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RESEARCH MEMORANDUM

MEASUREMENT OF UNIFORM FLAME MOVEMENT IN CARBON MONOXIDE -

AIR MIXTURES CONTAINING EITHER ADDED D_2O OR H_2O

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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MEASUREMENT OF UNIFORM FLAME MOVEMENT IN CARBON MONOXIDE - AIR

MIXTURES CONTAINING EITHER ADDED D_2O OR H_2O

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SUMMARY

Relative velocities were measured in a glass tube for the
flame in a carbon monoxide (CO) - air mixture containing either
added D_2O or H_2O. Differences in temperature, in flame-front area,
and in movement of the preflame gas occur between the two flames.
Because these differences were not measured in this investigation,
only qualitative comparisons can be made between the flame-velocity
measurements. Throughout the range of CO - air composition, the
flame containing added H_2O had a faster speed than the flame con-
taining D_2O. The flame-speed increase on addition of increasing
amounts of H_2O to the CO - air mixture was greater than the increase
produced by addition of increasing amounts of D_2O. An increase in
the temperature of the preflame gas increased the speed of the flame
that contains H_2O more than it increased the speed of the flame that
contains D_2O. A quantitative determination of the relative flame
velocities of CO - air mixtures containing either added H_2O or
D_2O was obtained by Bunsen cone measurement.

INTRODUCTION

Some investigators (reference 1) have ascribed the flame
velocity of a gaseous mixture to the rate of heat transfer from
the flame front to the unburned gas. Recently the suggestion
has been made (reference 2) that the diffusion of active radicals
from the flame front may control the flame velocity. It has been
postulated that active radicals diffuse from the flame zone into
the unburned mixture and there initiate combustion processes (for
example, reference 2). The rate of propagation has been related
to the hydrogen-atom concentration in the flame zone. The possible
effect of hydrogen atoms in propagating combustion outweighs the
effect of other active radicals because the hydrogen atom diffuses
many times faster than any other radical present in the flame.

If flame velocity could be measured in systems that differ in the rates of active radical diffusion, the effect of radical diffusion on flame velocity could be evaluated. This condition may be approximated by the use of certain isotopic materials, such as deuterium and hydrogen, that magnify changes in diffusion and minimize changes in thermal properties.

In this preliminary research, which was conducted at the NACA Lewis laboratory, relative flame velocities were measured for carbon monoxide (CO) - air mixtures that contained either added heavy water (D_2O) or light water (H_2O). This report presents the measurements of flame speed that have been completed to date. These two systems differ chiefly in the diffusion coefficient of active radicals. The deuterium atom differs from the hydrogen atom in having: (1) a much smaller diffusion coefficient; (2) a lower thermal equilibrium concentration; and (3) a possible lower rate of reaction with the unburned carbon monoxide - air mixture. If active radical diffusion influences flame velocity, the velocity of the flame that contains hydrogen atoms should be greater than the velocity of the flame that contains deuterium atoms because the diffusion of hydrogen atoms from the reaction zone into the unburned gas is significantly greater than the diffusion of deuterium atoms.

The use of D_2O was approved by the U.S. Atomic Energy Commission.

EXPERIMENTAL

The flame tube used in part of these measurements of flame velocity is diagrammatically shown in figure 1. The 25-millimeter inside-diameter pyrex tube (100 cm long) was fitted with a 4-millimeter orifice in one end. Relative rates of flame propagation were measured with this apparatus. The linear rate of flame propagation was determined by measuring the time required for the flame to move between the two pairs of tungsten electrodes.

The prepared mixture of CO, air, and water vapor was admitted to the evacuated tube, both ends were opened, and the gas was ignited by application of a flame to the end opposite the orifice. Photographs taken at 64 frames per second showed that the flame front area was constant and that the flame motion was uniform. The flame tube could be replaced with an identical tube that was externally wound with Nichrome wire to permit preheating of the gas.

Relative measurements of flame velocity were also made with a Bunsen technique. Shadowgraphs were taken of a projected Bunsen cone·that was burning the desired mixture of CO, air, and water vapor. The area of the flame front was determined by measurement of the cone photograph.

The CO used in this investigation was produced by the reaction of anhydrous formic acid and concentrated sulfuric acid. Analysis showed the carbon monoxide to be at least 99.9 percent pure. The stated purity of 99.8 percent for the D_2O was confirmed by density and refractive-index measurements. The air used in these measurements was dried with anhydrous magnesium perchlorate.

RESULTS AND DISCUSSION

The flame-tube measurements are only qualitative comparisons because: (1) The relative areas of the flames were not measured; (2) the pressure and the movement of the preflame gases were not measured for the different mixtures; and (3) the effect of the tube wall on the temperature and free radical concentration in the flames was not determined.

The variation of uniform flame movement with the change in CO content is shown in figure 2. In these experiments, 1 percent by volume of water vapor was added to the CO - air mixture and therefore the ratio of water vapor to CO decreases as the CO concentration increases. With added H_2O, CO has a faster uniform movement of flame than CO with an equal mole fraction of added D_2O.

Measurements were also made for a 42-percent CO - 58-percent air mixture to which had been added increasing amounts of either H_2O or D_2O. The results of these measurements are plotted in figure 3(a). The change in uniform flame movement with a change in concentration of added water is less for the flame that contains D_2O than for the flame that contains H_2O.

Measurements were made for several temperatures of the preflame gas on a 42-percent CO - 58-percent air mixture that contained 1 percent of added water vapor. The results are shown in figure 3(b). An increase in temperature increases the speed of the flame that contains H_2O more than it increases the speed of the flame that contains D_2O.

Quantitative determinations of relative flame velocity were secured with the Bunsen shadowgraph technique. The velocities of a 42-percent CO - 58-percent air mixture with 1 percent of added water were as follows:

Flame with added D_2O, cm sec^{-1} 32.9

Flame with added H_2O, cm sec^{-1} 39.5

Although the diffusion theory predicts the trends that are reported herein, no conclusions can be drawn as to the application of the thermal or diffusion theories until an analysis has been completed. Continued investigation should determine the effect of free radical diffusion on flame speed.

SUMMARY OF RESULTS

Measurements of the flame speed of carbon monoxide (CO) - air mixtures with added heavy water (D_2O) and light water (H_2O) gave the following results:

1. Throughout the range of CO - air composition, the flame that contains H_2O had a faster speed than the flame that contained an equivalent amount of D_2O.

2. The flame speed increase upon addition of increasing amounts of H_2O to the CO - air mixture was greater than the increase on addition of increasing amounts of D_2O.

3. An increase in temperature of the preflame gas increased the velocity of uniform movement of the H_2O flame more than it increased the velocity of the flame that contained D_2O.

4. A quantitative determination of the relative flame velocities of CO - air mixtures that contained either added H_2O or D_2O was obtained by Bunsen cone measurement.

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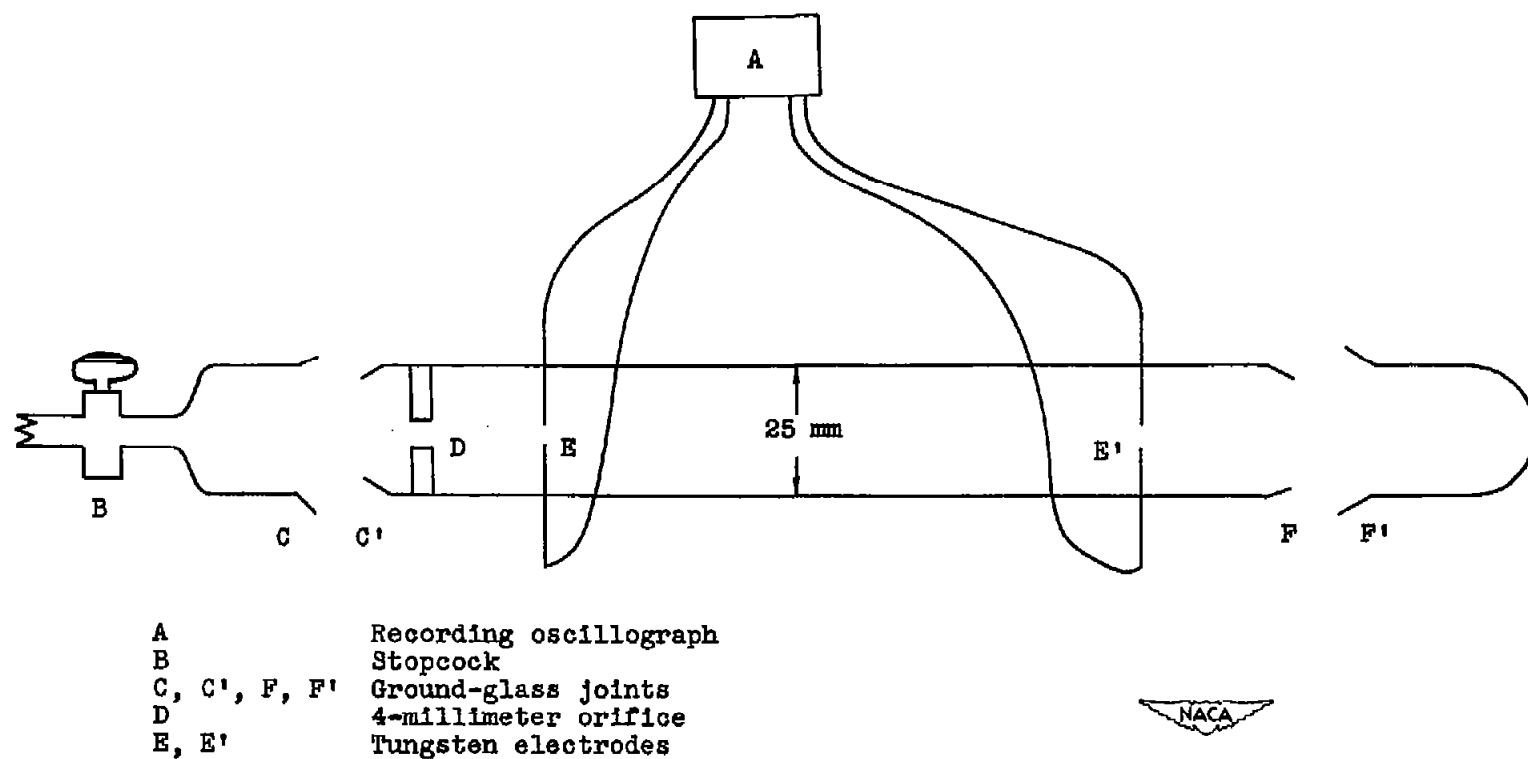   vol. 15, no. 7, July 1947, pp. 431-433.

A	Recording oscillograph
B	Stopcock
C, C', F, F'	Ground-glass joints
D	4-millimeter orifice
E, E'	Tungsten electrodes

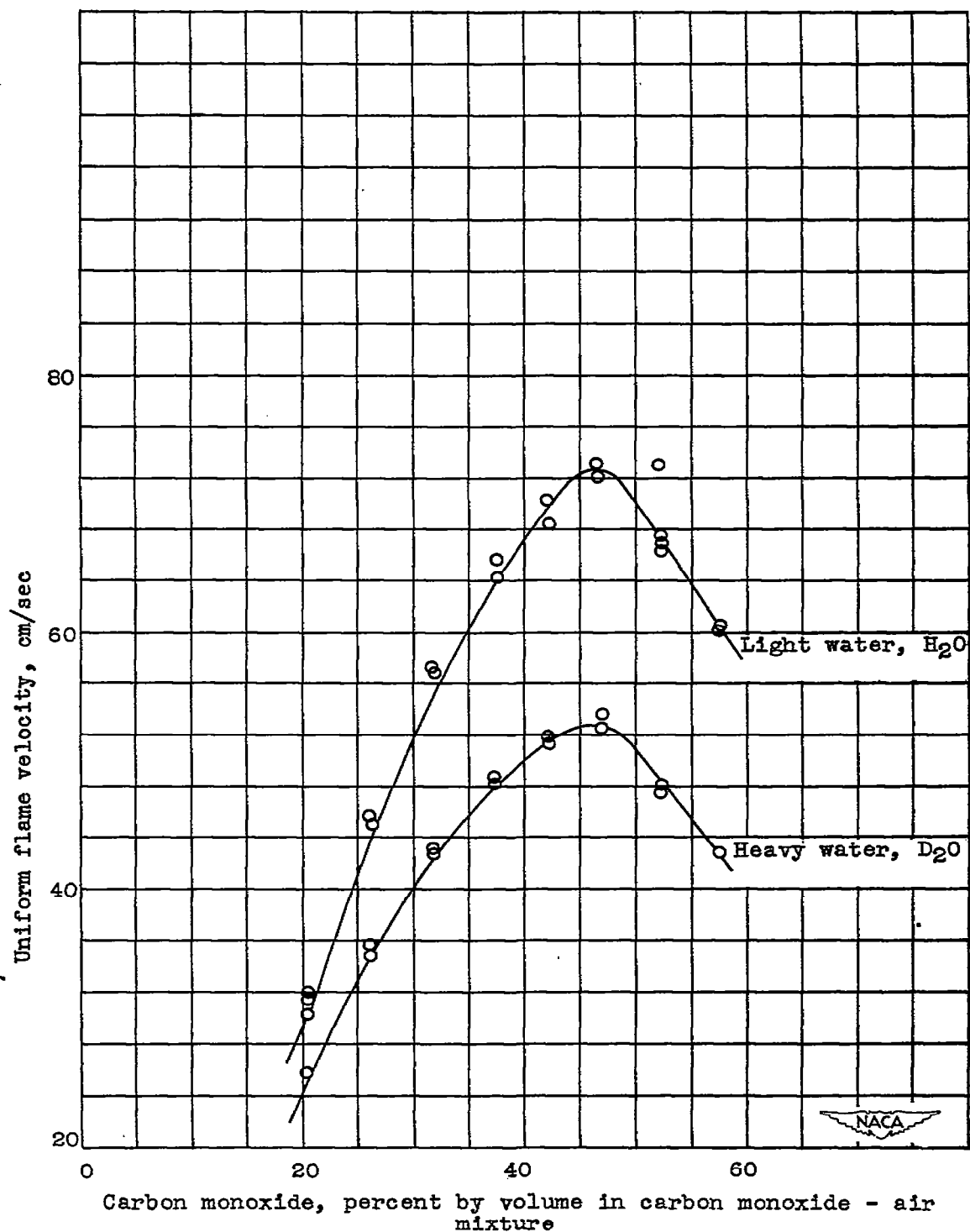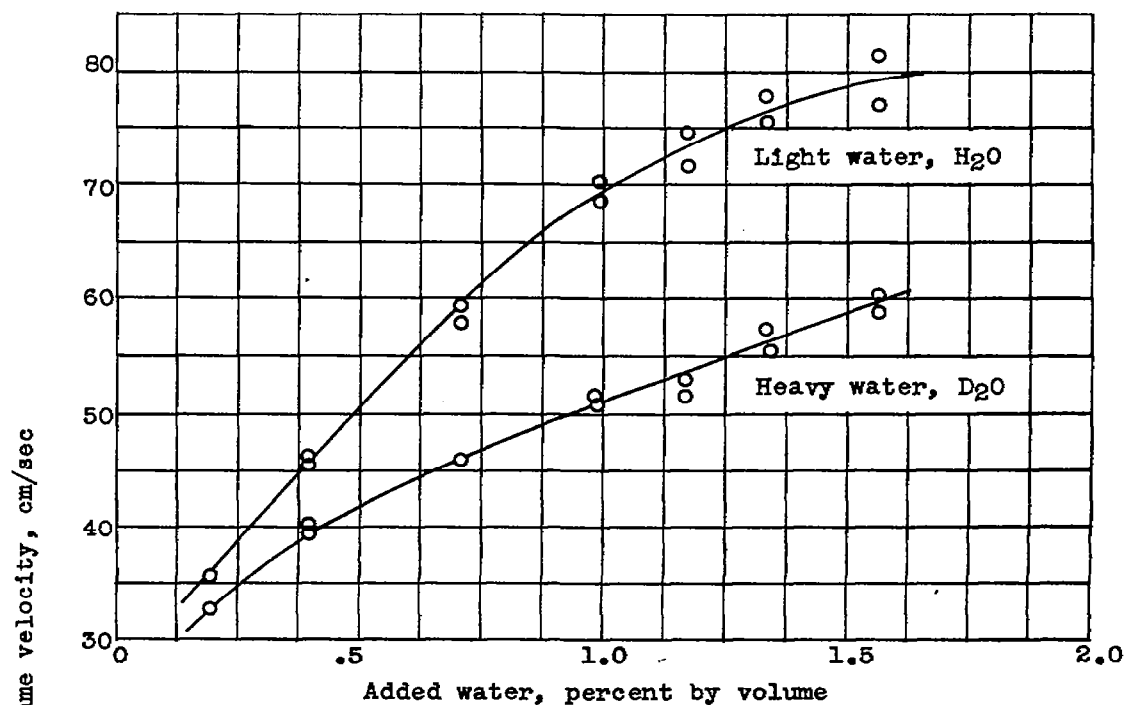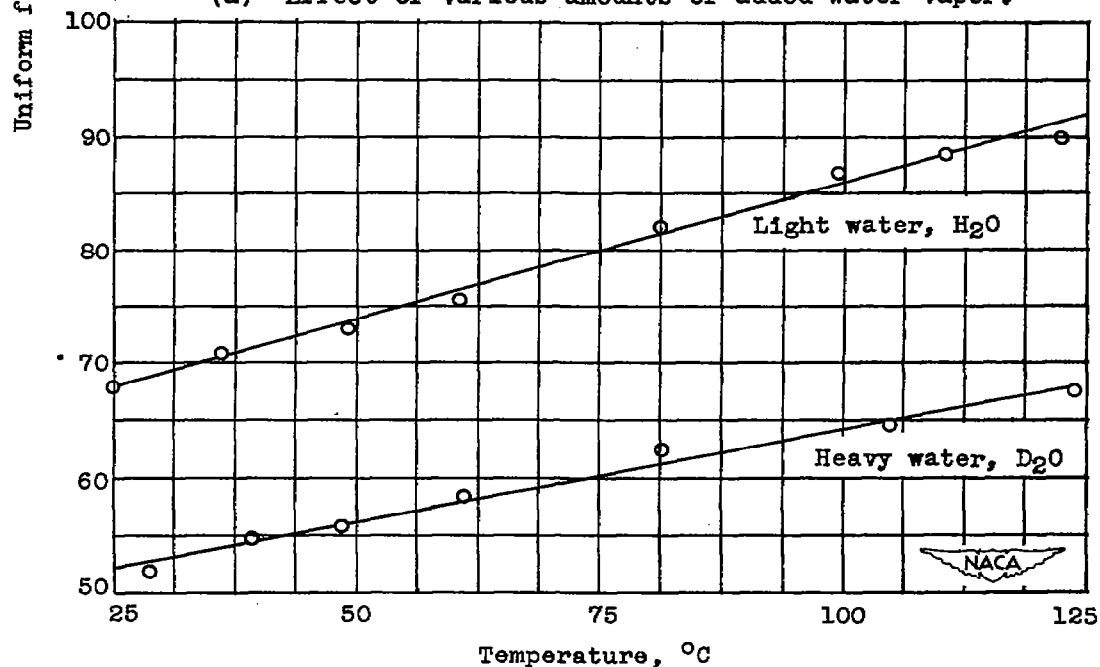Figure 1. - Glass flame tube used in making flame-speed measurements.

Figure 2. - Flame velocity of carbon monoxide - air mixtures with
1 percent of added water vapor.

(a) Effect of various amounts of added water vapor.

(b) Effect of various preflame temperatures and 1 percent of added water vapor.

Figure 3. - Flame velocity of 42 percent carbon monoxide - 58 percent air mixture.