ANALELE UNIVERSITATII BUCURESTI
Department of Physical Chemistry
4-12 Regina Elisabeta Blvd, District 3, Bucharest
phone: +40-21-3143508; fax: +40-21-3159249
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ARS DOCENDI PUBLISHING HOUSE
Sos. Panduri 90, District 5 Bucharest
phone/fax: +40-21-4102575
e-mail: arsdocendi@yahoo.com

ERROR PROPAGATION IN EVALUATION OF THE MAXIMUM EXPERIMENTAL SAFE GAP VIA QUENCHING DISTANCE MEASUREMENTS

Mihaela Puiu*, **Nicoleta-Gabriela Muşat, V. Munteanu and D. Oancea**

abstract: The indirect evaluation of the maximum experimental safe gap for explosive mixtures involves the measurement of the quenching distance for different initial pressures and compositions. A study concerning the precision of the experimental method was made. The low values of the standard deviations of the parameters in the empirical correlations initial pressure/quenching distance and quenching distance/maximum experimental safe gap allow the conclusion that the propagation of uncertainty does not significantly affect the calculated safety gap, and the precision of the method is maintained in acceptable limits.

key words: MESG, quenching distance, propane-air mixture, uncertainty, error propagation

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Introduction

Quenching distance is a critical parameter that characterizes the quenching of flames. While it depends on several mixture properties – like type and composition of the fuel – and specific experimental conditions, the quenching distance is correlated with several other critical properties, for instance the minimum ignition energy and the maximum experimental safe gap [1]. Following a previous study [2] the present paper focuses on propagation of the experimental errors of the quenching distance/initial pressure profiles to the estimation of the maximum experimental safe gap.

Experimental

The experimental setup [2,3] has been used to determine the quenching distance variation with initial pressure for propane-air compositions of 3.0; 3.5; 4.0; 5.0 and 6.0%, respectively. Two 10-L steel cylinders have been used to prepare the gas mixtures by partial pressure method, at 400 kPa absolute pressure. Propane, 99.97%, and compressed air, 5.0 grade, have been purchased from SIAD RD. The working pressure range was between

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* Dept. of Physical Chemistry, University of Bucharest, 4-12 Regina Elisabeta Blvd. 030018 Bucharest, Romania, *corresponding author e-mail*: mpuiu@gw-chimie.math.unibuc.ro

atmospheric and 21.3 kPa. The prepared mixtures were hold still for at least 24 hours prior to use.

The experimental quenching distances have been further used to evaluate the maximum experimental safe gap, *MESG*, through the means of an empirical correlation model. Alternatively, the test cell (Fig. 1), manufactured at PTB-Braunschweig, was used to directly measure MESG, for the same mixture composition and experimental conditions. The test cell, made of stainless steel, consists of two concentric cells that communicate through a variable slit opening which is set to the desired length with a micrometric screw. An observation window allows visualisation of the flame initiated in the inner cell, by the help of high voltage electric spark circuitry. The maximum experimental safe gap is determined by averaging two consecutive runs, one being the highest slit opening that forbids the flame to pass through and the second being the smallest that allows the flame into the outer cell.

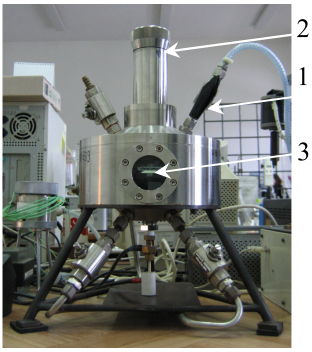

Fig. 1 *Explosion test cell for MESG measurement*
1–admission valve; 2–micrometric screw; 3–observation window.

Results and discussion

The empirical equation that has been tested on the experimental dependence of the quenching distance *versus* initial pressure is [3,4]:

$$y = a + \frac{b}{x} \tag{1}$$

where the initial pressure p_0 is the independent and the quenching distance (d_q) is the dependent variable. The values of the linear dependence parameters from eqn. (1) and the determination coefficients, r^2, are summarized in Table 1.

The correlation tests [5] between the parameters and flange diameters were made for each explosive mixture. The results of the correlation test, shown in Table 2, prove that there is no trend of variation of parameters values with the flange diameters, and the discrete differences among the values of a and b obtained in three different experimental conditions are due to the random experimental errors.

Table 1 Best-fit parameters and determination coefficients for the studied propane-air mixtures at different insulating disk diameters

% C_3H_8	Parameter	Best-fit values for the given disk diameter		
		10 mm	20 mm	40 mm
3.0	*a*	0.930	–0.710	0.386
	b	339.9	334	353.4
	r^2	0.9981	0.9984	0.9998
3.5	*a*	0.347	–0.017	0.131
	b	222.5	217.6	218.9
	r^2	0.9996	0.9984	0.9994
4.0	*a*	–0.230	0.236	–0.58
	b	192.5	192.3	192.4
	r^2	0.9988	0.9993	0.9973
5.0	*a*	–0.076	0.111	–0.276
	b	143.6	142.9	144.0
	r^2	0.9982	0.9962	0.9990
6.0	*a*	0.410	0.848	0.497
	b	139.9	132.0	134.5
	r^2	0.9966	0.9917	0.9959

Table 2 Correlation test between the equation parameters and the composition of the explosive mixtures

% C_3H_8	corell *a*	corell *b*
3.00	–0.1410	0.7502
3.50	–0.4267	–0.3605
4.00	–0.5906	–0.3243
5.00	–0.6691	–0.5291
6.00	–0.0014	–0.5161

Assuming that the independent variable is not affected by experimental errors, the uncertainty in measuring the quenching distance can be determined using the eqn. (1), the average values of *a* and *b* and the standard deviations of *a* and *b*.

$$\overline{d_q} = \overline{a} + \frac{\overline{b}}{p_0} \tag{2}$$

The standard deviation of the mean is:

$$s_{\overline{d_q}} = \sqrt{1 \cdot s_{\overline{a}}^2 + \frac{1}{p_0^2} \cdot s_{\overline{b}}^2} \tag{3}$$

The confidence interval of d_q for a significance level $\alpha = 0.05$ at a given initial pressure is:

$$d_{\mathrm{q}} = \overline{d_{\mathrm{q}}} \pm t_{\mathrm{crit}}\left(0.05, 2\right)\cdot\frac{s_{\overline{d_{\mathrm{q}}}}}{3} \tag{4}$$

where 2 represents the degrees of freedom.

For p_0 = 101.3 kPa one obtains the values shown in Table 3, and in a similar manner, for several initial pressures (Table 4).

Table 3 Uncertainty propagation in evaluating the quenching distance for a given initial pressure

% C_3H_8	$\overline{a}$	$s_{\overline{a}}$	$\overline{b}$	$s_{\overline{b}}$	$\overline{d_{\mathrm{q}}}$ /mm	$s_{\overline{d_{\mathrm{q}}}}$ /mm
3.00	0.202	0.047	342.40	5.20	3.58	0.07
3.50	0.154	0.049	220.0	1.8	2.325	0.052
4.00	-0.191	0.058	192.00	2.32	1.708	0.062
5.00	-0.080	0.047	143.50	1.90	1.336	0.051
6.00	0.585	0.075	135.46	2.75	1.92	0.080

Table 4 Uncertainty propagation in evaluating the quenching distance for different initial pressures

p_0/KPa	% C_3H_8	$\overline{d_{\mathrm{q}}}$ /mm	$s_{\overline{d_{\mathrm{q}}}}$ /mm
71.3	3.00	5.000	0.086
	3.50	3.230	0.104
	4.00	2.507	0.066
	5.00	1.932	0.054
	6.00	2.425	0.085
61.3	3.00	5.788	0.097
	3.50	3.742	0.057
	4.00	2.947	0.069
	5.00	2.261	0.056
	6.00	2.794	0.088
51.3	3.00	6.88	0.11
	3.50	4.442	0.061
	4.00	3.559	0.074
	5.00	2.710	0.060
	6.00	3.226	0.092

The average standard deviation of d_{q} for all the studied compositions and initial pressures was found equal to 0.07; this value does not exceed the accepted limit, i.e. 10%, for experimental relative errors.

Using again the equation for propagation of uncertainty to estimate the maximum experimental safe gap, since the empirical model of *MESG* against d_{q} has the form:

$$\overline{MESG} = \overline{c} + \overline{e}\cdot\overline{d_{\mathrm{q}}} \tag{5}$$

one obtains, for each composition of the studied explosive mixtures (data from Table 5), the standard deviation of $\overline{MESG}$:

$$s_{\overline{MESG}} = \sqrt{1 \cdot s_{\overline{c}}^2 + \overline{e}^2 \cdot s_{\overline{d}_q}^2 + \overline{d}_q^2 \cdot s_{\overline{e}}^2} \tag{6}$$

Table 5 Best-fit parameters of the *MESG* – d_q dependence for several propane-air mixtures

% C_3H_8		c	s_c	e	s_e
40mm disk diameter	3.5	0.117	0.019	0.489	0.017
	3.0	0.145	0.051	0.509	0.022
	4.0	0.317	0.044	0.4716	0.0095
	5.0	0.489	0.099	0.497	0.028
	6.0	0.818	0.142	0.455	0.036
20mm disk diameter	3.5	0.12	0.02	0.504	0.019
	3.0	0.23	0.05	0.5	0.033
	4.0	0.215	0.107	0.475	0.021
	5.0	0.327	0.097	0.449	0.024
	6.0	0.901	0.23	0.415	0.051
10mm disk diameter	3.5	0.151	0.013	0.487	0.023
	3.0	0.286	0.076	0.488	0.039
	4.0	0.24	0.10	0.475	0.019
	5.0	0.33	0.12	0.506	0.031
	6.0	1.02	0.15	0.407	0.034

For example, the average best-fit parameters for 5% C_3H_8 at 101.3 kPa, together with the corresponding standard deviations are: $\overline{c} = 0.382$, $\overline{e} = 0.484$, $s_{\overline{c}} = 0.105$ and $s_{\overline{e}} = 0.027$, respectively. Using these values one obtains $\overline{MESG} = 1.02$ and $s_{\overline{MESG}} = 0.10$. As in the case of the quenching distance the measurement errors do not exceed the admitted limit of 10%.

Conclusions

The estimated values of the parameters for both the empirical models used in order to calculate *MESG* proved that they describe with a reasonable precision the observed correlations initial pressure – quenching distance and quenching distance – maximum experimental safe gap.

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