results are analyzed to determine minimum surface temperature for ignition and ignition delay time, and their dependence on fuel-air equivalence ratio and the thermal plume generated prior to ignition. A timescale analysis is conducted to understand the relative importance of convective, diffusive processes induced by the thermal plume, and chemical kinetics with and without the inclusion of low-temperature reaction pathways to yield the rate limiting processes leading to ignition.

1 Introduction

The ignition of flammable mixtures under low-pressure, low-temperature conditions is relevant to safety considerations in various situations. In devices such as aircraft and automobile fuel tanks, gas pipelines, chemical reactors, and structures such as underground mines, it is critical to understand the underlying physics leading to hot surface ignition of a flammable mixture [1, 2]. The design considerations in these applications hinges on the potential for a disastrous fire or explosion caused by hot surface ignition [3].

The standard technique used to characterize the ignition hazard of a flammable mixture, in the absence of a spark or a flame, is using the autoignition temperature (AIT). AIT is defined as the maximum acceptable surface temperature in a particular area to prevent fire and explosion hazards [4]. Standard testing methods for AIT, however, utilize a sufficiently large vessel where the size of the hot surface and hence the rate of heat input is unimportant [5]. This makes understanding the hot surface ignition process and characterizing ignition criteria a separate study in itself.

Considerable amount of experimental work has been done to investigate hot surface ignition of hydrogen-air mixtures. Studies have been conducted using a cylindrical wire [6] or rod [7], placed in a combustion bomb and heated till the mixture ignites. Other experiments have used hot metal spheres to initiate ignition by dropping them into a flammable mixture [8]. Hot surface ignition of hydrocarbon fuels have been investigated, in the presence of natural convection, by Rae [9] and in

the presence of forced convection, by Kuchta [5] and Mullen [10]. A common observation is that ignition temperatures decrease with increasing surface area of the heat source. In situations where ignition occurs after the formation of a buoyant thermal plume, additional complications arise due to temperature stratification.

Simple models of hot surface ignition have been proposed to correlate experimental data. One of these suggested by Laurendeau [11] assumes that ignition occurs when the rate of heat loss from the surface equals the rate of heat gain due to chemical reactions. This criterion, known as the Van't Hoff criterion, has been used in previous work by Buckel [8] and Law [12]. In spite of several simplifying assumptions and a steady state approximation, good agreement was found with regard to hot surface temperature required for ignition. While results appear encouraging, the transient nature of the ignition process motivates the use of a multi-dimensional fluid dynamics code with detailed finite rate chemistry to capture the complete physics.

Recent development of flamelet based models utilizing tabulated chemistry allow multi-dimensional simulations for complex hydrocarbon fuels with detailed chemistry to be carried out at considerably lower cost and computation time while retaining all the necessary physics of the problem. These advantages have motivated the use of flamelet based models to study a variety of combustion problems [13, 14]. The applicability of tabulated approaches to model the thermal ignition process is explored in this work.

The objective of this work is to gain insight into the hot surface ignition process by combining experimental data with numerical simulations. More specifically, the focus of this paper is placed on identifying the rate controlling processes that determine the onset of ignition. Additionally, the simulations will be utilized to study the effect of global parameters such as hot surface temperature and fuel-air equivalence ratio on the onset of ignition.

The paper is organized as follows. First, the experimental setup is discussed, and the results are compared with predictions from an analytical model. Next, the reaction chemistry and its tabulation are discussed. Two test cases, one for a zero-dimensional homogeneous reactor and another for a one-dimensional hot-surface ignition problem are presented to validate the computational approach. The setup of the two-dimensional simulations of the experiment is discussed. Simulation results are presented and the effects of hot surface temperature and mixture equivalence ratio are analyzed. Finally, conclusions are presented and discussed.

2 Experiment

2.1 Setup

Figure 1(a) shows the layout and Fig. 1(b) shows a photograph of the closed 2 liter combustion vessel utilized in the experiment. The hot surface is simulated by a high temperature glow plug made by Bosch (part number 978801-0485). The glow plug is mounted on an aluminum stagnation plate giving a reference plane to facilitate comparison with the computational results. The vessel incorporates four access ports for schlieren visualization, and is instrumented with a fast response pressure transducer at the top, and four K-type thermocouples in contact with the glow plug for measurement of surface temperature at ignition. Figure 2(a) shows the geometry of the glow plug and Fig. 2(b) shows temperature traces as a function of time at the four locations on the glow plug

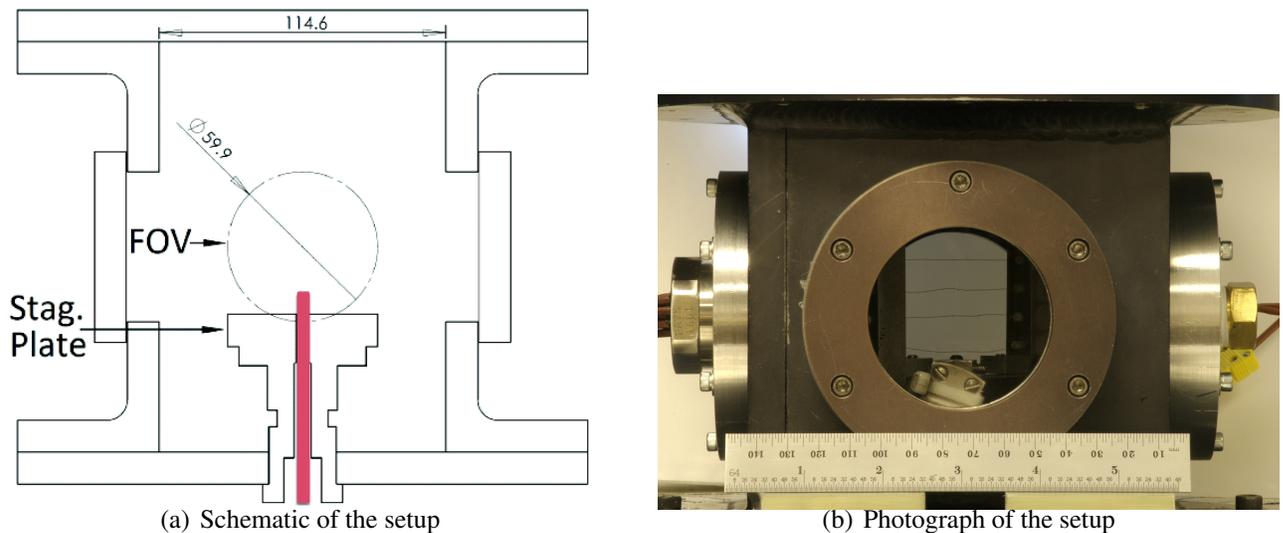


Figure 1: Details of the experimental apparatus.

surface. The temperature of the glow plug is controlled by a power source which steadily increases the current passing through the glow plug to give a constant heating rate of about 220 K/s. From these traces, it may be observed that the temperature around the glow plug is fairly constant (within a few percent) and only decreases at the base close to the stagnation plate.

The vessel is first evacuated and then filled to atmospheric pressure with a mixture of hexane, oxygen, and nitrogen, depending on the desired equivalence ratio, using the method of partial pressures. A circulation pump runs for about 2 minutes to produce a homogeneous mixture. This mixture is allowed to rest for another 2 minutes before heating up the hot surface.

Hexane is utilized as the fuel in the experiments due to its strong similarity to aviation and industrial hydrocarbon fuel. Additionally it is simple to handle experimentally. The hexane sample consists of 89% *n*-hexane and 10.91% other hexane isomers according to manufacturer specifications. Mixtures of hexane and air at equivalence ratios between 0.56 and 3.0 having fuel concentrations between 1.2% and 6.48% [15] respectively were investigated in the experiments. Since the hexane vapor pressure of 15.6 kPa is higher than the partial pressure of hexane used in the experiments (2.5 kPa) at room temperature, none of the fuel is expected to condense [16].

2.2 Results

Figure 3 shows a schlieren image obtained using a vertical knife edge for a fuel-rich ($\phi = 1.74$) hexane-air mixture just after ignition. A plume of hot gas is generated by natural convection and an ignition kernel is seen in contact with the tip of the glow plug. Results from multiple tests show that ignition always occurs after the formation of a thermal plume. Furthermore, ignition is typically seen to occur at the top of the glow plug. Data recorded by the pressure transducer show negligible change in pressure during the ignition process as only small pockets of gas ignite at a time.

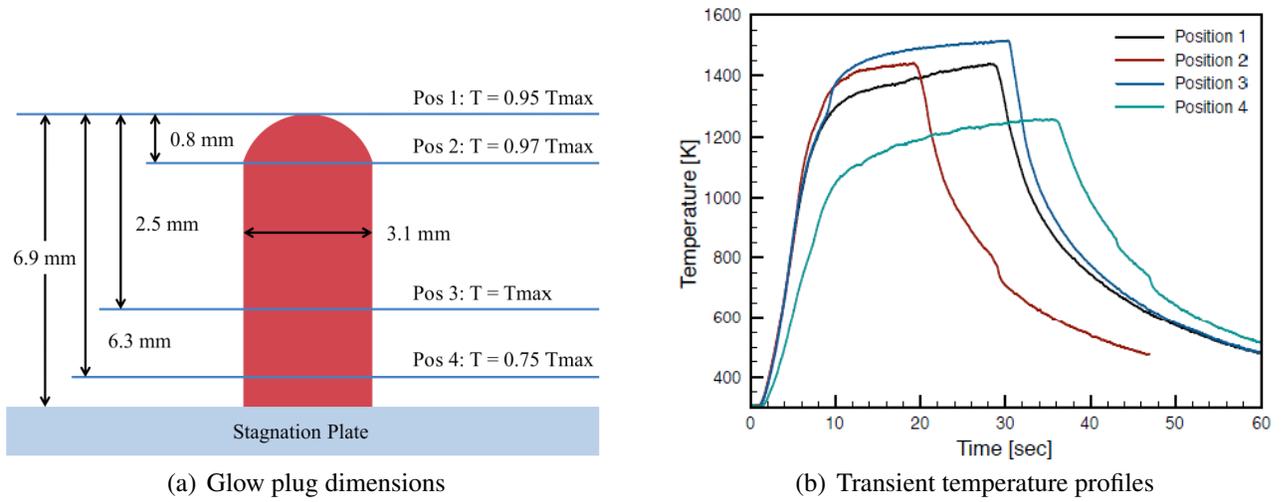


Figure 2: Glow plug details.

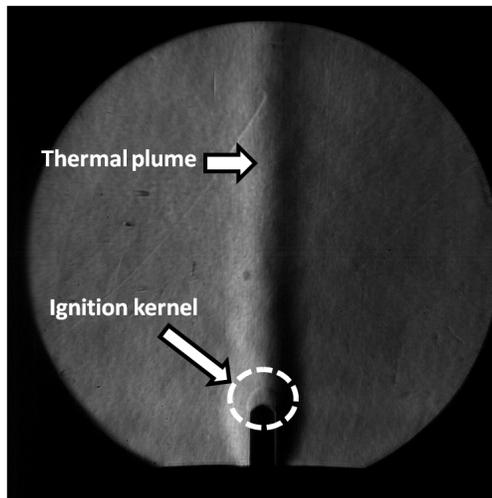


Figure 3: Schlieren photograph of the vessel just after ignition for $\phi = 1.74$.

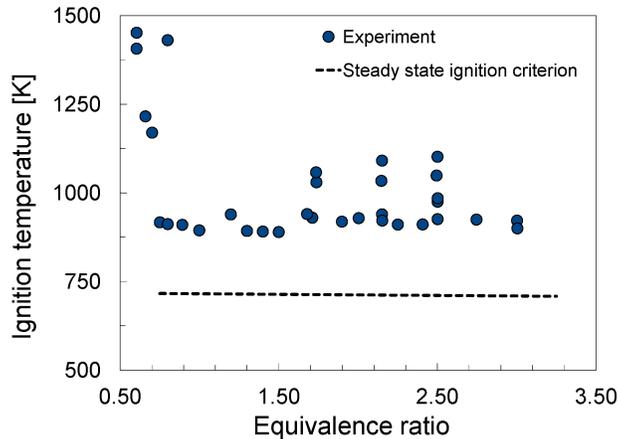


Figure 4: Hot surface temperature at ignition from experiments and correlation using the Laurendeau [11] ignition criterion.

Figure 4 shows thermocouple measurements of surface temperature at ignition for hexane-air mixtures with equivalence ratios between 0.75 and 3.0. The lower flammability limit is observed for $\phi = 0.6$ with the mixture at $\phi = 0.5$ not igniting after heating for 30 seconds and the glow plug surface reaching a temperature of 1520 K. This observation is consistent with previous work by Zabetakis [15]. Figure 4 shows the surface temperature for ignition to be about 920 +/- 20K across the range of equivalence ratios.

The response time of the thermocouple is 0.5 seconds, which is found by measuring its response to a propagating flame. Since the heating rate is about 220 K/s, the time response of the thermocouple introduces an ignition temperature uncertainty of about + 110K.

2.3 Analytical model

The minimum ignition temperature may be estimated using a simple analytical model such as that proposed by Laurendeau [11]. This model suggests that ignition occurs when the rate of heat loss from the reacting mixture equals the rate of heat gain by chemical reactions. The model assumes that the reactive mixture undergoing ignition is at the same temperature as the wall (T_w). The model applies a high activation energy approximation and assumes no depletion of reactants until ignition occurs. A one-dimensional energy conservation equation is integrated across a stagnant thermal boundary layer to obtain the chemical energy release at the wall. The rate constant for the chemical reaction is computed using a one-step global reaction mechanism for the fuel-air mixture.

In the present work, the rate of heat loss is estimated using a standard expression for convective heat transfer, where the Nusselt number corresponds to that for laminar free convection on a vertical surface [17]. The rate coefficients required to compute the global reaction rate for an *n*-hexane-air mixture are obtained from Turns [18]. The wall temperature required to satisfy the heat balance is computed iteratively to obtain the minimum surface temperature for ignition.

Figure 4 shows the results of this analysis. The model by Laurendeau predicts the overall trend of the minimum ignition temperature, albeit lower values. There are however, limitations with the

analysis which limit a complete understanding of the physics of the ignition process.

First, this analysis is conducted for ignition occurring in a thermal boundary layer next to a hot surface. However, in the present experiment, ignition was found to occur above the glow plug. Second, the analysis uses a single rate constant to describe the overall ignition chemistry. The thermal plume generated prior to ignition results in a range of temperatures in the mixture. The reactive processes could take on different rates depending on whether the low or high temperature reactive branches of the fuel (*n*-hexane) gets activated. Third, the analysis neglects multi-dimensional effects, inherently due to the geometry of the glow plug, and due to buoyancy induced convective transport of the heated mixture.

To overcome the deficiencies of this simple analysis, we undertake a time dependent, multi-dimensional simulation with detailed chemistry as explained in the following section.

3 Reaction chemistry

The goal of the numerical simulations is to analyze the fluid dynamic processes (convection and diffusion) in conjunction with finite rate chemistry that lead to hot surface ignition of a flammable mixture. As part of this process, the sensitivity of the results to changes in boundary conditions, and the presence or absence of low temperature reaction pathways are analyzed.

3.1 Reaction mechanism

This work utilizes a detailed reaction mechanism for heavy hydrocarbon fuels which has been validated extensively over a wide range of temperatures, pressures, and equivalence ratios [19, 20]. Although the fuel used in the experiments is hexane, the simulations were performed using *n*-heptane. This decision is justified because the chemistry of heptane at low temperatures is better understood than that of hexane; more experimental data exist for heptane to validate the chemical model; and previous studies have shown that normal alkanes have very similar ignition and flame propagation characteristics [21, 22, 23].

Figure 5 shows a comparison of the ignition delay times computed with the FlameMaster code [24] using the mechanism, at different pressures and equivalence ratios compared to experimental data [25, 26, 27, 28, 29, 22, 30]. The ignition delay times predicted with the detailed model are in very good agreement with experimental measurements over a wide range of conditions. More specifically, the chemical model captures the high temperature region as well as the NTC region with good accuracy.

However, it is important to note that, with the exception of an earlier work by Freeman and Lefebvre [31], no experimental data exist for validation of the chemical model under atmospheric pressure and moderate/low temperatures. This lack of validation renders the predictive capabilities of the chemical model uncertain for the experimental conditions presented in the previous section. To this end, simulations are performed with and without the low temperature reaction pathways to investigate their influence on simulation results.

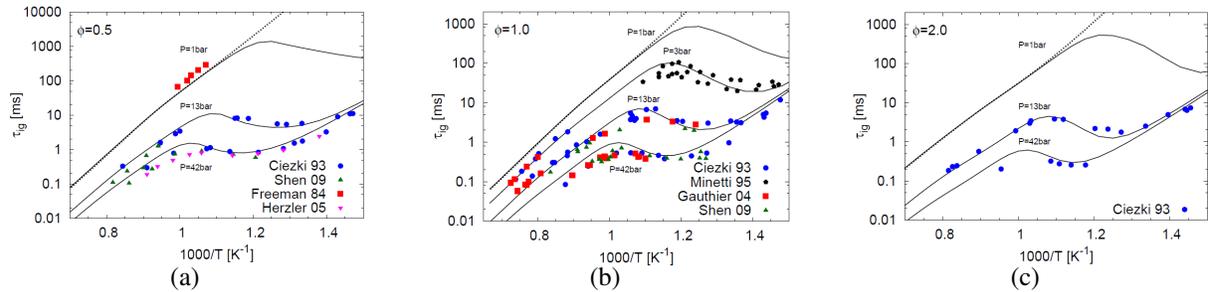


Figure 5: Comparison of ignition delay times predicted by the reaction mechanism with experimental data. The dashed lines correspond to the predictions without the low temperature reaction pathways.

3.2 Chemistry tabulation

To make the numerical simulations more affordable, the chemistry is tabulated with respect to a progress variable [32, 33, 13]. In this approach, all the mixture properties and chemical source terms are tabulated for use in the fluid dynamics simulations. The present work follows the approach outlined in Refs. [34, 35]. The library is constructed using a set of flamelets that have the same equivalence ratio as the experiment and different unburned gas temperatures. In previous work, this approach was found to accurately capture the formation of the thermal plume formed in the chamber prior to ignition as well as subsequent flame propagation in a similar experimental setup.

Since ignition is the phenomenon of interest here, detailed calculations are performed for isobaric homogenous reactors using FlameMaster, and the results are tabulated. The calculations are performed with the same equivalence ratio as in the experiment and for a range of unburned gas temperatures expected in the mixture. Isobaric conditions were preferred over isochoric as usually used for ignition delay times since the experiments did not reveal any significant pressure increase during the ignition process. The two independent variables used to generate the table are the progress variable (C) and the unburned gas temperature (T_u) [34]. The progress variable is calculated as the sum of mass fractions of the major product species (CO , CO_2 , H_2 , H_2O). Adding other species to the definition of the progress variable, such as OH radical, was considered but was not found to improve the prediction significantly.

Figures 6(a) and 6(b) show contour plots of the source term for the progress variable as a function of the progress variable (horizontal axis) and the unburned gas temperature (vertical axis). As expected, the source term is found to be high at high values of unburned gas temperature and progress variable. However, in Fig. 6(b), an area having a non-zero value for the source term is seen at lower temperatures. This arises from the low temperature chemistry of heptane where heptyl radical addition to molecular oxygen is followed by isomerization and reaction with a second oxygen molecule leading to production of OH radicals and chain branching [36]. As it will be shown later, capturing both regimes of the chemical source term (high and low temperature chemistry) is important to predict the minimum ignition temperature.

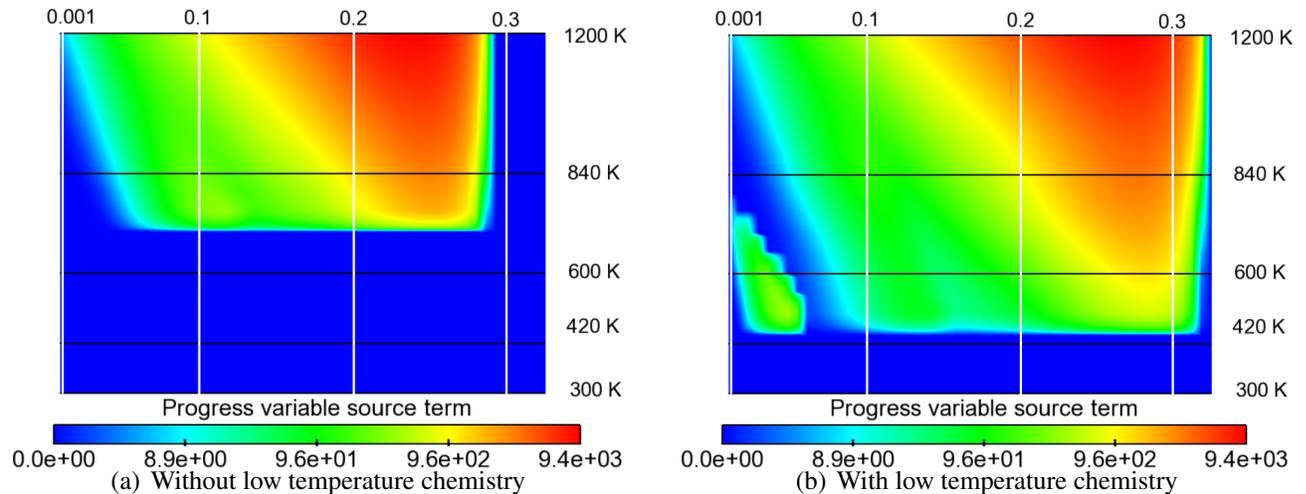


Figure 6: Contour maps of the source term for the progress variable as a function of progress variable and unburned gas temperature.

4 Test case validation

4.1 Zero dimensional homogenous reactor

The validity of the tabulated approach to predict thermal ignition is tested by considering a one dimensional isobaric homogeneous reactor. The reactor is filled with a fuel-air mixture with different initial temperatures and the solution is allowed to evolve until ignition is achieved. Figure 7 shows the ignition delay times thus computed for a case with $\phi = 1.74$. The results from the flamelet approach compare very well with results from detailed chemistry calculations.

4.2 One dimensional hot-surface ignition

The results for the zero-dimensional homogeneous reactor demonstrate the validity of the tabulated approach to model ignition problems by correctly predicting the chemical kinetics. However, the use of a tabulated approach in an environment where, additionally, transport of heat and species occurs between a flammable mixture and a hot-surface has yet to be demonstrated. To this effect, prior to performing a two-dimensional simulation of the experimental setup, we perform a one-dimensional simulation of a hot-surface ignition problem previously studied by Kumar [37] for hydrogen-air mixtures. Figure 8(a) shows the computational setup for the problem. A heated surface at a uniform temperature is situated next to a mixture of hydrogen and air having a uniform initial temperature, pressure and composition. The surface transfers heat to the mixture which ignites after a certain delay time. The boundary conditions utilized by Kumar and implemented in this work are as follows:

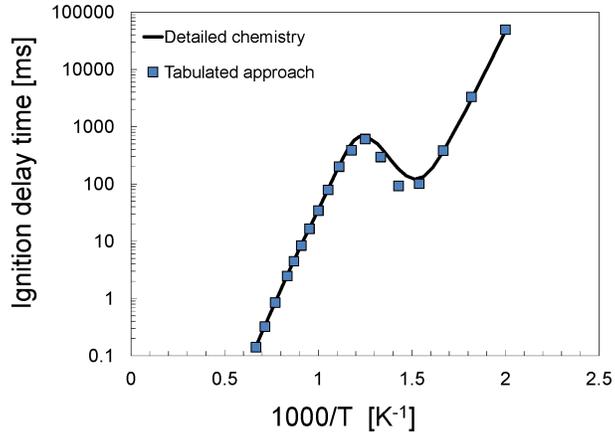


Figure 7: Ignition delay times for a 1D homogeneous isobaric reactor computed with detailed chemistry and the tabulated approach.

$$y_i(0, x) = y_i(t, \infty) = y_i^\infty \quad (1)$$

$$T(0, x) = T(t, \infty) = T_0 \quad (2)$$

$$T(t, 0) = T_s \quad (3)$$

$$v(t, 0) = v(0, x) = 0 \quad (4)$$

$$\frac{\partial y_i}{\partial x} = 0 \text{ at } x = 0 \quad (5)$$

$$\frac{\partial v}{\partial x} = 0 \text{ at } x = \infty \quad (6)$$

$$(7)$$

where, y_i are the species mass fractions, T is the temperature in gas phase, T_s is the hot-surface temperature and v is the velocity in the y -direction.

Kumar solved the problem using detailed chemistry for hydrogen and an explicit finite-difference scheme on a uniform mesh. The results were compared with experimental data and good agreement was obtained for the minimum surface temperature required for ignition as a function of hydrogen concentration at a temperature of 300 K and pressure of 1 atmosphere.

The one dimensional reactor is simulated in the NGA [38] code and the tabulated approach is utilized to estimate ignition delay as a function of hot-surface temperature for different equivalence ratios. Figure 8(b) shows these results compared with those obtained by Kumar [37] for three different equivalence ratios corresponding to 30%, 50% and 60% H_2 -air mixtures. Good agreement is obtained for ignition delay as a function of hot-surface temperature. These results validate the use of a tabulated approach in multi-dimensional simulations involving heat and mass transfer with reaction chemistry.

Further insight regarding the onset of ignition can be obtained by considering the timescales involved in the ignition process. In the absence of convection, there are two key timescales in this

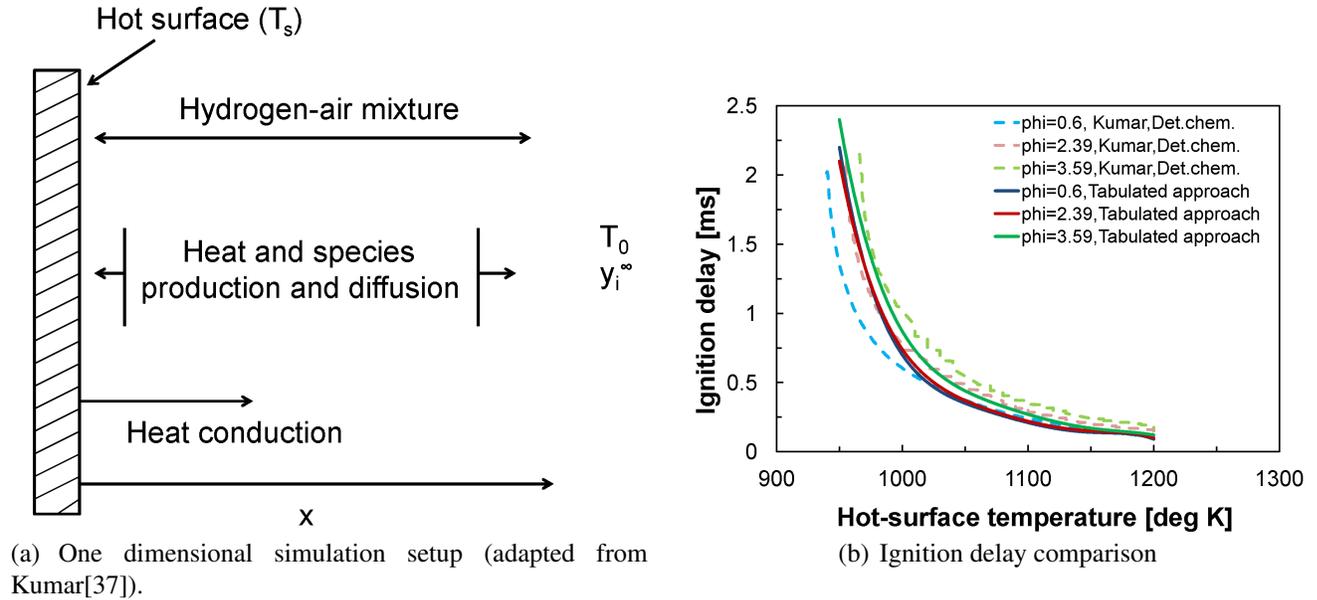


Figure 8: One dimensional simulation of hot-surface ignition of H₂-air mixtures.

problem — a diffusion timescale (corresponding to diffusion of species and heat) and a reaction timescale. The diffusive time scale is evaluated as the ratio of the square of a characteristic length scale over the local diffusivity $\tau_D = L^2/D$; and the reactive time scale is evaluated as the ratio of the progress variable to its source term $\tau_R = C/\dot{\omega}_C$. The length scale in this case is estimated to be the distance from the wall.

Figure 9(a) shows the maximum temperature in the gas phase as a function of time. Ignition is seen to occur at ≈ 0.3 ms. The diffusion and reaction timescales at the point of ignition are presented in Fig. 9(b). Prior to ignition, the reaction timescale is seen to be larger than the diffusion timescale in the entire domain. However, at the point of ignition, the reaction timescale drops slightly below the diffusion timescale and an ignition kernel is generated.

5 Computational model

We now proceed to simulate the two-dimensional hot-surface ignition problem as presented in the experiments in Section 2. In these simulations, a steady state thermal plume established with a uniform hot surface temperature in an environment at a pressure of 1 atm and a temperature of 300K is used as the initial condition.

5.1 Simulation setup

Simulations are carried out in a 2D axisymmetric domain with a height of 109 mm and a diameter of 115 mm corresponding to the volume of the combustion chamber above the stagnation plate as shown in Fig. 1(a). The symmetry plane established at the center-line of the cylinder is assigned a Neumann boundary condition, while all the other surfaces except the glow plug are modeled as

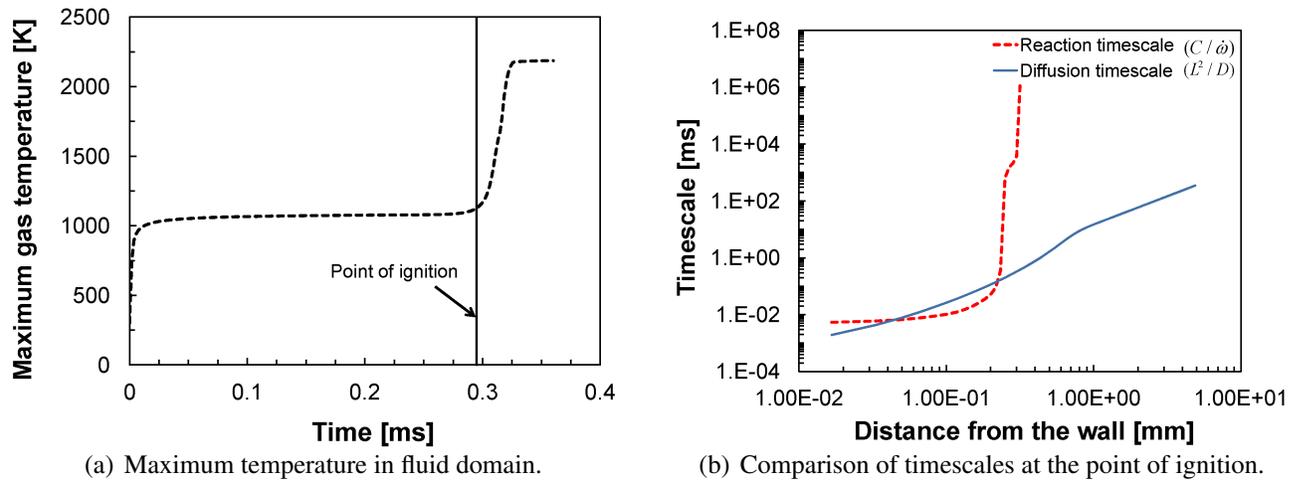


Figure 9: Results from one dimensional simulation of H_2 -air ignition

closed adiabatic walls.

The experimental observations indicated that the surface temperature of the glow plug is almost uniform (Fig. 2(b)). As a result, in the simulations, the glow plug is initialized spatially with a uniform temperature. Furthermore, the temperature of the glow plug is kept fixed in time, thus allowing heat exchange with the surrounding fluid.

The progress variable at the glow plug surface is set to zero. A zero value for the progress variable at the wall can be understood in two different ways. First, it means that no increase in temperature is seen above the imposed, unburned temperature (T_u). Second, it is representative of the destruction of radicals at the wall through their recombination into stable species. Sensitivity to this boundary condition will be presented later. The surface itself is inert having no chemical reactions with the mixture.

The solution is obtained on a mesh consisting of 256 grid points in the vertical direction and 128 points in the radial (horizontal) direction. The grid is clustered closer to the glow plug with 128 points for one glow plug height and 32 points for one glow plug diameter. Simulations are performed using the NGA code [38]. The code relies on high order conservative finite difference schemes developed for the simulation of variable density flows. A third order WENO scheme [39] is used to compute scalar transport.

5.2 Thermal plume

Prior to ignition, a plume of hot gases is established above the glow plug as seen in the schlieren images from the experiment in Fig. 3. The formation of the plume is a transient event involving a puff of hot gas that forms at the glow plug and continues to rise due to buoyancy till a steady state is established.

The simulation of the whole ignition process is decomposed into two consecutive steps. First, the velocity and temperature fields are solved for in the absence of chemical reactions until a steady

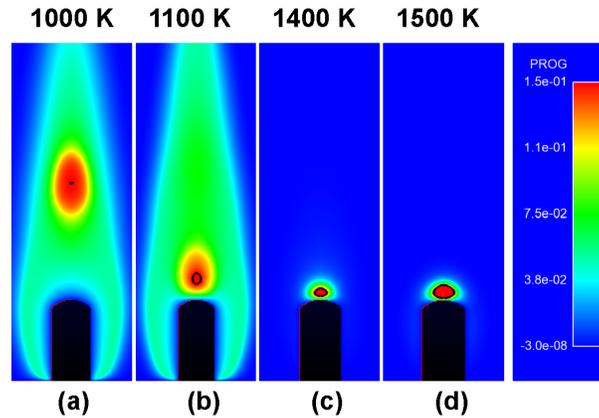


Figure 10: Comparison of ignition locations for different hot surface temperatures. The full chemical reaction mechanism is considered in (a) and (b). The low temperature reaction pathways are neglected in (c) and (d).

hot plume is established. Then, chemical reactions are "turned on" and the mixture slowly reacts. This two-step procedure is justified as the response time of the plume to changes in hot surface temperature is much shorter (estimated at about 0.25 s) than the ramp time required to change the hot surface temperature (estimated at about a few seconds).

5.3 Ignition process

Figure 10 shows contours of the progress variable at the time of ignition corresponding to different hot surface temperatures. Figure 7(a) and 7(b) correspond to simulations performed with the full chemical model, including low temperature reaction pathways. Figure 7(c) and 7(d) correspond to simulations performed without the low temperature reaction pathways. The ignition kernel is illustrated by the black iso-contour.

The numerical simulations predict that ignition occurs above the glow plug surface, consistent with experimental observations. The location of ignition is found to be insensitive to the surface temperature, when only the high temperature chemistry is considered. However, when the full model is used, the ignition location depends on the surface temperature and decreases in height with increase in surface temperature (Fig. 7(a) and 7(b)). Additionally, the minimum surface temperature required to ignite the mixture decreases when the full model is used.

Figure 11 shows ignition delay times obtained from the 2D simulations. The ignition delay times were evaluated from the time the chemical reactions are "turned on" (after the formation of a steady hot plume) until the appearance of the first kernel of hot gases (50 % of the maximum progress variable). As suggested by Kumar [37], the minimum surface temperature for ignition may be identified as the surface temperature at which ignition delay tends to infinity. The results of Fig. 11 also show the minimum surface temperature required for ignition.

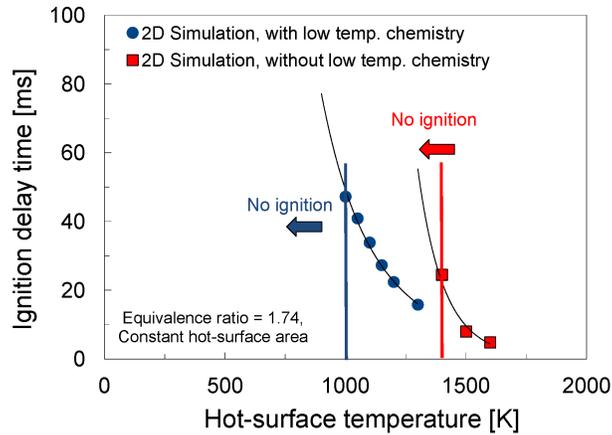


Figure 11: Ignition delay time as a function of hot surface temperature.

5.4 Sensitivity to boundary conditions

As mentioned previously, the progress variable is set to zero on the glow plug surface. The sensitivity of the simulation results to this boundary condition was checked by setting a Neumann boundary condition at the glow plug surface. The results indicated no change in the ignition location or delay time. This result suggests that diffusion away from the glow plug surface is the more dominant dissipative process and hence validates the analysis by Laurendeau presented in Section 2.3.

5.5 Timescale analysis

The flow field established by the buoyant plume of hot gases prior to ignition affects the ignition process. The initial thermal plume is characterized by convective, diffusive and reaction timescales. These properties are in turn affected by hot surface temperature, mixture equivalence ratio, and hot surface area. To better understand the physics of the ignition process, we compute the timescales of interest at different locations above the hot surface along the center line of the domain for a case with $\phi = 1.74$ and hot surface temperature of 1000K.

The convective time scale is computed as $\tau_C = \int dx/U$ along streamlines; the diffusive and reactive timescales are computed as described in Section 4.2. The length scale for diffusion is taken to be the thickness of the thermal boundary layer (δ) at the sides of the glow plug and half the plume width above the glow plug. Two reaction timescales have to be considered, one for high and another for low temperature chemistry.

For $\phi = 1.74$ and a hot surface temperature of 1000K, the convective time scale is found to be greater than 100 ms in the vicinity of the glow plug. On the other hand, the diffusion timescale is found to be of the order of 10ms on each side of the glow plug and about 40 ms at the top. Since the convective timescale is the largest, ignition can occur at a given location, if the local reactive timescale is smaller than the diffusive timescale. In the absence of low temperature chemistry, a smaller reaction time scale can only be achieved with a higher temperature. This implies that

ignition is more likely to occur 1) very close to the glow plug surface where the reaction time scale is smaller and 2) at the top of the glow plug where the diffusion time scale is larger. This analysis confirms the results presented in Fig. 7(c) and 7(d).

In the presence of low temperature reaction pathways, the situation is more complicated. Even if the surface temperature is too low to activate high temperature chemistry (as in Fig. 7(a) and 7(b)), ignition may still occur via low temperature reaction pathways. These reaction pathways will be activated at other locations in the thermal plume where the local temperature provides for a large reaction rate ($\dot{\omega}_C$). This reaction rate would be the largest at the end of the NTC region which at atmospheric pressure occurs around 600K (Fig. 5(b)). As the surface temperature increases, this location shifts closer to the glow plug surface. Once again, this analysis is consistent with the observations from Fig. 7(b).

5.6 Effect of equivalence ratio

Figure 12 shows the effect of mixture equivalence ratio on the minimum temperature for ignition. The experimental results are the same as presented in Fig. 4, however, only the minimum value corresponding to a particular equivalence ratio is included. In the simulations, for each equivalence ratio, the hot surface temperature is varied until ignition is no longer observed. Lack of ignition is indicated by an asymptotic constant behavior for the maximum value of the progress variable in the domain.

The ignition temperature obtained from experiments, appears to be fairly independent of the equivalence ratio (around 920K). A similar behavior, albeit at higher temperature ($T \approx 1400K$) is observed for the simulation where low temperature (LT) chemistry is excluded. However, when the full chemical model is used, the simulation results show a considerable effect of equivalence ratio on minimum hot surface temperature for ignition and lead to values that are smaller than that measured experimentally.

From the time scale analysis presented in the previous section, ignition was found to result from an imbalance between diffusion and chemical reactions. The diffusive processes resulting in the formation of a hot plume by natural convection are well captured by the present numerical framework and are independent of the chemical model. However, the results of the reacting flow are only as good as the kinetic mechanism used. While the chemical model gives very good results for low temperature ignition under high pressures, it remains unvalidated for atmospheric pressures. The present results may suggest that the low temperature chemistry is too fast for rich conditions. Despite uncertainties in the low temperature pathways, the simulations confirm that a mixture with an equivalence ratio less than 0.5 should not ignite.

6 Conclusions

A combined experimental and numerical study is undertaken to characterize the processes leading to hot surface ignition of a flammable mixture, and identify the parameters that influence the minimum ignition temperature. The experimental results correlated by a simple analytical model suggest a hot surface ignition temperature of about 920 K across a range of equivalence ratios for the current experimental setup. A numerical framework based on tabulated detailed chemistry was

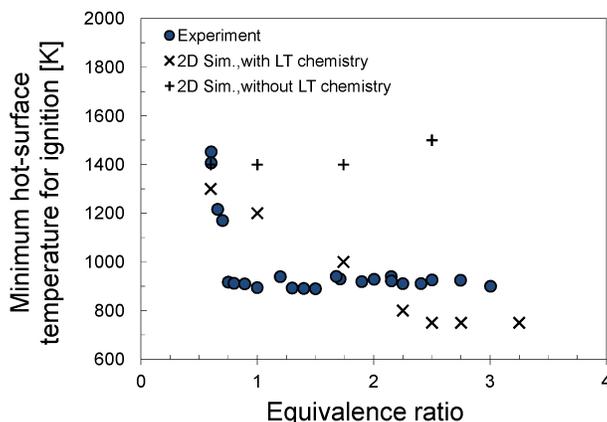


Figure 12: Effect of equivalence ratio on minimum temperature for ignition.

setup to study thermal ignition. The simulation results, including the location of ignition, are only weakly affected by boundary conditions for the progress variable at the hot surface. The effect of inclusion of low temperature reaction pathways is however, seen to considerably influence the ignition location and minimum surface temperature required for ignition. Analysis of the convective, diffusive and reacting timescales inside the plume of hot gas prior to ignition provides insight into the hot surface ignition process. The deviation from experimental results are seen to be primarily a result of incomplete understanding of the low temperature reaction kinetics and indicates an area of future research.

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