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Risks Assessment of Petroleum Fires at Elevated Pressures and Temperatures aboard Oil Tankers Using Computer Model

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Due to the serious threats of petroleum fires, which might take place every now and then, in ships (oil tankers), big fuel tanks aboard, oil refineries or conventional petrol stations ashore, which often leave big losses and injuries. Such Fires require big efforts and modern facilities in order to overcome difficulties with suppression. It becomes an essential issue to conduct research, which might help to understand the nature of such fires, and more important the effective ways of suppression using computer model at different pressures and temperatures.

This paper starts with briefs for effects of elevated pressures and temperatures on risks increase of petroleum fires including auto-ignition phenomenon. The paper then discuss some important parameters in combustion science such as burning velocities, which is a very important factor in risk assessment for any combustible material (fuels, oil products and chemicals) via using computer programs at different initial conditions to evaluate final temperatures of flames in the surroundings. Four different fuels are used in this work. The paper also explains other important issues such as, Flammability limits of such materials and flames instability. Those two parameters help to know and understand flames behaviors and their propagation in the surrounding environment. Flame instabilities are phenomenon, which not well understood in combustion due its complexity and the tremendous changes and fluctuations of physical and chemical states of burned species in flames. This situation makes fire more dangerous and harder to control. Finally, the paper ends with some conclusions.

Keywords: Risks,Flames, Auto Ignition, Combustion, Flammability, Instabilities

Introduction

The study of combustion and its control (including ignition) is ultimately important and even essential in order to have a better understanding of petroleum fires and its hazard. Throughout the world, the major challenge for investigators in such fires is to know the main causes which made a start of ignition and flames to propagate aboard huge ships (oil tankers). Most of the researches in this field analyse fundamental aspects such as ignition, burn rate, decomposition of mixtures, stretch effects on flame propagation, and other parameters. Yet our understanding is still incomplete. According to Webster's Dictionary, combustion is a "rapid oxidation generating heat, or both light and heat; also, slow oxidation accompanied by relatively little heat and no light" [1]. Others define it as the interaction of chemical reactions, which occur between the fuel and oxidant (normally air), involving transport processes and fluid motion [2].

The propagation of a reaction front takes two major forms. Deflagration involves the molecular transport processes of conduction and diffusion of species and a comparatively thin reaction zone. There are large temperature and species concentration gradients and the flame may be laminar or turbulent. The second form is autoignitive. Here, most of the mixture ignites after the autoignition delay time has elapsed and molecular transport processes are less important. In this form a shock wave may be created that generates temperatures and pressures sufficient for rapid chemical reaction. The shock and reaction fronts then move in tandem as a detonation front. The main physical - chemical parameter for deflagration is the laminar burning velocity: that for autoignition is the ignition delay time.

In practice, most of the chemical reactions that occur in flames do so in the gaseous phase. All flames can be classified as either premixed or non-premixed. In premixed flames the fuel and oxidant are mixed prior to the combustion, whereas in non-premixed flames mixing takes place close to the reaction zone. Flames can also be either laminar or turbulent. For intensive burning in power systems the combustion is usually turbulent. If the fuel is not completely vaporized or devolatilised before entering the reaction zone, then combustion is two phased. The focus in this study is on premixed gaseous combustion in both laminar and turbulent flames.

Burning Velocity

The burning velocity for any combustible substance (fuels) is very important factor in evaluating the degree of risks and hazard. It is essential issue to:

1. Evaluate risk and hazard of the combustible material (amount of heat flux from flames)
2. Estimate the flame speed
3. Efficiency of burned fuel (to produce energy)
4. Making the needed safety measures to prevent fires
5. Understand chemical and physical properties of

It is influenced by the chemical kinetics of the reactions which occur during combustion process firs, diffusion coefficients and thermal conductivity. It is dependent on the pressure, temperature and mixture. Andrews and Bradley have defined it as the relative velocity of the unburned gas, with which a plane, one-dimensional flame front travels along the normal to its surface [3]. Its value has been studied for close to one century, and yet there is still a lack of consensus both as to the most effective methods for its measurements and the reliability of the published data for various mixtures [4].

Different methods employing burners and spherical ignitions have been employed in the research of combustion with each one have advantages and disadvantages. Mallard and Le Chatelier have shown that, for more than one century, cylindrical tube method, close at one end and with ignition at the other end, is probably the one best able to achieve a constant flame speed over a distance sufficient to measure the laminar burning velocity [5]. Guénoche have used this method to study the flame oscillations, especially with lean methane, hydrogen and rich hydrocarbons mixtures with air, and then assumed a cellular structure with an enhanced flame speed [6]. However, due to the interest in achieving a constant flame speed regime, Guénoche and Laffitte have reduced the effects of potential acoustic oscillation by fitting an orifice to vent the burned gas at the open end of the tube [7]. After adopting this technique by subsequent workers, vertical open tube method became strongly recommended for measuring burning velocity [8]. The flame kernel method developed by Dery and used by Bolz and Burlage has an advantage of eliminating the effects of spark electrodes but produce a very complex flame-front shape since the kernel is not spherical [9-11]. Another method to measure burning velocity is called soap-bubble method, it was devised by Stevens and developed by Fiock and Roeder and has an advantage of the low quantities of combustible mixture needed and the ability to vary the initial temperature and pressure. A disadvantage of this method is that if water - based soap solutions are used, dry mixtures cannot be tested, Rallis and Garforth, Simon and Wong [4]. The double kernel method was also introduced to obtain, by direct measurements, the laminar burning velocity at the limit, where the two kernels merge [12-14].

The most common method is to employ spherical shaped kernels with central ignition [15]. It is well known as constant-volume method. A great number of experimental studies have been conducted to investigate spherical flames under Varity of conditions. This method has many advantages over the others such as: small quantities of combustible mixture are required, the ability to control pressure-temperature and the mixture composition, there are no surface interaction effect and the heat loss is negligible. Derivation of used equations for measuring (ul) laminar burning velocity, are found in Alshahrani.

Instabilities Effects in Flames

The study of the phenomena of flame instability goes back many years. Darrieus, Landau and Landau & Lifshitz showed that the propagation at a constant speed of a wave of density discontinuity creates a hydrodynamic instability [16-18]. A flame advancing into unburned gas comprises such a surface. In the models of these researchers, the structure of the flame was neglected and, consequently, thermo-diffusive effects were also neglected. The instability was explained by considering the gas motion relative to the wave. When cold reactants (unburned gas) move into the crest of a flame front they diverge and this locally increases the pressure. Conversely, when the oncoming cold gases approach the trough of the flame front, they converge and this motion locally decreases the pressure. These localized pressure changes deform the flame surface and, as a consequence, the overall burning velocity is increased. This type of instability, known as a Darrieus-Landau instability, results from the interaction of the flame with the hydrodynamic disturbances. This mechanism was thought to be responsible for the wrinkled, or cellular, flames structures that have been observed by several experimentalists [19, 20].

Evaluation of Flames Adiabatic Temperatures (Modeling)

The adiabatic temperature of the produced flames from petroleum fires are one of the main issues in risk assessment. It helps to predicate the amount of heat dumped to the surroundings. In this work, software was used to calculate the adiabatic temperature and equilibrium composition of a flame under certain pressure and temperature at a constant volume. Four different fuels were used, (iso-octane-methane-hydrogen-propane). The results of such calculations are shown in Tables:1 thru Table 4 and plotted in Figure 2. The details and discussion of the used model is beyond the scope of this paper, more information can be found in Alshahrany AS. A sample output for the model is shown in Figure 1. Results show, however, that hydrogen flames have the highest temperatures ranging from 2888 K to 2932 K, where as methane flames have the lowest temperatures, 2687 K to 2714 K. This is an evidence that hydrogen fires will dump more heat flux to the surroundings than the others [21].

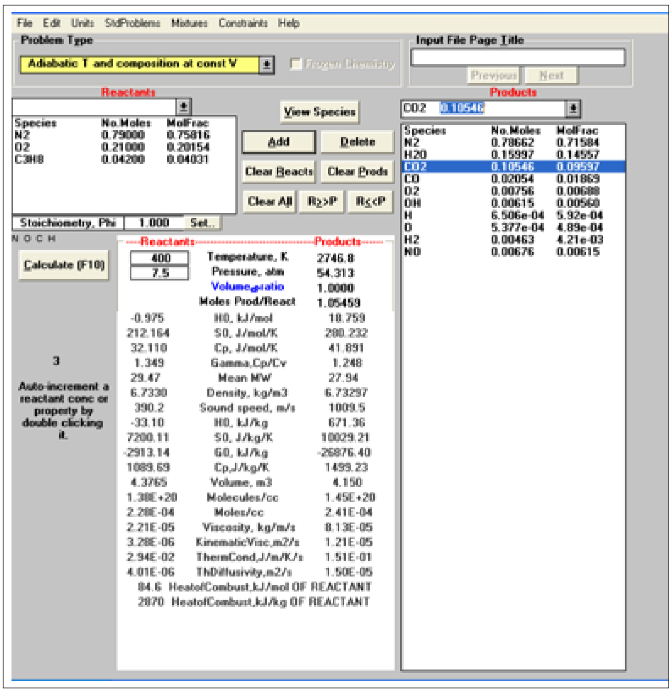

Figure 1: Sample Output Calculations Obtained from "Gaseq" Model

One the hand, an experimental work has been done by the author Alshahrany for measuring burning velocities. The results are presented in Figures 3 (A, B and C) which show hydrogen is the highest compared to methane and iso-octane. This clearly confirms that hydrogen burns faster than others, risky and more hazard.

Table 1: Temperatures of Iso-Octane Flames at Different Initial Pressures and Temperatures

Combustible material	Pu (bar)	Tu (k)	Tad(k)
Iso-octane (C_8H_8)	6.5	383	2747
	7	390	2752
	7.5	397	2758
	8	404	2763
	8.5	410	2767
	9	416	2771
	9.5	422	2776

Table 2: Temperatures of Methane Flames at Different Initial Pressures and Temperatures

Combustible material	Pu (bar)	Tu (k)	Tad(k)
Methane (CH_4)	6.5	387	2687
	7	395	2692
	7.5	400	2696
	8	406	2700
	8.5	414	2705
	9	421	2710
	9.5	427	2714

Table 3: Temperatures of Hydrogen Flames at Different Initial Pressures and Temperatures

Combustible material	Pu (bar)	Tu (k)	Tad(k)
Hydrogen (H_2)	6.5	383	2888
	7	395	2896
	7.5	400	2902
	8	408	2907
	8.5	415	2913
	9	422	2918
	9.5	428	2923

Table 4: Temperatures of Propane Flames at Different Initial Pressures and Temperatures

Combustible material	Pu (bar)	Tu (k)	Tad(k)
Propane (C_3H_8)	6.5	380	2735
	7	395	2741
	7.5	400	2747
	8	405	2751
	8.5	410	2755
	9	416	2760
	9.5	422	2764

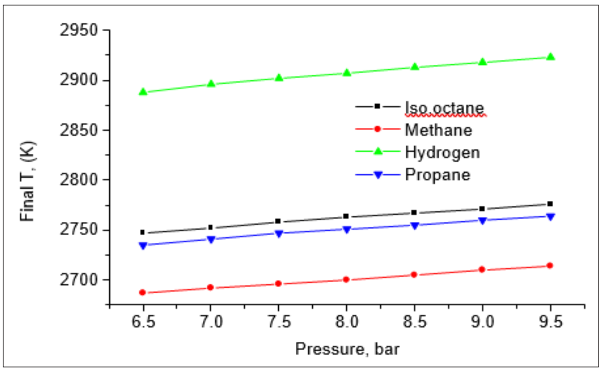

Figure 2: Final Temperatures for the Four Fuels at Different Pressure Values. Calculations were Obtained from "Gaseq" Model

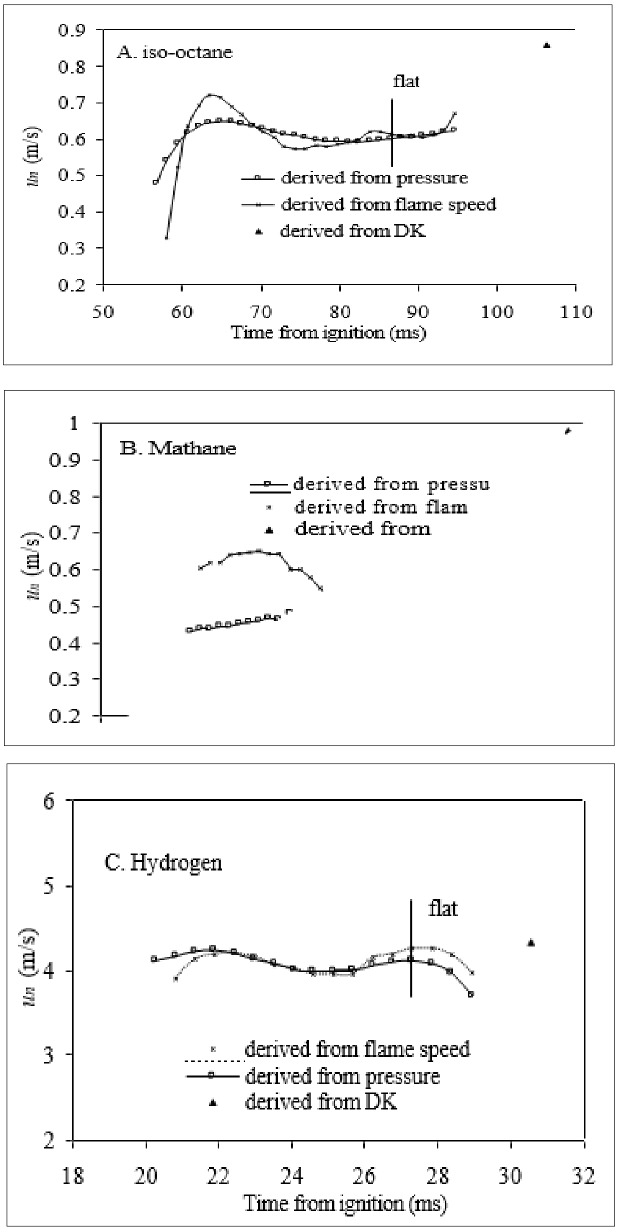

Figure 3: Burning Velocities of: A. Iso-Octan, B. Methane and C. Hydrogen at Initial Condition, $\phi = 0.5$, po = 0.5 MPa, To = 358 K

Conclusions

In summary, the principle findings are:

a) Adiabatic flames temperatures are very important issue for risk evaluation, in petroleum fires, as it helps estimating heat flux generated by such flames.
b) The model used in this work, was successful in calculating the final adiabatic temperatures for the four different combustible hydrocarbon fuels, iso-octane, methane, hydrogen and propane. Obtained results show that the highest temperature was produced by hydrogen flames, 2923 K, where Methane produced the lowest temperature, 2714 K..
c) The obtained results preformed by the model show that, as the unburned pressure and temperature increase, the flame adiabatic temperatures increases, which indicates that such fires will be more risky and hazard at elevated pressures and temperatures.
d) Hydrogen flames has the fastest burning velocities among the others and hence, has the highest flame speed. This is an important factor in fire suppression where it helps estimating the total time needed for fire to spread across the body and surface of such ships.
e) For future work, it will be very useful to conduct more researches to study effects of heat radiations on fire fighters members generated by petroleum fires aboard oil tankers.

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