

EXPLOSION BEHAVIOUR OF CO/H₂/O₂/N₂/CO₂ MIXTURES

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Abstract

In this paper, the explosion behavior of H₂/CO/O₂/N₂/CO₂ mixtures was analyzed. Experimental work was performed in order to quantify the effects of H₂/CO ratio, equivalence ratio, CO₂ content and oxygen-enrichment on maximum pressure and rate of pressure rise (the severity of explosion). All tests show the typical trends in closed combustion chamber. The effect of oxygen enrichment is dramatic with respect to equivalence ratio and H₂/CO ratio. The higher reactivity of hydrogen at rich conditions compensates the decrease of global reactivity for equivalence ratio greater than the stoichiometric value.

Introduction

The interest in oxy-fuel combustion is strongly increasing worldwide. Indeed, oxy-combustion is an important step towards zero-emission technologies because it reduces nitrogen concentration (hence NO_x emissions) and produces an exhausted gas stream which contains only carbon dioxide and water vapor (thus favoring CO₂ separation processes) [1]. However, this technology implies safety issues as both laminar burning velocity and flammability ranges are strongly increased by the use of oxygen.

The aim of the present study is the experimental and theoretical analysis of the combined effects of CO₂ and O₂ contents on the reactivity and explosion behavior of H₂/CO/O₂/N₂/CO₂ mixtures.

Experimental results

Experimental tests have been performed in an AISI 316 SS steel, cylindrical vessel (5 lt), wall thickness of 5 cm sketched in Figure 1.

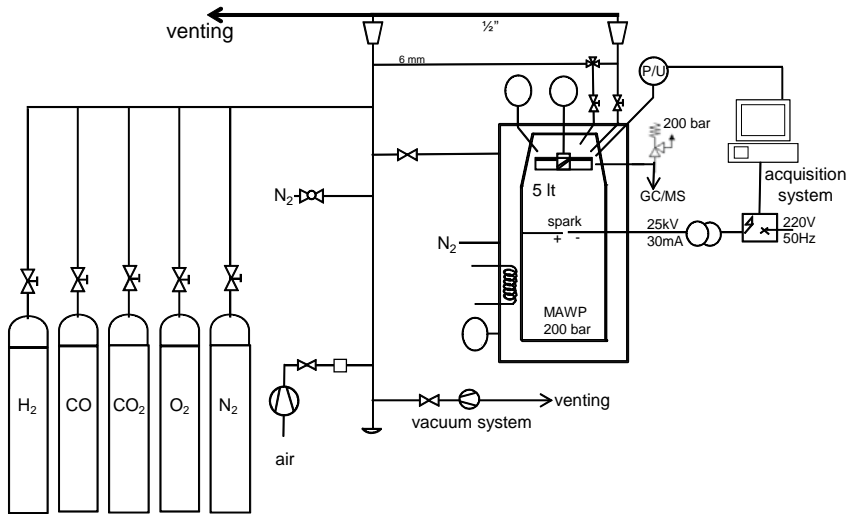


Figure 1. Experimental set-up adopted for this study.

The mixture composition was obtained by partial pressure method. Gases were premixed by mechanical stirring. Hence, they were allowed to settle for around 30 s and then ignited by electric spark (25 kV, 30 mA) positioned at the center of the vessel. Pressure histories were recorded by KULITE ETS-IA-375 (M) series transducers powered by chemical battery (12 VDC/7 Ah) in order to minimize any disturbance on the output supply. Data were recorded by National Instrument USB-6251 acquisition system (1.25 Msamples/sec). The initial pressure and temperature were namely 1 bar and 300 K. Further details on the equipment can be found elsewhere [2,3]. All tests have been repeated at least three times.

Table 1 reports the composition analyzed in this work.

Table 1. Compositions analyzed in this work: Y is the molar fraction.

Test 1: no CO₂. All other tests: 40% CO₂.

Test	ϕ	H ₂ /CO	E	YH ₂	YCO	YO ₂
1	1.00	1	0.21	0.148	0.148	0.148
2	1.00	1	0.21	0.089	0.089	0.089
3	1.00	1	0.60	0.164	0.164	0.164
4	1.00	2	0.21	0.118	0.059	0.089
5	1.00	2	0.60	0.218	0.109	0.164
6	1.75	1	0.21	0.127	0.127	0.073
7	1.75	1	0.60	0.203	0.203	0.116
8	1.75	2	0.21	0.169	0.085	0.073
9	1.75	2	0.60	0.271	0.135	0.116

In Table 1, the equivalence ratio ϕ and the oxygen-enrichment factor E are defined as:

$$\phi = \frac{\left(\frac{H_2 + CO}{O_2} \right)}{\left(\frac{H_2 + CO}{O_2} \right)_{st}} \quad (1)$$

$$E = \frac{O_2}{O_2 + N_2} \quad (2)$$

Results and Discussion

Table 2 reports the measured maximum pressure and the maximum rate of pressure rise calculated by analytically from the best fit 6th degree polynomial curve for the pressure history. The adiabatic pressure as calculated by GASEQ [4] is also shown, for the sake of validation.

Table 2. Maximum pressure and rate of pressure rise for the composition given in Table 1. The adiabatic pressures P_{ad} calculated by means of GASEQ code are also reported. Test 1: no CO₂. All other tests: 40% CO₂.

RUN	P_{ad} (GASEQ), bar	P_{max} , bar	$(dP/dt)_{max}$, bar s ⁻¹
1	7.88	6.31	553.92
2	5.22	4.15	15.15
3	6.92	5.67	210.15
4	5.15	4.08	19.16
5	6.89	6.16	696.04
6	4.54	3.29	9.5037
7	6.02	5.16	155.93
8	4.45	3.42	11.60
9	5.92	4.00	123.72

The maximum pressure calculated are, as expected, lower than theoretical due to non-adiabaticity of the combustion chamber, however confirming the thermodynamic trend. Also, the presence of 40% CO₂ decreases the severity of the explosion consistently.

From the data reported in Table 2, it is clear that the increase of H₂/CO ratio has negligible effects on rate of pressure rise when the air as oxidant (see Tests 2 – 4, 6-8, at different equivalence ratio). The increase of oxygen (E) affects largely the observed rate of pressure rise, by increasing its value up to one order of magnitude (Tests 2-3, 4-5, 6-7 and 8-9). The severity is indeed strongly dependent on the

oxygen content (in terms of rate of pressure rise, i.e. ability to mitigate).

The increase of the equivalence ratio ϕ is large, as expected, on the maximum pressure. However, on the contrary, the effects on the reactivity of the fuel mixtures follows apparently the opposite trend. Indeed, if comparing the rate of pressure rise (Tests 2-6, 3-7, 4-8, 5-9) it is clear that the higher reactivity of hydrogen at rich conditions compensates partially the decrease of reactivity on the total severity of the explosion, that according with findings by e.g. Lieuwen et al. [1].

Finally, Test 5 is clearly the more severe explosion as both the stoichiometry and oxygen enrichment are respected, even if CO₂ is present in the mixture.

Acknowledgments

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