F.R. Note No. 410/1959
Research Programme
Objective. D11/1

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANISATION

THE FLAMMABILITY LIMITS OF MOVING MIXTURES OF PROPANE AND AIR

by

K.N. Palmer and P.S. Tonkin

SUMMARY

The lower and upper flammability limits of propane/air mixtures flowing along a tube were determined for gas velocities up to 600 cm/s. At the lower end of the velocity range the limits were wider than with static mixtures, but they narrowed again as the flow velocity was increased.

August, 1959.
F.1000/10/84B

Fire Research Station,
Boreham Wood,
Herts.

F.R. Note No. 410/1959
Research Programme
Objective. D11/1

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANISATION

THE FLAMMABILITY LIMITS OF MOVING MIXTURES OF PROPANE AND AIR

by

K.N. Palmer and P.S. Tonkin

SUMMARY

The lower and upper flammability limits of propane/air mixtures flowing along a tube were determined for gas velocities up to 600 cm/s. At the lower end of the velocity range the limits were wider than with static mixtures, but they narrowed again as the flow velocity was increased.

August, 1959.
F.1000/10/84B

Fire Research Station,
Boreham Wood,
Herts.

Introduction

The flammability limits of gas mixtures have received a considerable amount of attention, both experimental and theoretical, for many years. A comprehensive review by Coward and Jones (1) discussed the available experimental methods and results, and gave detailed lists of values of flammability limits. There have been further more recent reviews, e.g. by Linnett and Simpson (2). From these reviews it appeared that the determination of the flammability limits of gas mixtures in motion had received relatively little attention. Most of the determinations with moving gases had been made with flat flame burners; these tests were confined to the lower flammability limit and very slow rates of flow and the results showed that weaker mixtures would burn under these conditions than would burn in static mixtures in a tube. However, with burners, the conditions of test are quite different from those with tubes and the variations in the limits may not necessarily be due solely to the flowing gas. Coward and Jones also mentioned tests in which gas mixtures were moving slowly along pipes or were stirred by fans in more compact vessels. The gases tested under one or both of these conditions were methane, ethane, diethyl ether, and natural gas, mixed with air. When the gas mixtures were moving slowly the lower flammability limits fell slightly, and this also occurred when the fans were running at moderate speeds. With high speed fans the lower limits increased again. There was, however, no record of experimental investigations covering gas mixtures flowing in tubes over a wide range of velocities and covering both the lower and upper flammability limits. An investigation of the flammability limits of propane/air mixtures has therefore been undertaken in which the flows ranged from static conditions to well into the turbulent flow region.

The possibility of the lower flammability limit varying with the gas velocity has an important industrial application. In this country it is usual to design industrial plant carrying flammable solvent vapours, mixed with air, so that the concentration of flammable vapour in the ventilation and solvent recovery systems does not exceed about one-third of the lower limit as measured under static conditions. If the lower limit decreased markedly when the gas was in motion the margin of safety would be seriously reduced.

Experimental

The perspex tube in which the flammability limit determinations were made was straight and horizontal in the experimental section (Fig. 1). The internal diameter of the tube was 6.4 cm. The airflow from a centrifugal blower was mixed with propane from a cylinder, after metering with rotameters, and the gas mixture then flowed along a straight tube 411 cm long, round a right-angled bend, through a straightener and into the experimental section (Fig. 1). The straightener consisted of a crimped ribbon flame arrester, crimp height 0.053 cm, and depth 3.2 cm, which also prevented flame from propagating back into the mixing section. The most satisfactory form of igniter, which was sited 291 cm downstream from the straightener, was found to be a 15 cm or 30 cm length of 34 S.W.G. constantan wire, wound into a coil, which was fused by 18 or 24v accumulators.

The propane was specified by the manufacturers as being at least 97 per cent pure; atmospheric air was used, without drying.

The experimental procedure adopted when measuring the flammability limits of moving mixtures was to allow the mixture to flow for about ten changes of the gas in the tube, before attempting to fire the mixture. If the mixture ignited a dim flame could often be seen 1 - 2 m downstream from the igniter and the pressure pulse caused by the flame disturbed the bob of the air rotameter. When firing a static mixture the tube was filled in the usual way but just before firing the air and propane flows were cut off sufficiently rapidly to prevent any change in the composition of the gas mixture in the experimental section of the tube. Ignition was detected by visual observation either of flame or of water condensation on the walls of the tube. If a mixture ignited the propane concentration was changed by 0.25 per cent and the test repeated until a concentration was found which failed to ignite in at least five successive tests.

Results and Discussion

The results obtained for the lower and upper flammability limits of propane/air mixtures flowing at various velocities are shown in Fig 2 and 3 respectively. It is clear that both limits are affected by the gas flow, particularly at gas velocities up to 100 cm/s. The effect is less marked at the lower limit, Fig 2, but is, however, real. In six tests with a static 2 per cent mixture, after filling the tube at 26 or 52 cm/s, no ignitions occurred, whereas when the same mixture was fired whilst in motion ignitions occurred at both velocities. The value obtained for the lower limit under static conditions lay between 2·0 and 2·25 per cent propane in air; closer values could not be obtained with the flowmeters used. The value given by Coward and Jones (1) for upward propagation through a static mixture in an open vertical tube is 2·2 per cent propane, and a similar value was given for propagation in a 2 ℓ globe. The present result is in agreement with these findings. With moving mixtures the lower limit dropped in the present experiments to within the range 1·75 to 2·0 per cent propane but did not decrease further, and appeared to revert to the 2·0 to 2·25 per cent range at gas velocities above 400 cm/s.

The variation at the upper limit was more marked (Fig 3); under static conditions the value was below 8 per cent propane, whereas in a flow of only 52 cm/s it had increased to above 9 per cent propane. This difference was not due to errors in gas flow measurements since in five tests with a static 8 per cent mixture, after filling the tube at 52 cm/s, no ignitions were obtained. A further effect obtained fairly often with upper limit mixtures was the stabilisation of a flame at the mouth of the tube after ignition of the gas had occurred. This flame stabilisation occurred with gas flows of 26, 52, 104, 129 and 220 cm/s composed of the respective ignitable mixtures shown in Fig 3 and proved that the flame had travelled down from the igniter to the mouth of the tube, a distance of more than 11m (Fig 1). The values given by Coward and Jones (1) for the upper limit, measured under static conditions, ranged from 9.5 per cent propane for upward propagation in an open vertical tube to 7.3 per cent propane for propagation in a large closed globe. All the present results, for static and flowing mixtures, fall inside this range.

By taking the viscosity and density of the gas mixture to be those of air at 20°C it may be shown that a Reynolds number of 2000 was obtained when the gas flow was 48 cm/s, and a value of 3000 was obtained with a gas flow of 72 cm/s. Thus appreciable variation in the flammability limits occurred whilst the gas flow before ignition was streamline, and the variation was maintained until the initial flow was well into the turbulent region. It appears that a more detailed examination of the lower range of velocities might yield interesting results.

Conclusions

1. The flammability limits of propane/air mixtures were wider when the gas was moving at moderate velocities than when the gas was stationary. The effect was more marked with the upper limit than with the lower limit.

2. At higher velocities the limits narrowed again.

3. The variation of the lower limit was not sufficient to appreciably reduce the safety of industrial plant designed to carry the vapours of flammable solvents in concentrations of about one third of the lower flammability limit, as measured under static conditions.

Acknowledgment

Miss J.S. Hall and Mr. B. Langford assisted in the experiments.

References

1. Coward H.F., Jones G.W. Limits of Flammability of Gases and Vapors. U.S. Bureau of Mines. Bull 503. 1952.

2. Linnett J.W., Simpson C.J.S.M. 6th Symposium (International) on Combustion, 1956. Reinhold. New York. 1957.

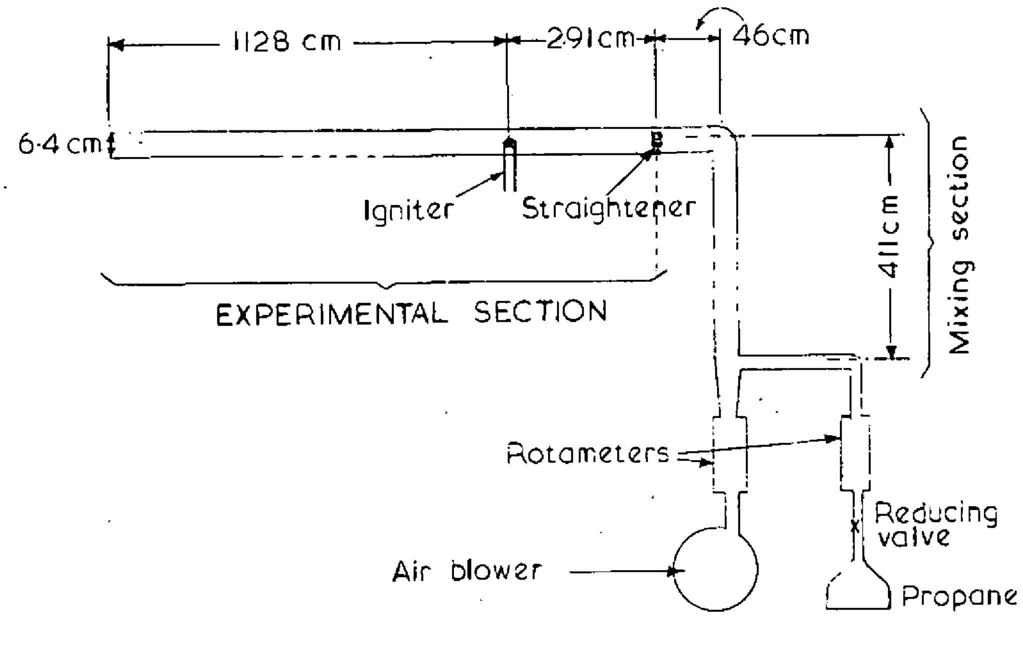
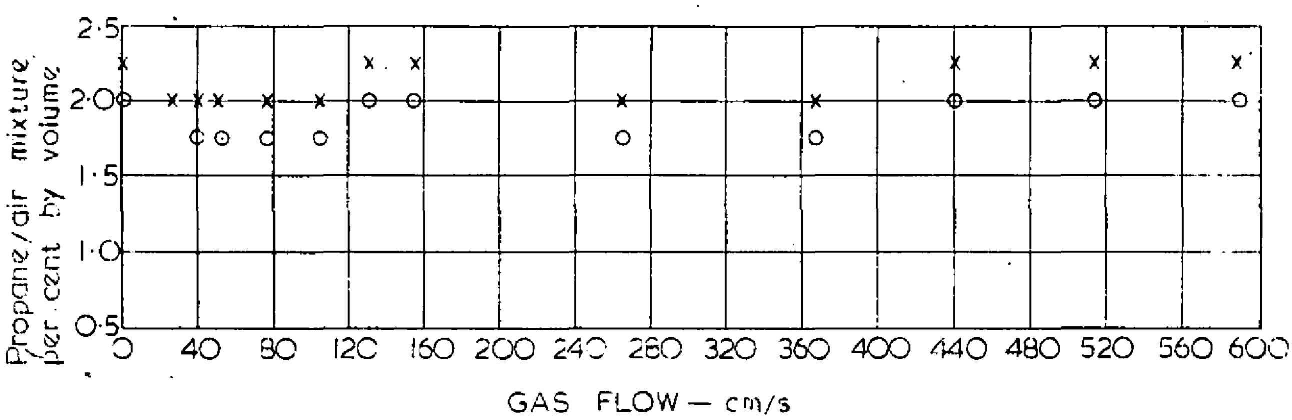
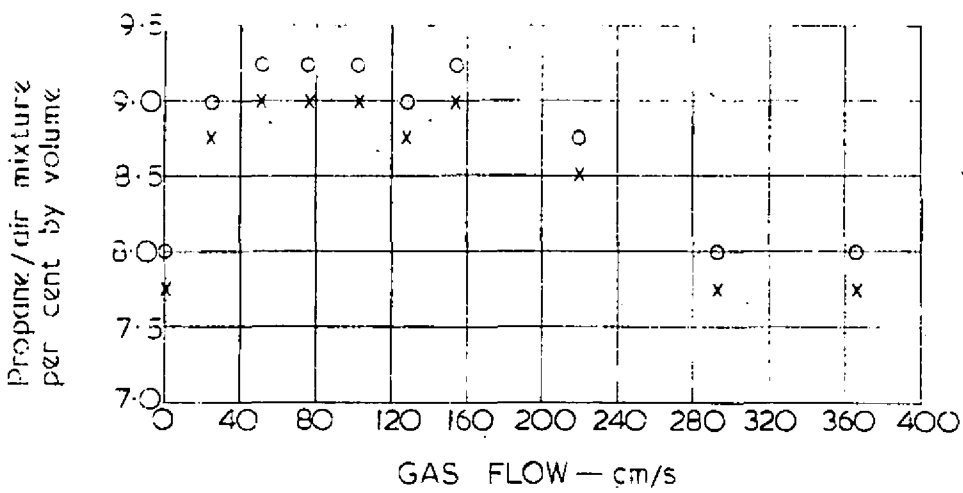


FIG.1. SKETCH OF LAYOUT OF APPARATUS



x Mixture ignited
o Mixture did not ignite in at least 5 tests

FIG. 2. EFFECT OF MIXTURE VELOCITY ON THE LOWER FLAMMABILITY LIMIT



x Mixture ignited
o Mixture did not ignite in at least 5 tests

FIG. 3. EFFECT OF MIXTURE VELOCITY ON THE UPPER FLAMMABILITY LIMIT

I/3375 F.R. 410