NISTIR 6588

FIFTEENTH MEETING OF THE UJNR PANEL ON FIRE RESEARCH AND SAFETY MARCH 1-7, 2000

VOLUME 1

Sheilda L. Bryner, Editor

1901-2001
NIST CENTENNIAL

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Fire Extinguishing Effect of Water Vapor

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Abstract

Flame extinguishing effect of water vapor for premixed flame was investigated using tubular flame burner method. Extinction limits for methane-air-water vapor mixture were estimated by calculating adiabatic flame temperature as the effect of water vapor was the same as inert gases. The estimated flame extinguishing effect of water vapor was more than that of nitrogen and less than carbon dioxide. The extinction limit was compared with observed extinction limit for the mixture with added 10 percent of water vapor and inert gas. The observed data showed that the estimated effect of water vapor was slightly underestimated.

1. Introduction

After prohibition of the production of the halon fire-extinguishing agents, several types of new agents have been developed to date as halon replacements, and the current agents are also noticed as candidate [1-2]. Water is one of the considerable options for halon replacements, and it has been investigated and applied to fire-extinguishing systems as sprinkler, water mist and so on. Some of fire extinguishing effect of water based systems are considered as high latent heat of evaporation. After evaporation, water will act as water vapor, hence it need to investigate the fire extinguishing efficiency of water vapor. In ambient condition, it was investigated that the fire extinguishing efficiency of water vapor for diffusion flame and premixed flame using cup burner method and tubular flame burner method, respectively [3-4], however water vapor can be mixed only 3 percent into ambient air because of saturated vapor pressure of water is only 3 kPa under 25 °C and atmospheric pressure.

In this study, estimation of extinction limit of methane-air mixture containing water vapor was carried out by calculation of adiabatic flame temperature at the extinction limit measured by the tubular flame burner method. To confirm the estimated fire extinguishing efficiency of water vapor, the measurements of extinction limits of methane-air mixture added with water vapor under elevated temperature were performed using tubular flame burner method.

2. Experimental

A tubular flame burner system [5-7] was used for measurement of the extinction limits. Figure 1 is a schematic diagram of the apparatus. The system consists of two parts. One is the tubular flame burner and the other is a gas mixture supply unit. The tubular flame burner consists of a porous bronze cylinder. The dimensions of the burner are 30 mm in inner diameter, 80 mm in length, 5 mm in thickness, and 5 μm in porosity. To prevent the burner heating by the flame, it was equipped with water-cooled ends of 25 mm in length, and nitrogen injection parts of 25 mm in length at both sides as shown in Fig. 1.

Methane with purity of more than 99.9 percent by volume was used as fuel. Dry air is supplied from an air compressor equipped with dryer. Carbon dioxide (CO_2) and nitrogen (N_2) are used as agent, and their purity were more than 99 percent by volume. Water vapor was generated by evaporation of commercial distilled water through high temperature heater. The flow rate of water vapor was calculated from water weight supplied to the heater. The flow rates of gases were adjusted freely by the precision-type mass flow controllers, then they were mixed. Temperature of mixture was kept above 70 °C from heater to burner.

The mass flow controllers calibrated by wet gas meters, and the maximum relative errors of the flow rate are estimated within plus or minus 1 percent. It is expected that the extinction limit concentrations measured by this system include an experimental error of less than 3 percent.

Since a set-up angle of the burner and injection velocity of the gas mixture affect the extinction limits, such effects were investigated to decide the experimental conditions. Here, the injection velocity stands for average flow velocity at the porous cylinder surface of the burner, calculated by dividing the mixture flow rate by the area of the surface. To obtain much wider extinction limits in this burner, the set-up angle of the burner and the injection velocity of mixture from burner surface were chosen as horizontal and 50 mm/s, respectively [6].

3. Estimation of extinction limit of water vapor mixture by calculation of adiabatic flame temperature at extinction

It was reported that the adiabatic flame temperature calculated for fuel-air-inert gas mixture at the extinction limits was the same to the temperature for other inert gas mixture in case of that the equivalence ratio of fuel to oxygen was constant [8], and the fire extinguishing effect of water vapor was almost the same as the effect of inert gases [9]. Here the extinction limit of the mixture with added water vapor was estimated by calculating the adiabatic flame temperature of the mixture at extinction.

The adiabatic flame temperatures were calculated for the methane-air-agent mixtures at the condition of the extinction limits. A previously developed code was used for the calculation [10]. The calculations were carried out taking dissociation fully into account. The calculation of mixture composition containing water vapor was continued until the temperature difference between water vapor mixture and the mixture with added nitrogen or carbon dioxide at the same equivalence ratio was reduced within 5 K.

4. Results and Discussions

4.1 Mixture temperature and extinction limit of methane-air-carbon dioxide mixture

Temperature effect of mixture for flammability limit is discussed in following equations [11],

$$L_t/L_{25}=1-7.21\times10^{-4}(t-25) \qquad (1)$$

$$U_t/U_{25}=1+7.21\times10^{-4}(t-25) \qquad (2)$$

L_{25} and U_{25} are lower and upper flammability limits of mixture temperature at 25 °C, respectively. L_t and U_t are also lower and upper limits at t °C, respectively. In case of mixture temperature at 70 °C, answers of equations (1) and (2) are,

$$L_t/L_{25}=0.97$$

and

$$U_t/U_{25}=1.03$$

It shows that lower and upper flammability limits are both expanded to 3 percent relatively since the temperature of mixture is elevated until 70 °C. These expansion of flammability limits are the same degree as the experimental error of this burner system, therefore there expects small difference on flammability limits between under 25 °C and 70 °C.

To verify above expectation, the extinction limits were measured for 70 °C of methane-air-carbon dioxide mixture. Result is shown in Fig. 2. The ordinate represents agent mixture concentration and the abscissa shows fuel concentration. There are no difference between the extinction limits at 25 °C and 70 °C.

4.2 Estimated extinction limit of methane-air mixture containing water vapor

Through the calculation of the adiabatic flame temperature for methane-air mixture with added agent, the flammable region of methane-air-water vapor mixture was obtained as shown in Fig. 3. The peak concentration of water vapor was 35.8 percent by volume. The peak concentration of carbon dioxide and nitrogen were 29.6 and 41.7 percent by volume, then in order for high efficiency, the agents were lined up as carbon dioxide, water vapor, and nitrogen.

4.3 Extinction limits of methane-air mixtures with added water vapor and inert gas

To investigate fire extinguishing effect of water vapor, the extinction limits of methane-air mixture with added agent were measured under 70 °C. The agents were carbon dioxide-water vapor mixture and nitrogen-water vapor mixture. Each methane-air-agent mixture contains 10 % of water vapor except upper and lower limits without agent. Figure 4(a) shows the measured and the calculated result for carbon dioxide-water vapor mixture. To calculate the extinction limits of mixture containing 10 % of water vapor, following equation was used [8],

$$\frac{1}{C} = \sum_{j=1}^{n} \frac{Xj}{Cj} \qquad (3)$$

Here, C is the concentration at extinction limit of inert gas-water vapor mixture, Xj is mole fraction of j th component in the mixed agent, and Cj is the concentration of j th component as the pure agent under the condition of the constant equivalence ratio. As compared with both limits in Fig. 4(a), the calculated results were larger than the measured extinction limits. The peak concentrations of the measured and the calculated were 28.3 percent and 30.8 percent, respectively.

As shown in Fig. 4(b), the measured result for nitrogen with 10 % water vapor was similar to the calculated for the fire extinguishing efficiency. The peak concentrations of the measured and the calculated were 38.5 percent and 39.7 percent, respectively. They show that the fire extinguishing efficiency of water vapor estimated by calculation for the adiabatic flame temperature was underestimated.

5. Conclusion

The estimated flame extinguishing effect of water vapor was obtained as provisional index through the calculation, and was more than the effect of nitrogen and less than carbon dioxide. The extinction limit was compared with observed extinction limit for the mixture with added 10 percent of water vapor and inert gas. The observed data showed that the estimated effect of water vapor was slightly underestimated.

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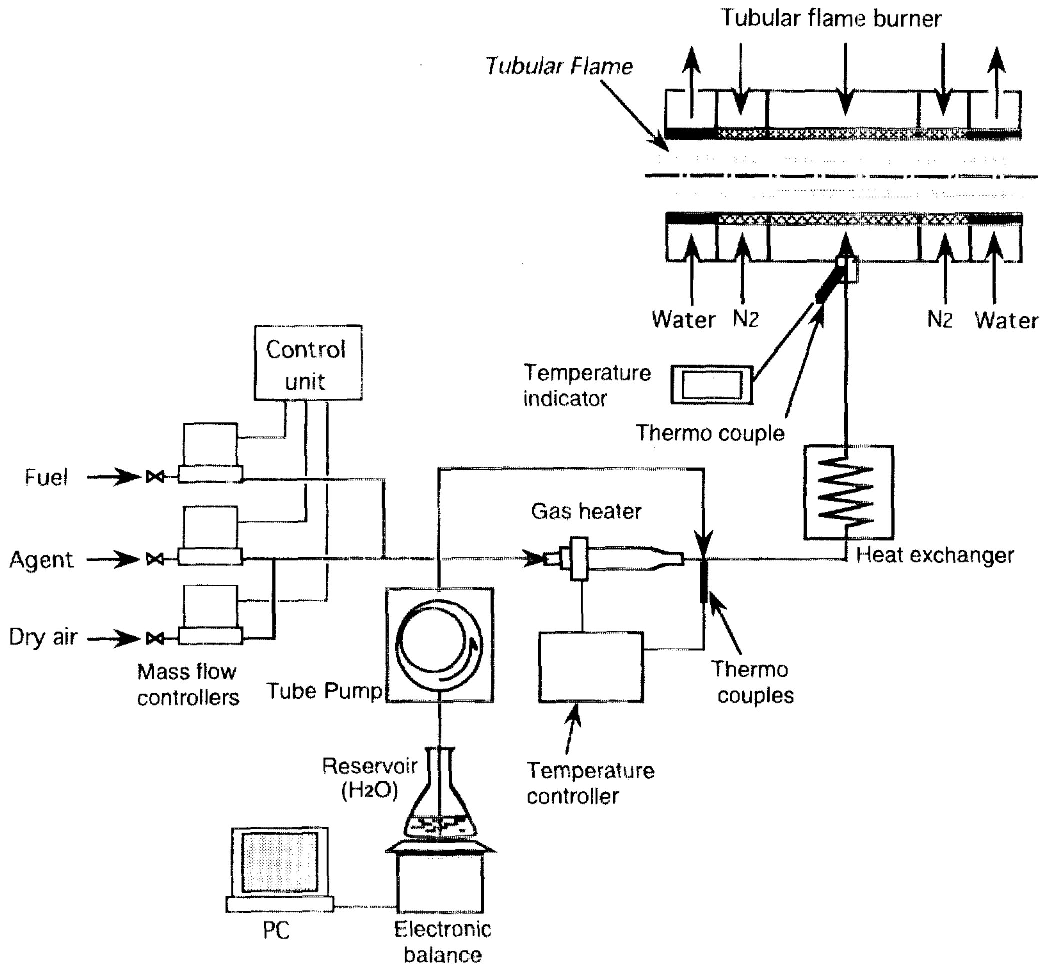


Fig. 1 Experimental apparatus

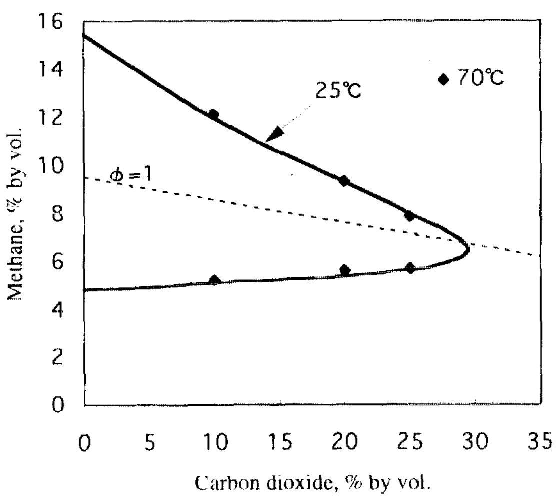


Fig. 2 Extinction limits of methane-air-carbon dioxide mixture under 25℃ and 70℃

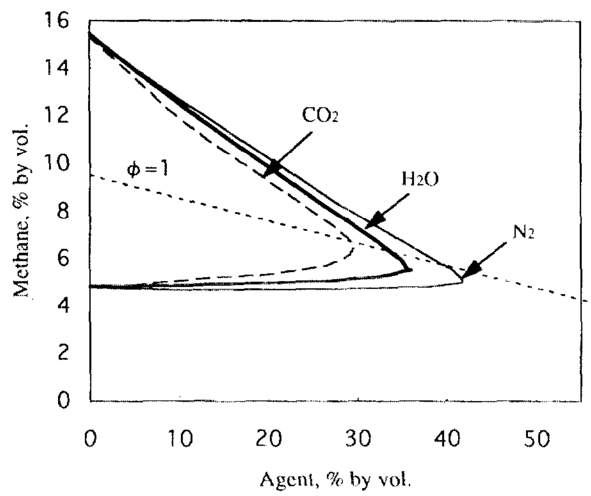
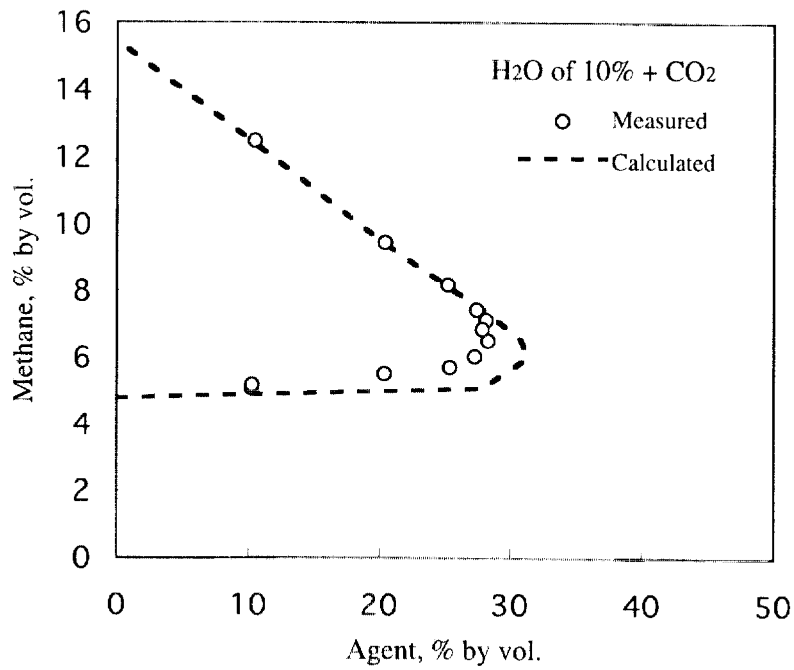
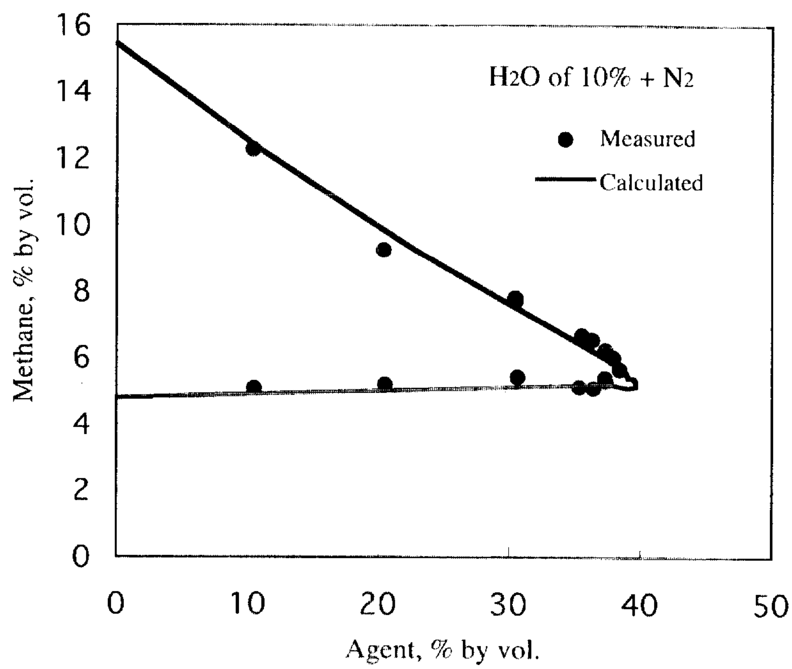


Fig. 3 Estimated extinction limit of methane-air-water vapor mixture from calculation of adiabatic flame temperature



(a)



(b)

Fig. 4 Extinction limits of methane-air mixture added with water vapor and inert gas ((a)water vapor & CO_2, (b)water vapor & N_2)