Stability and Burning Velocity of Bunsen Flames with Propane-Carbon Monoxide Mixtures

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Blow-off, flash-back and burning velocity data are presented for 'commercial grade' propane, 'pure grade' cylinder carbon monoxide and for mixtures of the two gases. Blow-off and flash-back data may be satisfactorily correlated in terms of velocity gradient at the burner wall. The effect of composition changes is shown to be non-linear. The peak velocity gradient for flash-back occurs at 4 per cent propane in the fuel gas mixture and the peaks for all mixtures investigated were higher than for either of the constituent gases alone. The burning velocity of carbon monoxide is markedly influenced by the presence of small percentages of moisture and of other hydrogen-producing constituents such as propane. Maximum burning velocity for the propane-carbon monoxide mixtures used occurs at 4 per cent propane in the fuel gas and, over the entire range of mixtures investigated, maximum flash-back tendency was roughly proportional to maximum burning velocity of the same mixture composition.

ALTHOUGH a great deal of information has been published in recent years on the stability and structure of burner flames when burning pure or mixed fuel gases of fixed composition, surprisingly little information is available on the influence of systematic composition changes in mixtures of fuel gases. Because of the widespread interest in the behaviour of mixed fuel gases, systematic studies have been initiated by the authors on a number of commonly used fuel gas mixtures. The first paper[1] of this series dealt with the system propane-hydrogen, the second[2] with the system methane-carbon monoxide, while the present paper deals with results obtained for the system 'commercial grade' propane, 'pure grade' carbon monoxide.

Blow-off and flash-back were determined by the conventional apparatus and procedure previously described[1,2] using air cooled *Pyrex* No. 744 burner tubes of 1·273, 1·030, 0·930, 0·770 and 0·573 cm internal diameter. Burning velocities were determined using the same apparatus and burner tubes, by means of the dynamic or Bunsen method[3] in which the burning velocity is calculated from the area of the flame cone. All tests were conducted at atmospheric pressure and at room temperature.

The 'commercial grade' propane used, was analysed on the low temperature Podbelniak apparatus and showed the following percentage composition: propane 73·73, propylene 21·62, ethane 3·83, butane 0·69 and butylene 0·13. The 'pure grade' cylinder carbon monoxide used showed the following mass spectrometer analysis (percentage on the dry basis): carbon monoxide 97·6, carbon dioxide 0·58 and hydrogen 1·82.

RESULTS AND DISCUSSION

The experimental results for blow-off and flash-back are presented in *Figure* 1 for carbon monoxide. Similar data for propane were shown in a
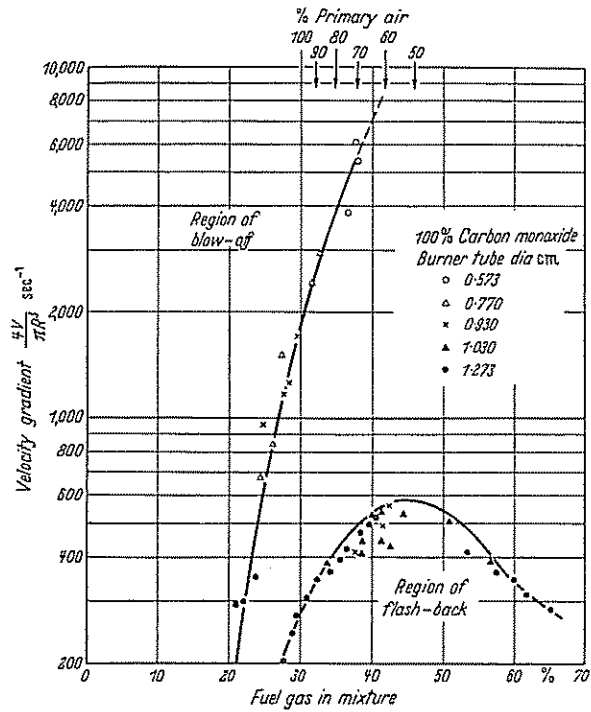
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Figure 1 Critical velocity gradients at boundary of gas stream for flash-back and blow-off from cylindrical air cooled Pyrex burner tubes of different diameters; primary air and 'pure grade' carbon monoxide dry, secondary air humidity 0·013 lb water/lb bone dry air

previous paper[1] and are reproduced on the blow-off and flash-back curves for various composition mixtures of 'commercial grade' propane and carbon monoxide shown in *Figures* 2a and b respectively. As few data were secured in the region of transition flow and none in the region of turbulent
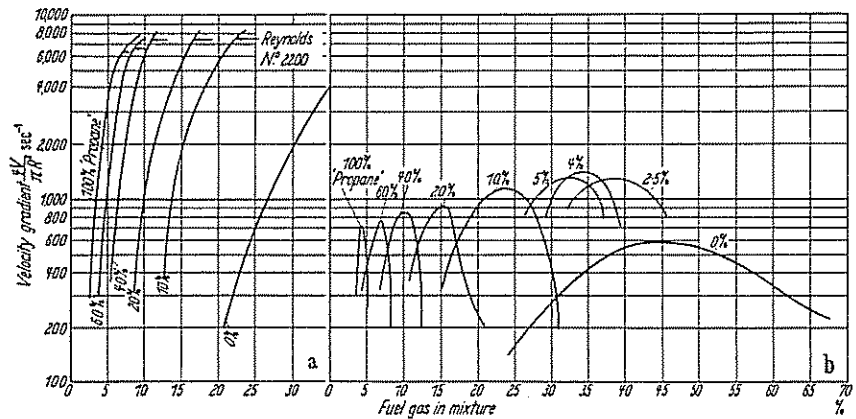

Figure 2 Critical velocity gradients at boundary of gas stream for a blow-off at various mixture compositions (primary air, 'commercial grade' propane and 'pure grade' carbon monoxide dry; secondary air humidity 0·013 lb water/lb dry air) b flash-back at various mixture compositions of 'commercial grade' propane and 'pure grade' carbon monoxide (primary air and fuel gases at room temperature and dry; secondary air humidity 0·013 lb water/lb bone dry air)

46

flow, velocity gradients were calculated from the flow data using the relation $g = 4V/\pi R^3$, where g is velocity gradient at the burner wall (sec^{-1}), V is the total flow in the burner tube (cc/sec) and R is the burner tube radius (cm).

Blow-off and flash-back—Excellent reproducibility was obtained for blow-off with the mixture compositions shown in *Figure 2a*. The flash-back data shown in *Figure 2.b* are somewhat less reproducible, especially near the flash-back peaks which represent regions of marked instability where a considerable scatter of experimental points is to be expected. Both sets of curves show that the effect of composition changes is non-linear.

The effect of composition changes upon the height of the flash-back peaks can be seen more readily in *Figure 3* which shows a graph of velocity
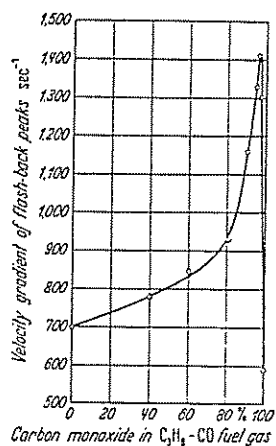

Figure 3 Relation between flash-back peaks and fuel gas composition for binary mixtures of 'commercial grade' propane and 'pure grade' carbon monoxide
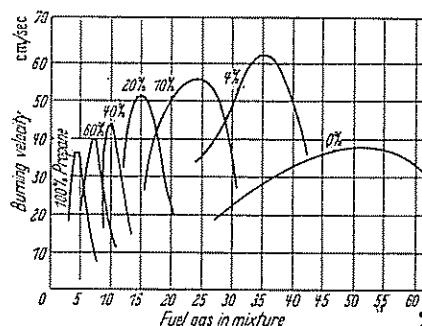

Figure 4 Burning velocity of various binary mixtures of 'commercial grade' propane and 'pure grade' carbon monoxide as a function of the percentage fuel gas in the gas-air mixture; primary air and fuel gases at room temperature and dry, secondary air humidity 0 013 lb water/lb bone dry air

gradient at flash-back peaks against the percentage carbon monoxide in the fuel gas mixture. It is of interest to note that the flash-back peak is higher for all mixtures investigated than for either of the constituent gases alone.

A common method of presenting the data for individual fuel gases is to plot critical velocity gradients for blow-off and flash-back as ordinates, against the percentage stoichiometric air in the gas-air mixture. However, for the fuel gas mixtures so far investigated, this method of plotting has not yielded satisfactory correlations; such graphs are not, therefore, reproduced.

Burning velocity—Burning velocities were calculated from measured values of the flame cone height and burner radius using the relation:

$$S_u = \frac{V}{\pi R \, (R^2 + H^2)^{\frac{1}{2}}}$$

47

where S_u is burning velocity (cm/sec), V is the total flow in the burner tube (cc/sec), R is the radius (cm) of the flame cone base (taken as the radius of the burner tube) and H is the measured height of the cone (cm). This method of determining burning velocity does not give absolute values and numerous refinements to the Bunsen method can be applied[1-6] which are claimed to give more accurate results. None of these is accepted as standard, however, and as the principal interest in the present work is relative results, the less time consuming and simpler cone height method was employed.

The influence of fuel gas composition upon burning velocity is shown in *Figure* 4. For any single curve, data were obtained using at least three burner sizes, yet the data all fall on smooth curves within the limits of experimental reproducibility, and appear to be independent of burner port diameter. These results differ somewhat from the conclusions reached by F. A. SMITH and S. F. PICKERING[6] which may be due primarily to the fact that virtually all the present data were obtained with burner port diameters substantially larger than those used by these authors. The deviations resulting from the cone area method of burning velocity measurement are magnified as the size of the burner port decreases.
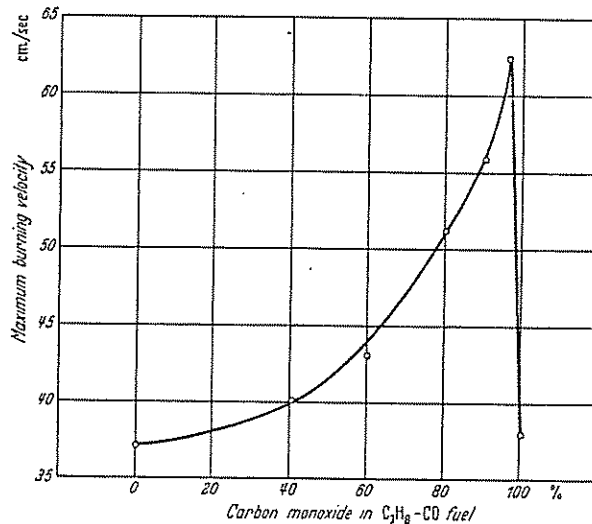

Figure 5   Relation between maximum burning velocity and fuel gas composition for binary mixtures of 'commercial grade' propane and 'pure grade' carbon monoxide; secondary air humidity   0·013   lb water/lb bone dry air

The maximum burning velocity peaks for the various mixtures are shown in *Figure* 5 plotted against per cent carbon monoxide in the fuel gas. There is a striking similarity between this curve and that for flash-back peaks shown in *Figure* 3.

The burning velocity curve for carbon monoxide, as has been shown by several investigators[7, 8], will vary markedly with the percentage of water vapour present. During the present investigation, data were obtained at varying water vapour contents in the primary and secondary air and in the carbon monoxide. Varying the water vapour content of the primary air from substantially zero to a partial pressure of 15·7 mm, resulted in an

48

increase of about 30 per cent in burning velocity. It is apparent from *Figure* 5, that propane, which can also furnish atomic hydrogen to serve as chain carrier, behaves in a similar but more pronounced manner.

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