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STUDY OF PROPANE-AIR FLAME PROPAGATING IN NARROW CHANNELS UNDER QUENCHING CONDITION

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abstract A new apparatus has been constructed to investigate the quenching of laminar hydrocarbon-air flames, at elevated initial pressures. The pressure-tight quenching channel is of trapezoidal form, with very smooth decrease of the channel width along its one meter length that is almost equivalent to a parallel-plate flame arrester. Propane-air mixture has been tested on the entire flammability domain, for both upward and downward propagation, and for pressure range from 40kPa to 700kPa. Differences between upward and downward propagation have been observed in the lean flammability domain, while for the reach domain, a new flammability limit has been established for the downward propagating flame at elevated initial pressure. A discussion is also made on the differences between experimental quenching distances determined in this study and previously reported literature data.

Introduction

It is important to know quenching distance as a function of pressure and direction of flame propagation both for scientifical and practical reasons [1÷3]. It is necessary to obtain reliable experimental data with respect to specific conditions as they can be acquired, regardless of the method used to measure it.

New test channel has been constructed to allow deflagration under different constant pressure conditions.

The objectives of the preliminary sets of experiments were:

– testing of the equipment's capability to provide reliable experimental data;

– comparison between upward and downward propagation of propane-air flame within the lean to stoichiometric range of compositions; and

– observation of the phenomena accompanying flame quenching in narrow channel.

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Apparatus, Materials, Methods

The experimental apparatus (Fig. 1) was designed to withhold gas pressures up to 2000 kPa. It consists of two parts: the mixture preparation/admission/evacuation system, made of ¼" copper piping (the needle valves and the fittings were purchased from Cole Parmer), and three custom-made test channels with different width ranges, namely:

– 0.5÷3.0 mm width range; 989 mm in length; further referred as narrow channel;
– 2.5÷7.0 mm width range; 990 mm in length; further referred as average channel;
– 6.5÷12.0 mm width range; 994 mm in length; further referred as wide channel.

Pressure in the piping system has been monitored by two Cole Parmer digital mano-vacuum meters of different sensitivity and range.

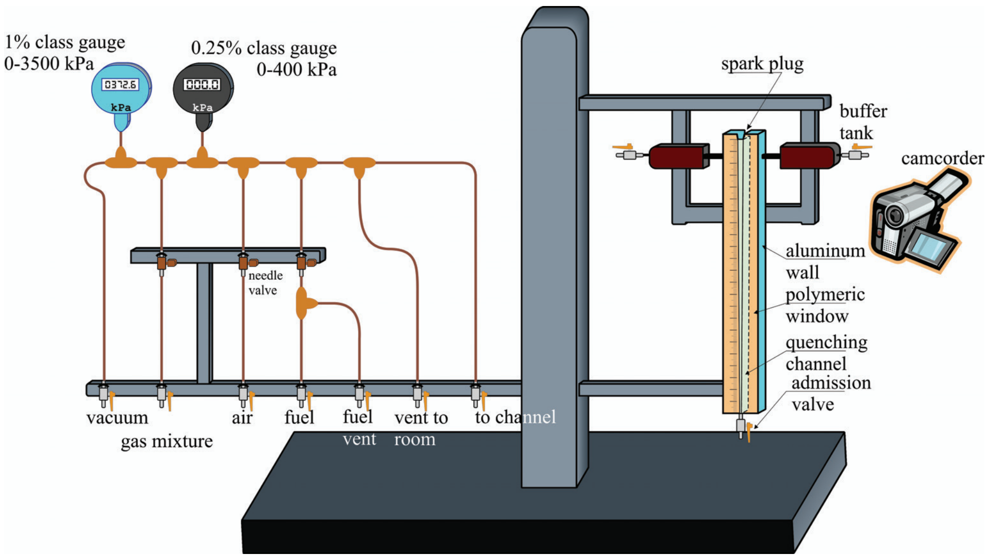

Fig. 1 *Sketch of the experimental setup.*

The trapezoidal form test channels, made of two aluminium sidewalls and two polymeric transparent walls, are equipped with a commercial automotive spark generator, an analogous manometer, and a CL1 type pressure transducer, made by Zepwn, coupled to a 40MHz Hung Chang digital oscilloscope, to allow monitoring of pressure variation during flame propagation. In order to diminish the pressure increase during flame propagation, each test channel was provided with a pair of metallic cylinders – labeled as buffer tanks, displaced nearby the ignition point, with a total volume at least ten times higher the volume of the channel. Different buffer tanks of volume equal to 250mL, 500mL and 1000mL were used for narrow, average and wide channel, respectively. The test channel could be hanged in vertical position by either of the two heads, providing condition for upward and downward propagation, respectively.

Vacuum was made available through a preliminary oil vacuum pump that delivered 10^{-2} torr vacuum level.

Pneumatic connection was provided for the input of gas components, for the vacuum pump, and for the gas mixture transfer to the test channel, respectively.

In experiments, premixed propane-air mixture was used in the concentration range from 2.5% C_3H_8 to 9.0% C_3H_8. Propane, 99.5% purity, and dried air have been provided by Linde Gas. Mixture was made by partial pressure method in 10 L steel cylinders, at a maximum 1400 kPa absolute pressure. At least 24 hour period was allowed for each composition to homogenize prior to performing the test.

Motion pictures have been recorded with a high sensitivity Sony 3CCD camcorder, and video files have been further processed with AVD Video Processor ® version 7.3 (developed by Avlan Design).

Results and Discussion

There is a small difference between upward and downward propagation in narrow channel; as it has been encountered for several compositions in the lean to stoichiometric range, the quenching distances for the upward propagation are slightly smaller than those for the downward propagation. Fig. 2 shows such comparison for experimental data acquired in similar condition – the narrow channel; ones can observe that, within 95% prediction limits, downward propagation data fall into the interval of the upward propagating ones.

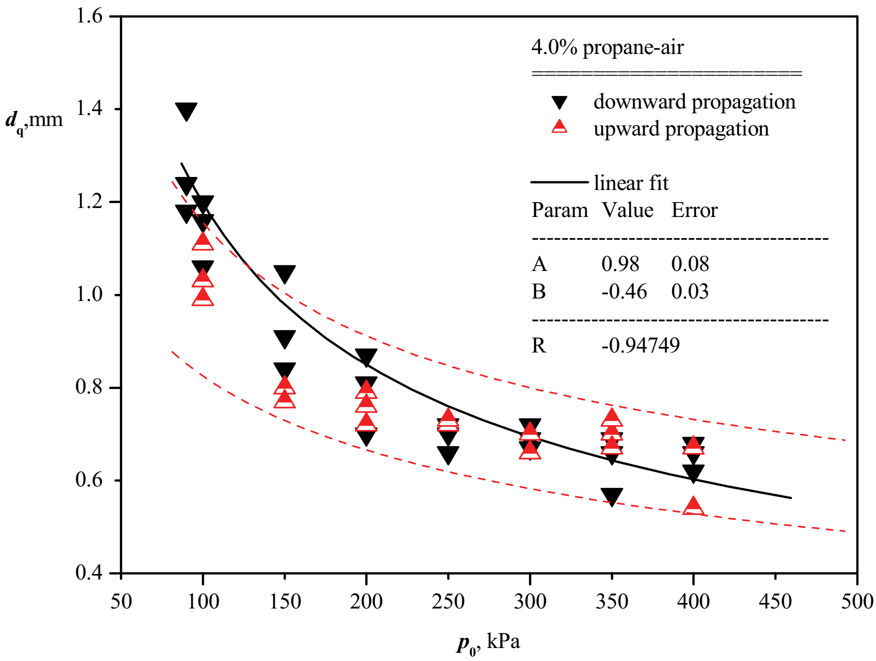

Fig. 2 *Comparison between upward and downward propagation of 4.0% propane-air flame in narrow channel; linear fitting was performed on the linearized bilogarithmic scale.*

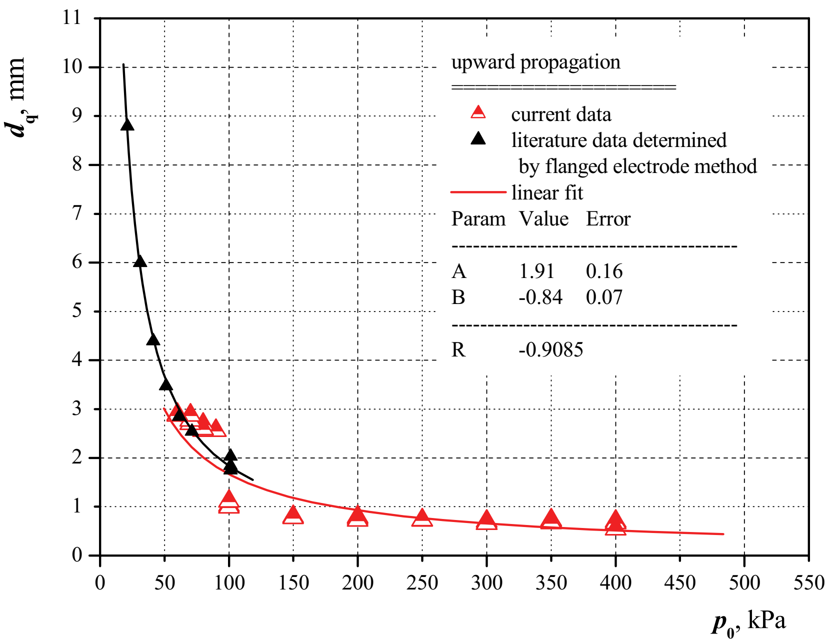

Fig. 3 *Pressure dependence of the quenching distance, for flame propagating upward in 4.0% propane-air mixture in narrow and average channel; linear fitting was performed on the linearized scale (bilogarithmic).*

Also, the range of initial pressures for which the quenching distance could be determined is wider for the upward propagation as compared to the downward one, for the same composition of propane-air, under similar conditions (see Fig. 3); explanation resides not only on the physical forces (gravitational, buoyancy) that interact in the flame propagation process, but also on the property of the mixture itself – preferential diffusion of the deficient component, resulting from the Lewis number effect (Le < 1). When compared to data obtained by flanged electrode technique [1,4], the present results show poor agreement (Fig. 3); moreover, they are grouped together as function of the specific test channel used to measure them. This observation is clearer from Table 1, for 3.0% propane-air flame propagating upward: at 200 kPa initial pressure, the quenching distance is 1.27 mm in narrow channel and 2.65 mm in the average channel.

Linear regression performed on the linearized $\ln\left(d_q\right) = f\left(\ln\left(p_0\right)\right)$ dependence is not resulting in better agreement: correlation coefficient is –0.9085 in case of upward propagation and –0.9475 in case of downward propagation. While the first one is due to the presence of two distinct groups of data, the second one is strictly related to the precision of the method itself.

Pressure increase during the experiments does not exceed 2% of the initial pressure, due to buffer tank, but its effect is rather significant, especially at elevated initial pressures; the experimental quenching distances are shifted toward smaller values, and grouped together with regard to the range of channel width used for the test; moreover, a continuous range of channel width between 0.5 and 12.0 mm could not the obtained, although range overlapping has been provided for each channel; improvement of the testing equipment is to be done in the nearest future, in order to minimize this effect.

Table 1 Quenching distance of 3.0% propane-air flame, as function of initial pressure

Initial pressure, kPa	quenching distance, mm	
	upward propagation	downward propagation
	narrow channel	
700	0.65	0.57
700	0.71	0.57
700	0.68	0.57
650	0.71	0.56
650	0.68	0.56
650	0.70	0.56
600	0.76	0.59
600	0.68	0.59
600	0.70	0.60
550	0.70	0.61
550	0.76	0.60
550	0.75	0.62
500	0.71	0.62
500	0.70	0.65
500	0.65	0.64
450	0.90	0.83
450	0.75	0.71
450	0.75	0.70
400	0.76	0.69
400	0.81	0.68
400	0.81	0.68
350	0.92	0.74
350	0.92	0.75
350	0.92	0.74
300	0.85	0.81
300	0.86	0.79
300	0.79	0.80
250	0.93	0.95
250	0.95	0.96
250	0.93	0.96
200	1.08	1.02
200	1.27	1.00
200	1.39	0.99
150	1.40	1.43
150	1.40	1.43
150	1.39	1.43
	average channel	
200	2.89	–
200	2.65	–

Table 1. ***continued***

Initial pressure, kPa	quenching distance, mm	
	upward propagation	downward propagation
200	2.62	–
200	2.61	–
150	2.91	2.62
150	3.02	2.61
150	2.98	2.61
100	3.53	3.03
100	3.31	3.21
100	3.32	3.18
80	6.75	–
80	6.74	–
80	6.71	–
70	6.80	–
70	6.83	–
70	6.80	–
60	6.91	–
60	6.91	–
60	6.93	–
40	–	6.73

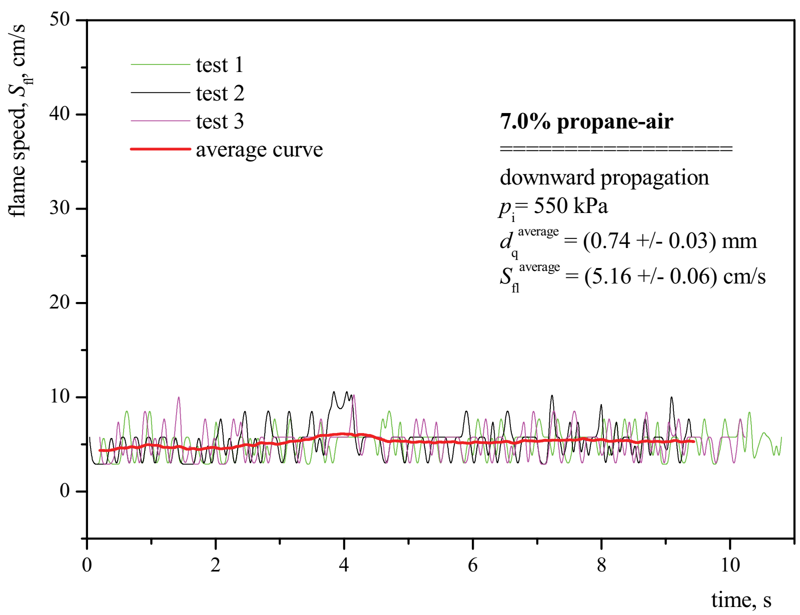

Fig. 4 *Determination of flame speed under quenching condition for downward propagation at elevated pressure.*

Although upper flammability limit for a downward propagating propane-air flame has been previously reported as being 6.3% [3,5], at atmospheric initial pressure, the current investigation revealed that a composition of 7.0% propane-air is still propagating downward, at 550kPa initial pressure, with quenching at 0.74 mm channel width (see Fig. 4); considered also interesting about this test mixture is the flame speed, very small and almost constant throughout the entire flame propagation, with and average value of 5.16 cm/s.

Conclusions

Flame propagation has been investigated in a custom shaped channel to acquire quenching distance data under pressure condition, and to observe the behavior of the flame near quenching.

In the lean range of compositions, the difference between upward and downward propagation, in terms of quenching distance, is not significant; for a 95% predictive limits they both fall within the interval.

The data collected so far does not show a very good correlation with previously reported ones; they are also poor correlated as straight line dependence of the quenching distance on pressure, in bilogarithmic linearized scale.

A new limit for downward propagation has been established at elevated pressure (550kPa). For this specific test the flame speed has been calculated to be 5.16 cm/s.

Nevertheless, the method shows potential when the quenching process and its accompanying phenomena is under study.

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