

# ASSESSMENT OF THE EFFECTS OF INERT GAS AND HYDROCARBON FUEL DILUTION ON HYDROGEN FLAMES

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## Abstract

To advance hydrogen into the energy market, it is necessary to consider risk assessment for scenarios that are complicated by accidental hydrogen release mixing with other combustible hydrocarbon fuels. The paper is aimed at examining the effect of mixing the hydrocarbon and inert gas into the hydrogen flame on the kinetic mechanisms, the laminar burning velocity and the flame stability. The influences of hydrogen concentration on the flame burning velocity were determined for the hydrogen/propane ( $H_2-C_3H_8$ ), hydrogen/ethane ( $H_2-C_2H_6$ ), hydrogen/methane ( $H_2-CH_4$ ), and hydrogen/carbon dioxide ( $H_2-CO_2$ ) mixtures. Experimental tests were carried out to determine the lift-off, blow-out and blow-off stability limits of  $H_2$ ,  $H_2-C_3H_8$ ,  $H_2-C_2H_6$ ,  $H_2-CH_4$  and  $H_2-CO_2$  jet flames in a 2 mm diameter burner. The kinetic mechanisms of hydrogen interacting with  $C_3$ ,  $C_2$  and  $C_1$  fuels is analysed using the kinetic mechanisms for hydrocarbon combustion.

Keywords: hydrogen, hydrogen/hydrocarbon fuel, chemical kinetics, stability limits,

## 1.0 INTRODUCTION

The kinetic mechanisms of premixed hydrogen flames has been studied extensively in the past a few decades [1-4]. The full chemical kinetic mechanisms for hydrogen flame has been well established and involve eight reacting species ( $H_2$ ,  $O_2$ ,  $H$ ,  $O$ ,  $OH$ ,  $HO_2$ ,  $H_2O_2$  and  $H_2O$ ). Comparing to hydrogen flames, the kinetic mechanisms for hydrocarbon combustion are much more complicated. For oxidation of hydrocarbons up to propane, the order of hundred reactions around 30 species were found for a sufficiently accurate calculations of the chemistry [4]. In the recent development of numerical studies of flame structures, it was found necessary to develop reduced mechanisms for simplified descriptions and reduction of the chemistry to the smallest number of global steps. It is expected that the kinetic mechanisms would be even more complicated if the hydrogen is mixed with hydrocarbon fuel. So far there is very little kinetic information available on hydrogen-hydrocarbon mixtures. To carry out risk assessment for hydrogen energy system, the scenarios of the accidental hydrogen release mixing with other combustible hydrocarbon fuels have to be assessed. Therefore the kinetic mechanisms for hydrogen and hydrocarbon have to be established to allow detailed numerical simulation of flame structure and the hazard assessment. This paper examines the lift-off and blow-out stability of the hydrogen/hydrocarbon flames. The flame lift-off and blow-out parameters are strongly influenced by the flame burning velocity, which are directly linked to the kinetic mechanisms in the combustion reactions. The paper is aimed at examining the effect of mixing the hydrocarbon and inert gas into the hydrogen flame on the kinetic mechanisms, the laminar burning velocity and the flame stability.

## 2.0 EXPERIMENTAL TESTS ON THE FLAME STABILITY

The experiments were carried out using a burner with a 2 mm inner diameter. The burner was fitted with flow settling chamber and flow straightening device. The gasses were introduced from compressed gas bottles through flow meters and were mixed before channelling into the settling chambers. The visual characteristics of the flames of pure hydrogen were very different from  $H_2/C_3H_8$ ,  $H_2/CH_4$  and  $H_2/CO_2$  flames. The pure hydrogen jet flames were almost invisible.  $H_2/CO_2$  flames and  $H_2/CH_4$  were in blue. The  $H_2/C_3H_8$  flames resembled characteristics of propane ones and appeared in blue in the base of the flame, but bright yellow in the main combustion zone. To visualise the flames

and establish the lift off height of the flames, both schlieren technology and direct digital photography technology were used to capture the flame images of hydrogen, hydrogen/carbon dioxide flames. All flame images were captured using digital camera and processed using computer graphic packages.

## 2.1 Lift-off Velocity

A comparison of effect of propane addition and methane additions on lift-off velocity is shown in Figure 1. It is shown that for the same volume concentration, hydrogen/methane flames require much higher lift-off velocity than hydrogen/propane flames.

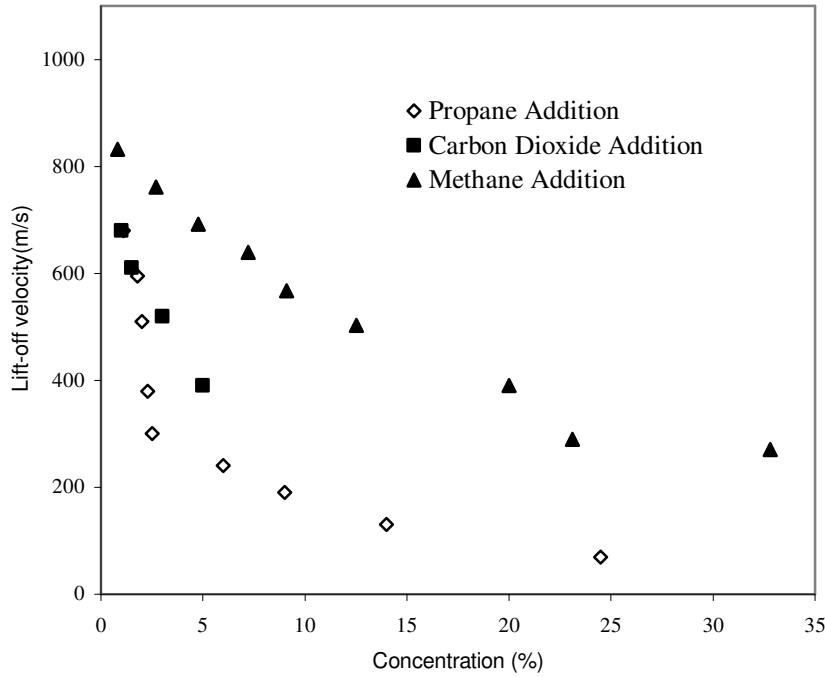


Figure 1: Comparison of the effect of  $C_3H_8$ ,  $CO_2$  and  $CH_4$  addition on the flame lift-off velocity.

## 2.2 Blow-out and Blow-off Velocity

The experimental measured blow-out or blow-off velocities for hydrogen/propane ( $H_2-C_3H_8$ ), hydrogen/methane ( $H_2-CH_4$ ), and hydrogen/carbon dioxide ( $H_2-CO_2$ ) flames are presented in Figure 2. The comparison shows that for the same additive concentration,  $H_2-CH_4$  flames exhibit higher blow-out or blow-off velocity than  $H_2-C_3H_8$  or  $H_2-CO_2$  flames. However the blow-out or blow-off velocities are in the same order for  $H_2-C_3H_8$  or  $H_2-CO_2$  flames.

Based on the Premixed Combustion Model assumption that the incoming gas velocity at the stabilization zone balances the local turbulent velocity  $S_T$ , Kalghatgi [5] successfully derived an empirical formula that correlates the blow-out velocity,  $U_{blowout}$ , for various fuel mixtures ( $CH_4/Air$ ,  $CH_4/CO_2$ ,  $C_3H_8/Air$  and  $C_3H_8/CO_2$ ) and burner diameters. The correlation for blow-out velocity is expressed as:

$$U_{blowout} = S_{L,max} \left( \frac{\rho_{\infty}}{\rho_{Jet}} \right)^{1.5} \times 0.017 Re_H \left( 1 - 3.5 \times 10^{-6} Re_H \right) \quad (1)$$

Where  $Re_H$  is Reynolds number based on dimensionless height,  $H$ , which is obtained from the following formula:

$$H = \left\{ 4 \frac{Y_o}{Y_{ST}} \left( \frac{\rho_{Jet}}{\rho_\infty} \right)^{0.5} + 5.8 \right\} d_o \quad (2)$$

Where  $Y_o$  is the fuel mass fraction at burner exit;  $Y_{ST}$  is the stoichiometric mass fraction.

Since the blow-out velocity is proportion to the fuel maximum laminar burning velocity, the flame blow-out stability data in Figure 2 indicated that for the same concentration,  $H_2/CH_4$  is more active than  $H_2/C_3H_8$ ,  $H_2/CO_2$  mixtures, which is in the contrary to pure  $CH_4$  and  $C_3H_8$  fuels where  $C_3H_8$  is more active than  $CH_4$ . The presence of hydrogen has reversed the reactivity order of the  $C_1$  and  $C_3$  fuels.

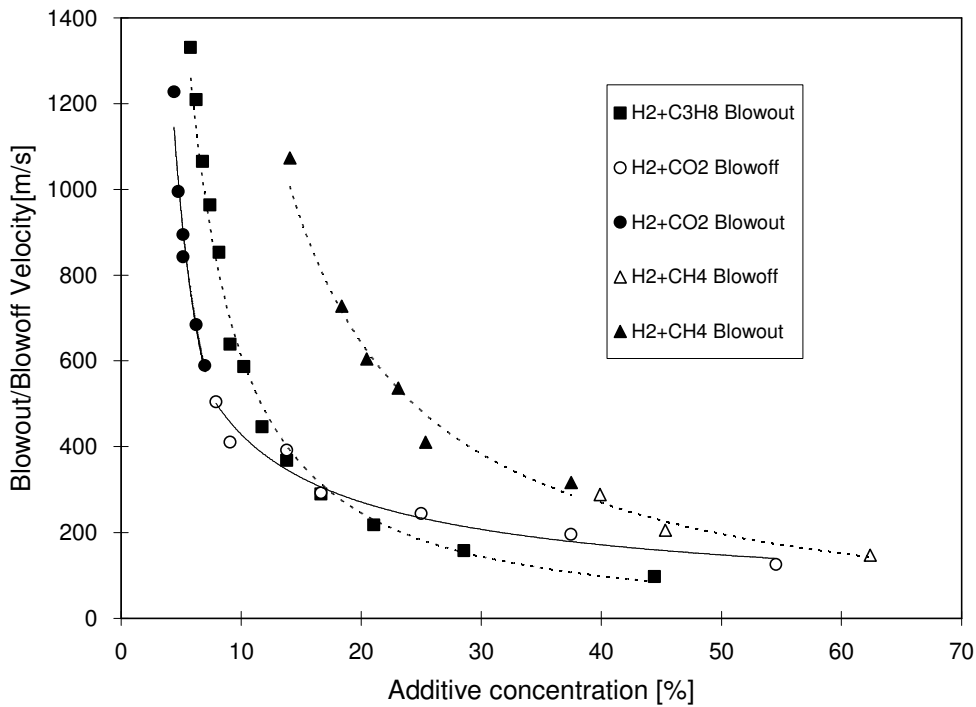


Figure 2: Comparison of the effect of  $C_3H_8$ ,  $CO_2$  and  $CH_4$  addition on the flame blow-out or blow-off velocity.

### 3.0 LAMINAR BURNING VELOCITY

Experimental studies of the laminar or fundamental flame velocity of hydrogen-air mixtures, hydrogen/hydrocarbon mixtures and hydrogen rich syngas have been reported in a number of studies [6-12] and selected burning velocity values are presented in Figure 3. The measured laminar burning velocity of pure hydrogen flames peaked at a rich mixture of equivalence ratio 1.8. However the hydrogen/hydrocarbon mixtures assembled the features of hydrocarbon fuels, with the peak close to the stoichiometric. Comparing the magnitude of the burning velocity for the same equivalent ratio, the descending order of the burning velocity for pure hydrocarbon fuels is  $C_3H_8$ ,  $C_2H_6$  and  $CH_4$ . Comparing the hydrogen-hydrocarbon flames, the descending order is  $H_2-CH_4$ ,  $H_2-C_2H_6$  and  $H_2-C_3H_8$ . It is confirmed that the reactive order for  $C_3H_8$ ,  $C_2H_6$  and  $CH_4$  fuels seems reversed if hydrogen is added. This is more clearly shown in Figure 4 if the values of maximum laminar burning velocity is compared for  $H_2-C_3H_8$ ,  $H_2-C_2H_6$  and  $H_2-CH_4$  mixtures. This clearly indicates that the role of hydrogen in the chemical kinetic mechanisms for hydrogen/hydrocarbon mixtures needs to be examined.

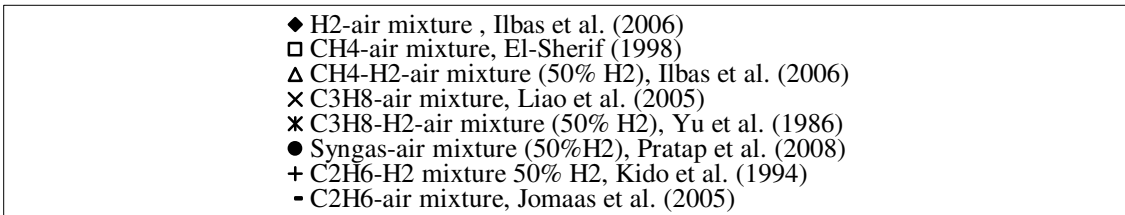
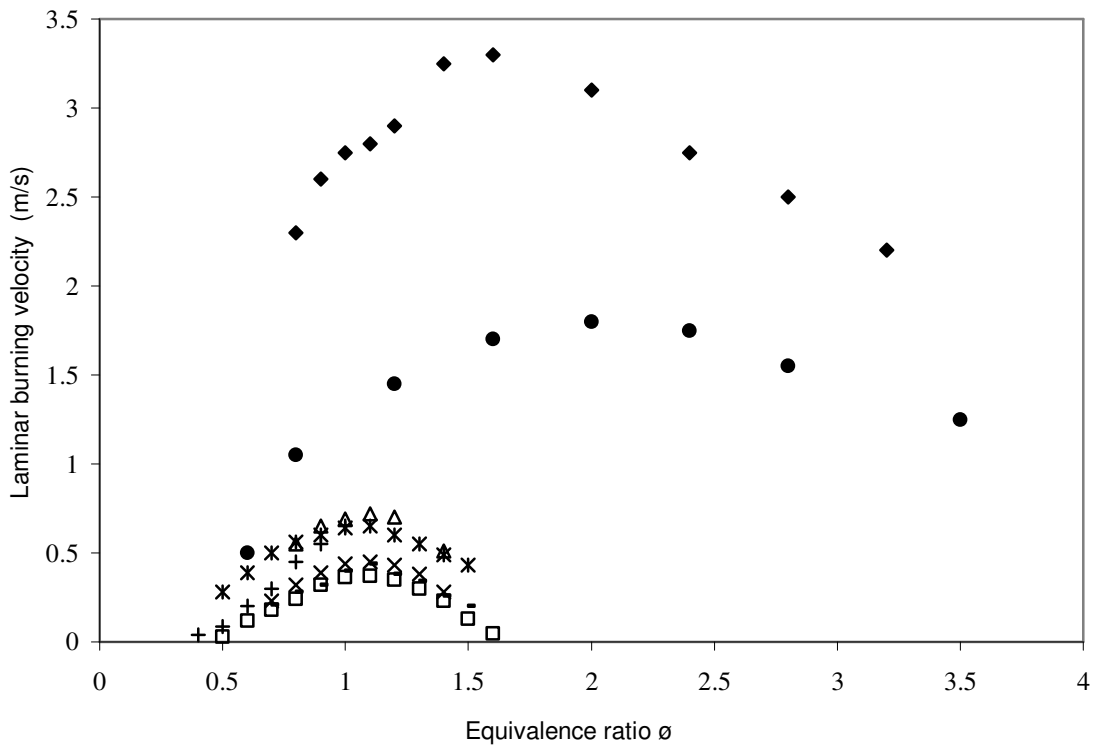


Figure 3: The laminar burning velocity of H<sub>2</sub>, H<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>, H<sub>2</sub>-C<sub>2</sub>H<sub>6</sub> and H<sub>2</sub>-CH<sub>4</sub> mixtures.

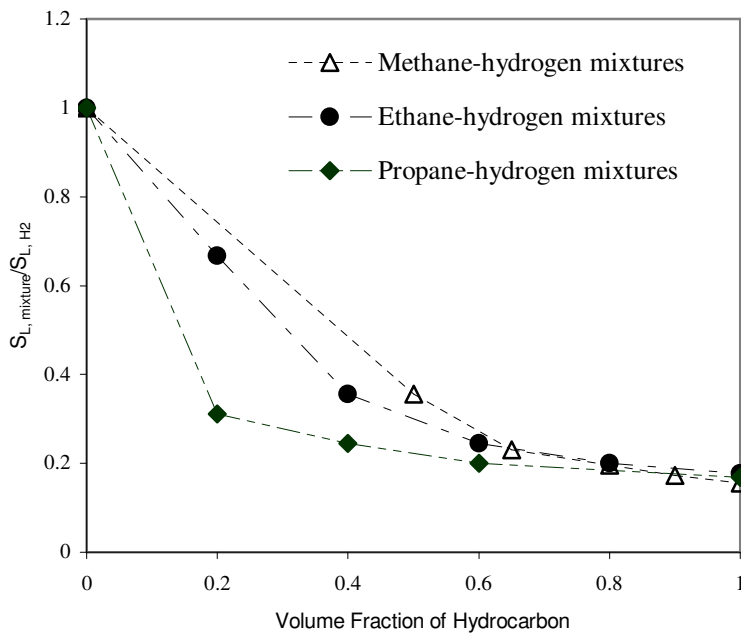


Figure 4: The ratio of maximum burning velocity to hydrogen maximum laminar burning velocity for H<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>, H<sub>2</sub>-C<sub>2</sub>H<sub>6</sub> and H<sub>2</sub>-CH<sub>4</sub> mixtures.

#### 4.0 ANALYSIS OF KINETIC MECHANISMS

At present, there is no established detailed or reduced kinetic pathway for hydrogen/hydrocarbon mixtures. In this paper, the analysis is based on comparing the kinetic mechanism established for pure hydrogen premixed flames and the kinetic mechanism for hydrocarbon fuels up to propane. A detailed kinetic mechanism by Warnatz [2, 4] for hydrogen and hydrocarbon fuels up to propane is listed in Table 1.

The full 8-species kinetic mechanism for premixed hydrogen flame is presented in the reactions 1 to 15 in the Table 1. For the kinetic mechanism of C<sub>3</sub>-chain, the dominant consumption path of C<sub>3</sub>H<sub>8</sub> is to form normal- and iso- C<sub>3</sub>H<sub>7</sub> radicals via reactions 77 & 78 with radical H, reaction 79 & 80 with O and reactions 81 & 82 with OH. Both n-C<sub>3</sub>H<sub>7</sub> and i-C<sub>3</sub>H<sub>7</sub> radicals decompose quickly to form C<sub>2</sub>H<sub>4</sub> and CH<sub>3</sub> via reaction 87 and with minor formation of C<sub>3</sub>H<sub>6</sub> via reaction 88 & 89. The remaining reaction paths produce subsequent consumes of C<sub>3</sub>, C<sub>2</sub> and C chains involve with attacks of free radicals H and OH detailed in the Table 1. Ethane (C<sub>2</sub>H<sub>6</sub>) combustion is initiated with H, OH and O radicals in reactions 44 to 46. The path way for Methane (CH<sub>4</sub>) is presented in reactions 18 to 40.

The analysis the reactions shows that the C<sub>3</sub>, C<sub>2</sub> and C chains use radicals H, OH and O to break the C-H bond and C-C bond and to decompose to lighter hydrocarbons during combustion. Comparing hydrogen flames and hydrocarbon flames, hydrogen flames have high concentration of H, OH and O radicals, which are responsible for the high burning velocity, in the contrary the hydrocarbon flames have low concentration of H, OH and O radicals.

When hydrogen is mixed with hydrocarbon, hydrogen has provided a pool of H, OH and O radicals. However the reaction pathway is dominated by hydrocarbon consumptions, the radicals are absorbed by the decomposition of carbon chains and therefore the flames actually exhibit the features of hydrocarbon flames unless very large proportion of hydrogen (over 50% hydrogen) is present. The demand for H, OH and O radicals increase with the carbon numbers, the heavier hydrocarbon such as C<sub>3</sub>H<sub>8</sub> would absorb much more radicals than the lighter hydrocarbon such as CH<sub>4</sub>. Therefore the improvement on burning velocity by hydrogen is less effective in the carbon heavier fuel due to the disappearance of the radicals. This results that the H<sub>2</sub>-CH<sub>4</sub> has slight higher burning velocity than H<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>. For the hydrogen rich syngas and H<sub>2</sub>-CO<sub>2</sub>, the reaction pathways are clearly dominated by hydrogen reactions and produce higher burning velocity than hydrogen/hydrocarbon.

Table 1: Warnatz (1985) [5] kinetic mechanisms for hydrocarbon combustion

No.	Reaction	A [cm,mol,s]	n	E kJ/mole
Mechanism of the oxidation of H <sub>2</sub> and CO				
H <sub>2</sub> -O <sub>2</sub> Chain propagation and branching reactions				
1	O <sub>2</sub> + H → OH + O	1.200E+17	-0.91	70.30
2	OH + O → O <sub>2</sub> + H	7.100E+15	-0.91	0.00
3	H <sub>2</sub> + O → OH + H	1.500E+07	2.00	31.60
4	OH + H → H <sub>2</sub> + O	6.700E+06	2.00	23.30
5	H <sub>2</sub> + OH → H <sub>2</sub> O + H	1.000E+08	1.60	13.80
6	H <sub>2</sub> O + H → H <sub>2</sub> + OH	4.600E+08	1.60	77.70
7	OH + OH → H <sub>2</sub> O + O	1.500E+09	1.14	0.00
8	H <sub>2</sub> O + O → OH	1.500E+10	1.14	72.20
Recombination reactions				
9	H + H + M' → H <sub>2</sub> + M'	1.800E+18	-1.00	0.00
10	OH + H + M' → H <sub>2</sub> O + M'	2.200E+22	-2.00	0.00

HO <sub>2</sub> Formation and Consumption				
11	$O_2 + H + M' \rightarrow HO_2 + M'$	2.000E+18	-0.80	0.00
12	$HO_2 + H \rightarrow OH + OH$	1.500E+14	0.00	4.20
13	$HO_2 + H \rightarrow H_2 + O_2$	2.500E+13	0.00	2.90
14	$HO_2 + O \rightarrow OH + O_2$	2.000E+13	0.00	0.00
15	$HO_2 + OH \rightarrow H_2O + O_2$	2.000E+13	0.00	0.00
CO Oxidation				
16	$CO + OH \rightarrow CO_2 + H$	4.400E+06	1.50	-3.10
17	$CO_2 + H \rightarrow CO + OH$	1.600E+14	0.00	110.00
Mechanism of the oxidation of C <sub>1</sub> /C <sub>2</sub> hydrocarbons				
Formation and consumption of CH <sub>4</sub>				
18	$CH_3 + H \rightarrow CH_4$	6.000E+16	-1.00	0.00
19	$CH_4 + H \rightarrow CH_3 + H_2$	2.200E+04	3.00	36.60
20	$CH_3 + H_2 \rightarrow CH_4 + H$	6.600E+02	3.00	32.40
21	$CH_4 + O \rightarrow CH_3 + OH$	1.200E+07	2.10	31.90
22	$CH_3 + OH \rightarrow CH_4 + O$	1.300E+05	2.10	19.60
23	$CH_4 + OH \rightarrow CH_3 + H_2O$	1.600E+06	2.10	10.30
24	$CH_3 + H_2O \rightarrow CH_4 + OH$	2.900E+05	2.10	70.30
CH <sub>3</sub> Consumption				
25	$CH_3 + O \rightarrow CH_2O + H$	7.000E+13	0.00	0.00
CH <sub>2</sub> O Consumption				
26	$CH_2O + H \rightarrow CHO + H_2$	2.500E+13	0.00	16.70
27	$CH_2O + O \rightarrow CHO + OH$	3.500E+13	0.00	14.70
28	$CH_2O + OH \rightarrow CHO + H_2O$	3.000E+13	0.00	5.00
CHO Consumption				
29	$CHO + H \rightarrow CO + H_2$	2.000E+14	0.00	0.00
30	$CHO + O \rightarrow CO + OH$	3.000E+13	0.00	0.00
31	$CHO + O \rightarrow CO_2 + H$	3.000E+13	0.00	0.00
32	$CHO + OH \rightarrow CO + H_2O$	5.000E+12	0.00	0.00
33	$CHO + O_2 \rightarrow CO + HO_2$	3.000E+12	0.00	0.00
34	$CHO + M' \rightarrow CO + H + M'$	7.100E+14	0.00	70.30
CH <sub>2</sub> Consumption				
35	$CH_2 + H \rightarrow CH + H_2$	4.000E+13	0.00	0.00
36	$CH_2 + O \rightarrow CO + H + H$	5.000E+13	0.00	0.00
37	$CH_2 + O_2 \rightarrow CO_2 + H + H$	1.300E+13	0.00	6.30
38	$CH_2 + CH_3 \rightarrow C_2H_4 + H$	4.000E+13	0.00	0.00
CH Consumption				
39	$CH + O \rightarrow CO + H$	4.000E+13	0.00	0.00
40	$CH + O_2 \rightarrow CO + OH$	2.000E+13	0.00	0.00
Formation of C <sub>2</sub> hydrocarbons by CH <sub>3</sub> recombination				
41	$CH_3 + CH_3 \rightarrow C_2H_6$	2.400E+14	-0.40	0.00
42	$CH_3 + CH_3 \rightarrow C_2H_5 + H$	8.000E+13	0.00	111.00
43	$CH_3 + CH_3 \rightarrow C_2H_4 + H$	1.000E+16	0.00	134.00
C <sub>2</sub> H <sub>6</sub> Consumption				

44	$C_2H_6 + H \rightarrow C_2H_5 + H_2$	5.400E+02	3.50	21.80
45	$C_2H_6 + O \rightarrow C_2H_5 + OH$	3.000E+07	2.00	21.40
46	$C_2H_6 + OH \rightarrow C_2H_5 + H_2O$	6.300E+06	2.00	2.70
47	$C_2H_5 + H \rightarrow CH_3 + CH_3$	3.000E+13	0.00	0.00
48	$C_2H_5 + H \rightarrow CH_3 + CH_3$	5.000E+13	0.00	0.00
49	$C_2H_5 + O_2 \rightarrow C_2H_4 + HO_2$	2.000E+13	0.00	20.90
50	$C_2H_5 \rightarrow CH_4 + H$	2.000E+13	0.00	166.00
C <sub>2</sub> H <sub>4</sub> Consumption				
51	$C_2H_4 + H \rightarrow C_2H_5$	1.000E+13	0.00	6.30
52	$C_2H_4 + O \rightarrow CHO + CH_3$	1.600E+09	1.20	3.10
53	$C_2H_4 + OH \rightarrow C_2H_3 + H_2O$	7.000E+13	0.00	12.60
54	$C_2H_4 + H \rightarrow C_2H_3 + H_2$	1.500E+14	0.00	42.70
C <sub>2</sub> H <sub>3</sub> Consumption				
55	$C_2H_3 + H \rightarrow C_2H_2 + H_2$	2.000E+13	0.00	0.00
56	$C_2H_3 + O_2 \rightarrow C_2H_2 + HO_2$	1.000E+12	0.00	0.00
57	$C_2H_3 \rightarrow C_2H_2 + H$	1.000E+15	0.00	178.00
C <sub>2</sub> H <sub>2</sub> Consumption				
58	$C_2H_2 + H \rightarrow C_2H_3$	5.500E+12	0.00	10.10
59	$C_2H_2 + O \rightarrow CH_2 + CO$	4.100E+08	1.50	7.10
60	$C_2H_2 + OH \rightarrow C_2HCO + H$	3.000E+12	0.00	4.60
CH <sub>3</sub> CHO Consumption				
61	$CH_3CHO + H \rightarrow CH_3 + CO + H$	4.000E+13	0.00	17.60
62	$CH_3CHO + O \rightarrow CH_3 + CO + OH$	5.000E+12	0.00	7.50
63	$CH_3CHO + OH \rightarrow CH_3 + CO + H_2O$	1.000E+13	0.00	0.00
CH <sub>2</sub> CO Consumption				
64	$CH_2CO + H \rightarrow CH_3 + CO$	7.000E+12	0.00	12.60
65	$CH_2CO + O \rightarrow CHO + CHO$	2.000E+13	0.00	9.60
66	$CH_2CO + OH \rightarrow CH_2 + CHO$	1.000E+13	0.00	0.00
67	$CH_2CO + M \rightarrow CH_2 + CO + M$	1.000E+16	0.00	248.00
CHCO Formation and consumption				
68	$C_2H_2 + OH \rightarrow CHCO + H$	4.300E+14	0.00	50.70
69	$CHCO + H \rightarrow CH_2 + CO$	3.000E+13	0.00	0.00
70	$CHCO + O \rightarrow CO + CO + H$	1.200E+12	0.00	0.00
C <sub>2</sub> H Formation and consumption				
71	$C_2H_2 + H \rightarrow C_2H + H_2$	1.500E+14	0.00	79.60
72	$C_2H_2 + OH \rightarrow C_2H + H_2O$	1.000E+13	0.00	29.30
73	$C_2H + O \rightarrow CO + CH$	1.000E+13	0.00	0.00
74	$C_2H + H_2 \rightarrow C_2H_2 + H$	3.500E+12	0.00	8.80
75	$C_2H + O_2 \rightarrow CO + CHO$	5.000E+13	0.00	6.30
Mechanism of the oxidation of C <sub>3</sub> hydrocarbons (C <sub>3</sub> H <sub>4</sub> chemistry excluded)				
C <sub>3</sub> H <sub>8</sub> Formation and consumption				
76	$C_2H_5 + CH_3 \rightarrow C_3H_8$	7.000E+12	0.00	0.00
77	$C_3H_8 + H \rightarrow n-C_3H_7 + H_2$	1.300E+14	0.00	40.60
78	$C_3H_8 + H \rightarrow i-C_3H_7 + H_2$	1.000E+14	0.00	34.90

79	$C_3H_8 + O \rightarrow n-C_3H_7 + OH$	3.000E+13	0.00	24.10
80	$C_3H_8 + O \rightarrow i-C_3H_7 + OH$	2.600E+13	0.00	18.7
81	$C_3H_8 + OH \rightarrow n-C_3H_7 + H_2O$	3.700E+12	0.00	6.90
82	$C_3H_8 + OH \rightarrow i-C_3H_7 + H_2O$	2.800E+12	0.00	3.60
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C <sub>3</sub> H <sub>7</sub> Consumption				
83	$n-C_3H_7 + H \rightarrow C_3H_8$	2.000E+13	0.00	0.00
84	$i-C_3H_7 + H \rightarrow C_3H_8$	2.000E+13	0.00	0.00
85	$n-C_3H_7 + O_2 \rightarrow C_3H_6 + HO_2$	1.000E+12	0.00	20.90
86	$i-C_3H_7 + O_2 \rightarrow C_3H_6 + HO_2$	1.000E+12	0.00	12.50
87	$n-C_3H_7 \rightarrow C_2H_4 + CH_3$	3.000E+14	0.00	138.00
88	$n-C_3H_7 \rightarrow C_3H_6 + H$	1.000E+14	0.00	156.10
89	$i-C_3H_7 \rightarrow C_3H_6 + H$	2.000E+14	0.00	161.90
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C <sub>3</sub> H <sub>6</sub> Consumption				
90	$n-C_3H_6 + H \rightarrow n-C_3H_7$	4.000E+12	0.00	11.00
91	$i-C_3H_6 + H \rightarrow i-C_3H_7$	4.000E+13	0.00	4.00
92	$C_3H_6 + O \rightarrow CH_3 + CH_3 + CO$	5.000E+12	0.00	1.90
93	$C_3H_6 + OH \rightarrow CH_3CHO + CH_3$	1.000E+13	0.00	0.00

## 5.0 CONCLUSIONS

- Comparisons of the stability of H<sub>2</sub>-CO<sub>2</sub>, H<sub>2</sub>-C<sub>3</sub>H<sub>8</sub> and H<sub>2</sub>-CH<sub>4</sub> flames shows that descending order of blow-out or blow-off velocity is H<sub>2</sub>-CH<sub>4</sub>, H<sub>2</sub>-O<sub>2</sub> and H<sub>2</sub>- C<sub>3</sub>H<sub>8</sub>. The lift-off and blow-out process of H<sub>2</sub>-C<sub>3</sub>H<sub>8</sub>, H<sub>2</sub>-CH<sub>4</sub> and H<sub>2</sub>-CO<sub>2</sub> jet flames was strongly influenced by the chemical kinetics. Analysis using the stability theory indicates that reactive order of the flames is H<sub>2</sub>-CH<sub>4</sub>, H<sub>2</sub>-O<sub>2</sub> and H<sub>2</sub>- C<sub>3</sub>H<sub>8</sub> flames.
- Comparing the magnitude of the burning velocity of pure C<sub>3</sub>H<sub>8</sub>, C<sub>2</sub>H<sub>6</sub> and CH<sub>4</sub> fuels and H<sub>2</sub>-CH<sub>4</sub>, H<sub>2</sub>-C<sub>2</sub>H<sub>6</sub> and H<sub>2</sub>- C<sub>3</sub>H<sub>8</sub> mixtures confirms that the reactive order for C<sub>3</sub>, C<sub>2</sub> and C<sub>1</sub> fuels seems reversed if hydrogen is added. This findings supports the conclusions made in the flame lift-off and blow-out stability study.
- The analysis on the kinetic pathways indicates that hydrocarbons act as a sink for the active radicals that are of importance in the combustion chemistry of H<sub>2</sub>. The hydrocarbon is the dominant element in determine the burning velocity of hydrogen/hydrocarbon mixtures. In H<sub>2</sub>-CO<sub>2</sub> mixture, hydrogen reactions remand as the main kinetic mechanism.
- Based on the kinetic mechanism analysis, it is possible to produce reduced kinetic mechanisms for hydrogen/hydrocarbon, which would be important for numerical simulations of the flame structure, propagation and hazard analysis.

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