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The flame response in realistic situations is governed by the detailed kinetics of chemical reactions, the diffusion of heat and mass, and the aerodynamic processes of stretching, turbulence, and large-scale flow nonuniformity. During the reporting period good progress was made in the areas of high pressure flame propagation, soot formation in diffusion flames, and analytical modeling of the kinetic and thermal effects on the structure of diffusion flames.

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ANNUAL REPORT

(March 1, 1986 to February 28, 1987)

AERODYNAMIC AND KINETIC PROCESSES IN FLAMES

(AFOSR 85-0147)

For Review by

Dr. Julian M. Tishkoff
Air Force Office of Scientific Research
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Submitted by
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SUMMARY

The flame response in realistic situations is governed by the detailed kinetics of chemical reactions, the diffusion of heat and mass, and the aerodynamic processes of stretching, turbulence, and large-scale flow nonuniformity. During the reporting period good progress was made in the areas of high pressure flame propagation, soot formation in diffusion flames, and analytical modeling of the kinetic and thermal effects on the structure of diffusion flames.

PUBLICATIONS

1. "Experimental and numerical determination of laminar flame speeds of hydrocarbon/air mixtures under elevated pressures," by F. Egolfopoulos, C. K. Law, and P. Cho, 1986 Eastern Section/Combustion Institute Meeting. Manuscript under revision for journal publication.

2. "Temperature and concentration effects of inert addition on soot formation in a counterflow diffusion flame," by R. L. Axelbaum, W. L. Flower, and C. K. Law, 1987 Western States Section/Combustion Institute Meeting. Manuscript under revision for journal publication.

3. "Theory of kinetic and thermal extinction in diffusion flames," by M. Birkan and C. K. Law, 1987 Western States Section/Combustion Institute Meeting. Manuscript under revision for journal publication.

RESEARCH PERSONNEL

C. K. Law, Principal Investigator

M. Birkan, Research Associate

P. Cho, Research Associate

R. L. Axelbaum, Ph. D. Student

F. Egolfopoulos, Ph. D. Student

RESEARCH PROGRESS

1. Flame Structure and Propagation under Elevated Pressures

In this phase of the investigation, we have accurately determined the laminar flame speeds of methane/air and propane/air mixtures over their entire ranges of flammability and over the pressure range of 0.25 atm to 3 atm. The experimental flame speeds of lean methane/air mixtures are then compared with those calculated with the Sandia kinetic/flame code; only lean methane/air results are compared because there still exists considerable uncertainty regarding the C_2 mechanism. Comparison between results from these two independent determinations show excellent agreement, to within 1 to 2 cm/sec which is within the experimental accuracy. Such an agreement is significant because previous numerical/experimental results can differ from 10 to 20 cm/sec, and because the present comparison covers extensive ranges in concentrations and pressures and thereby exerts severe constraints on the possibility of "chance agreement." This work is reported in Publication No. 1.

2. Soot Formation in Diffusion Flames

Our work on soot formation addresses the issue of the effect of temperature on soot formation in diffusion flames. An existing school of thought has emphasized that temperature has the dominant influence on soot formation. Support of this concept has come from experiments in which the flame temperature is lowered by diluting the fuel stream with inerts and observing the corresponding reduction in soot. The complication with this technique is that it changes two variables at the same time, namely the flame temperature and the fuel concentration, and it has not been independently demonstrated that fuel dilution is unimportant. In the present investigation,

conducted in collaboration with Dr. W. L. Flower of Sandia, we have isolated the effect of fuel dilution by diluting the fuel stream with nitrogen while holding the maximum flame temperature _fixed_ by substituting like quantities of nitrogen in the _oxidizer stream_ by argon. Note that nitrogen and argon have different specific heats but very similar diffusivities. The results demonstrate conclusively that fuel dilution has a significant influence on soot formation, and therefore temperature is not the only dominant factor as previously believed. This work is reported in Publication No. 2.

3. Kinetic and Thermal Structure of Diffusion Flames

We have analyzed the structure of a diffusion flame supported by a representative branching-termination reaction scheme

$$F + R_1 \rightarrow 2R_2$$
$$O + R_2 \rightarrow 2R_1$$
$$R_1 + R_2 + M \rightarrow 2P + M$$
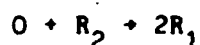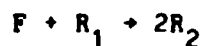
where R_1 and R_2 are regenerated radicals. The analysis yields three types of flame behavior, depending on the efficiency of the recombination reaction. Of particular interest is the fast recombination regime in which branching and recombination take place in the same, thin reaction zone. An explicit extinction criterion has been derived which respectively specialize to a kinetic extinction limit and a thermal extinction limit; in the latter case we recover Linan's extinction criterion. This work is reported in Publication No. 3.

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