THE INFLUENCE OF FLOW PARAMETERS ON MINIMUM IGNITION ENERGY AND QUENCHING DISTANCE

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SUMMARY

Experiments have been carried out on the effects of pressure, velocity, mixture strength, turbulence intensity and turbulence scale on minimum ignition energy and quenching distance. Tests were conducted at room temperature in a specially designed closed-circuit tunnel in which a fan was used to drive propane/air mixtures at subatmospheric pressures through a 9 cm square working section at velocities up to 50 m/s. Perforated plates located at the upstream end of the working section provided near-isotropic turbulence in the ignition zone ranging from 1 to 22 percent in intensity, with values of turbulence scale up to 0.8 cm. Ignition was effected using capacitance sparks whose energy and duration could be varied independently.

The results of these tests indicated an optimum spark duration for minimum ignition energy of 60 μsec. Rectangular, arc-type sparks of this duration gave lower than previously reported values of ignition energy for both stagnant and flowing mixtures. It was found that both quenching distance and minimum ignition energy increase with (a) increase in velocity, (b) reduction in pressure, (c) departures from stoichiometric fuel/air ratio, and (d) increase in turbulence intensity. Increase in turbulence scale either raised or lowered ignition energy, depending on the level of turbulence intensity. Equations based on an idealized model of the ignition process satisfactorily predicted all the experimental data on minimum ignition energy.

INTRODUCTION

Although the process of ignition has been subjected to many experimental investigations, the amount of published data on spark ignition in turbulent, flowing gases is relatively small. In fact, the only major contribution in this area is that of Swett[1] who studied the effects on ignition energy of variations in pressure, velocity, fuel/air ratio and turbulence. Experience on many types of combustion system have generally confirmed the trends observed by Swett. Nevertheless, his experimental values are considered suspect for the following reasons:

1 In some experiments the spark gap width was below the quenching distance, thereby incurring excessive heat loss to the electrodes.[2]

2 No independent control was exercised over certain important spark characteristics. For example, spark duration varied with flow velocity and often exceeded the optimum value.[3]

3 A glow discharge was employed instead of the more efficient arc discharge.[1]

4 The treatment of turbulence was very limited; for example, no consideration was given to the effects of turbulence scale.

In view of these deficiencies, and bearing in mind the importance of accurate experimental data to the design of ignition equipment and the development of ignition theory, it was decided to undertake a detailed and systematic investigation of the main parameters influencing minimum ignition energy and quenching distance in flowing mixtures, namely, pressure, velocity, fuel/air ratio, turbulence intensity and turbulence scale.

EXPERIMENTAL

Tests were carried out at room temperature in a specially designed closed-circuit tunnel in which a fan is used to drive air through a 9 cm square working section at velocities up to 50 m/s. As this system is totally enclosed it is ideally suited to the study of ignition in flowing gaseous mixtures at subatmospheric pressures. Located at the upstream end of the working section are various perforated plates which can generate near-isotropic turbulence in the ignition zone ranging from 1.0 to 22 percent in intensity, with values of turbulence scale up to 0.8 cm. The working section, as illustrated in Fig.1, is fitted on two opposing walls with schlieren-free glass windows to allow the initiation and development of the spark kernel to be visually observed and photographed.

The turbulence properties of the flow were examined in detail at a pressure of 0.17 atmospheres. At such low pressures Knudsen number effects on the heat transfer from conventional hot wires of 2 - 5 μm diameter become significant. To overcome this problem a 70 μm diameter hot wire was chosen, based on the criterion of Boltz.[4] This has an upper frequency response of 30 KHz which was considered adequate. Further details of the lengthy calibration procedures employed are contained in Ref.5.

The signals from the hot wire were processed using a Disa 55D01 Universal anemometer, a Disa 55D10 linearizer and a B & K type 2107 frequency analyzer. Turbulence intensity was read directly off an RMS voltmeter. Measurements were made of both large scale, L, and Taylor microscale, λ. The Kolmogoroff scale, η, was then computed since it is useful for calculating the dissipative effects of turbulence and also facilitates examination of the role of turbulent vorticity in combustion. Moreover, the combination of L, λ and η provides a fairly complete description of the turbulent energy spectrum.[6]

Details of the perforated plates employed to generate turbulence are contained in the Appendix. From measurements carried out with an X probe, it was found that the turbulence was nearly isotropic ($u' \approx 0.9\ v'$ for $u'/U < 5$ percent, $u' \approx 0.75$ to $0.8\ v'$ for high values of u'/U). At all conditions the Reynolds number of turbulence, Re_λ, was sufficiently high for the turbulent flow in the ignition zone to be in the 'initial period' of its decay.

Although many different electrode geometries and materials were investigated, plain electrodes were selected because of their relatively large area of contact with the gas which allowed accurate definition of quenching distance. Heat resistant stainless steel was considered to be the most suitable electrode material due to its low thermal conductivity and high wear resistance. The choice of electrode diameter posed problems since it was recognized that too large a size would alter the intensity and scale of the turbulence in the flame propagation zone, while too small a size would prohibit accurate definition of quenching distance. An electrode diameter of 1 mm was eventually decided upon as being slightly smaller than the lowest measured value of λ. Accurate control of the gap width was accomplished using a micrometer head attached to one electrode.

Spark energies were measured by mounting high voltage Tektronix P6015 probes (supplied with compensating networks) on the electrodes and feeding their output into a two-channel oscilloscope. Traces of current and voltage were recorded on a