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Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

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COMPUTED FLAMMABILITY LIMITS OF OPPOSED-JET $H_2/O_2/CO_2$ DIFFUSION FLAME AT LOW PRESSURE

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Hydrogen and oxygen are gases involved in the proposed in-situ resource utilization (ISRU) scheme in the exploration of Mars. Hydrogen is not only a feedstock of methane production in the proposed Mars mission but also a propellant candidate in many propulsive systems. On the other hand, Carbon dioxide has been used as a fire extinguishment agent and is the main atmospheric component on Mars. Although many of the characteristics of hydrogen premixed or non-premixed flames are well known, their combustion behavior in the unique environments on Mars is beyond the current database. The unusual conditions include reduced gravity, very low pressure (about 0.01 earth atmospheric pressure) and CO_2 atmosphere (95.6%). To be able to determine the flammability of H_2/O_2 flame under this very low pressure condition as a function of the percentage of CO2 dilution has practical implication to fire fighting strategy for Mars operations. One notices that because of the scarcity of water on Mars, depressurization and the use of CO2 as an extinguishment agent are few of the options readily available.

In this work, a detailed numerical calculation of opposed-jet hydrogen and oxygen diffusion flames with varying amounts of CO_2 as diluent is carried out in this work. The numerical analysis utilizes the capability of the OPPDIF program to handle detailed chemical kinetics and transport. A narrow-band radiation model is coupled with this code in order to predict the extinction limits with improved accuracy. The flammability boundary of $H_2/O_2/CO_2$ system at a total pressure of 1.013 kPa is constructed in terms of stretch rate and the percentage of CO_2 dilution. Both the cases with and without the consideration of radiation are presented. Fig. 1 shows that the extinction limits could not be computed accurately without the consideration of radiation. At low stretch rate, the model without radiation actually produces the wrong trend. With radiation two branches of extinction, quenching and blow off, are obtained. At high stretch the flame blows off because of inadequate gas residence time and at low stretch the flame quenches due to the radiative heat loss. The merging point of these two branches defines a fundamental limit on CO2 dilution (64%) above which the system is not flammable at any stretch rate. Besides, the most flammable stretch rate is between 5 – 10 s^{-1}, a rather low value by ordinary standard.

The above calculation shows that at Martian pressure, hydrogen and oxygen can combust as a diffusion flame albeit in a narrower range of stretch rates in comparison with that in normal earth pressure. If such a flame occurs in a confinement, depressurization to Martian atmosphere alone may not be adequate to extinguish the fire and additional application of carbon dioxide will be required. The computed maximum flame temperature with several levels of CO2 dilution is shown in Fig. 2. As expected, more dilution decreases the flame temperature and the flammable range. It should be pointed out ,however, that the fire suppression function of CO2 comes from the combination of thermal, chemical and radiative effects. With a detailed model such as the one we have, individual contribution can be sorted out. This application to the proposed Martian operation is just an example.

Acknowledgement
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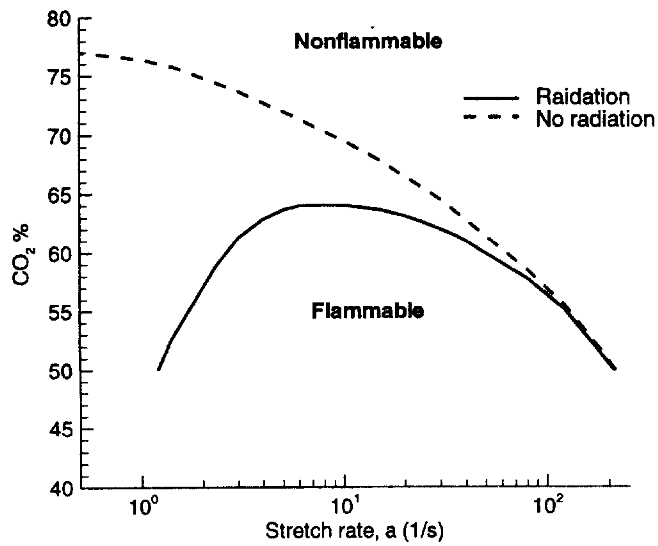

Figure 1. Flammability boundary of $H_2/O_2/CO_2$ opposed-jet diffusion flame with and without consideration of flame radiation. Total pressure, 1.013 kpa , ambient temperature , 300 K.

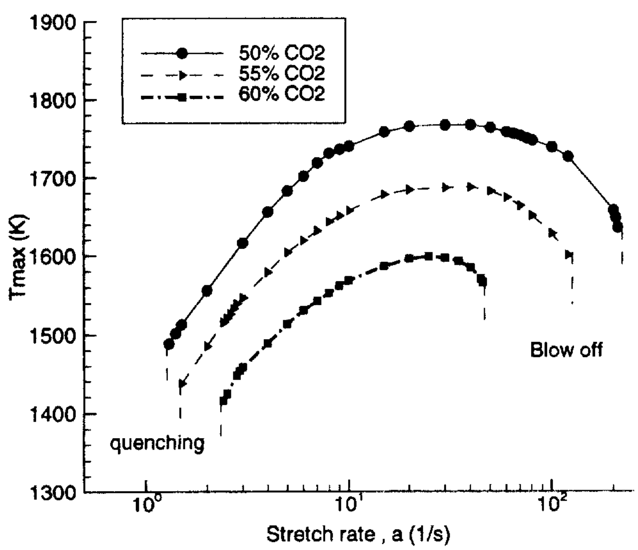

Figure 2. The maximum flame temperature as a function of stretch rate at different CO_2 dilution levels.