Chapter 22

Effect of Size of Ignition Energy on the Explosion Behaviour of Selected Flammable Gas Mixtures

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Additional information is available at the end of the chapter

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Abstract

The determination of explosion indices of flammable gases is an important part of explosion prevention. Explosion indices could be influenced by initial temperature, initial pressure, humidity, ignition energy and others. This contribution deals with the effect of ignition energy size on explosion indices of flammable gases. For experimental measurements, three flammable gases were chosen—methane, propane and hydrogen. The chapter introduces the measurement results of the gas explosion parameters at various sizes of the ignition energy using explosion autoclave VA-20. Conclusions include the evaluation of influence of the ignition energy size on particular explosion indices.

Keywords: Explosion indices, 20-L apparatus, methane, Propane, Hydrogen, Ignition energy

1. Introduction

The explosion could happen wherever fuel, oxygen and sufficient ignition source appear together. The ignition energy is really significant. An explosive mixture is not ignited unless energy of the ignition source is sufficient. The ignition energy with a value of 10 J is used by default for the determination of explosion parameters of gases and vapours of flammable liquids. If the mixture is not ignited under given experimental conditions, it does not mean necessarily that the examined mixture is not explosive. When a higher ignition energy is used, the mixture could be ignited and high explosion indices could be reached (Mynarz et al., 2012).

Besides ignition source—the standard (EN 1127-1, 2011) defines 13 groups of ignition sources—duration time also matters. The explosion range is more wide with increasing size of the ignition energy— the lower explosive limit (LEL) is decreasing and the upper explosive limit (UEL) is growing. **Table 1** introduces the effect of the ignition energy on the methane explosive limits.

Ignition energy Ei (J)	LEL (vol.%)	UEL (vol.%)	Explosion range (vol.%)
1	4.9	13.8	8.9
10	4.6	14.2	9.6
100	4.3	15.1	10.8
10,000	3.6	17.5	13.9

Table 1. The effect of the ignition energy on the explosive limits of methane-air mixture (SAFEKINEX, 2002).

Increasing ignition energy affects the explosive limits but also increases maximum explosion pressure and the maximum rate of explosion pressure. The effect of the ignition energy is significant especially at the rate of explosion pressure rise.

The most common ignition sources suitable for measurement of explosive limits and explosion indices are inductive spark, chemical (pyrotechnic) igniter and fuse wire. Efficiency of each mechanism is different; various results could be reached with the above-mentioned ignition sources. This is manifested by results of measurements of the effect of initial pressure on hydrogen explosive limits using nickel fuse wire and electric spark, see **Figure 1**.

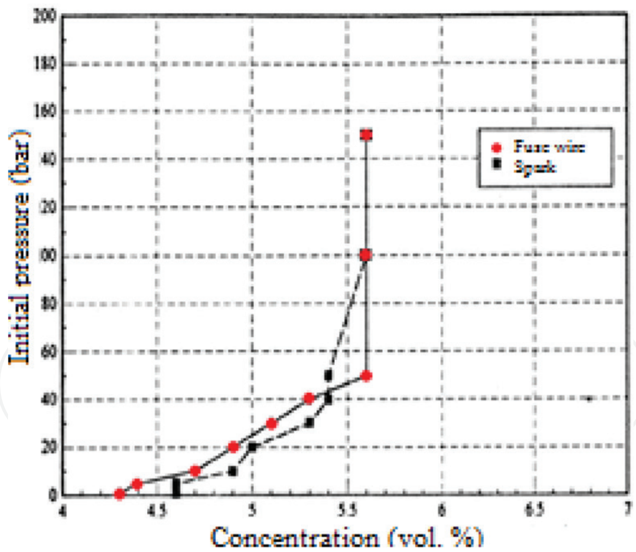

Figure 1. The effect of initial pressure on explosive limits with the use of nickel fuse wire and electric spark (Conrad and Kaulbars, 1995).

2. Tested samples

For experimental measurements of the effect of the ignition energy size on explosion indices, three samples of gases were chosen—methane, propane and hydrogen. Parameters of particular gases are shown in **Table 2**.

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	Methane	Propane	Hydrogen
Physical state at 20°C/101.3 kPa	Gas	Gas	Gas
Molar mass (g/mol)	16.04	44.00	2.01
Melting point (°C)	−182	−188	−259
Boiling point (°C)	−161	−42	−253
Density (kg/m^3)	0.676	1.910	0.090
Critical temperature (°C)	−82.7	97.0	−239.9
Critical pressure (MPa)	4.60	4.25	0.13
Auto-ignition temperature (°C)	595	470	560

Table 2. Properties of tested gases (Material Safety Data Sheet-Methane, Propane, Hydrogen).

3. Experimental setup

The explosion autoclave VA-20 was used for experimental measurement of the effect of the ignition energy size on gas explosion indices. The setup is made for determination of the explosion indices of dust, gases and hybrid mixtures. The volume of the experimental double-coat chamber is 20 L (Kuhner Safety). **Figure 2** presents the scheme of the explosion autoclave VA–20.

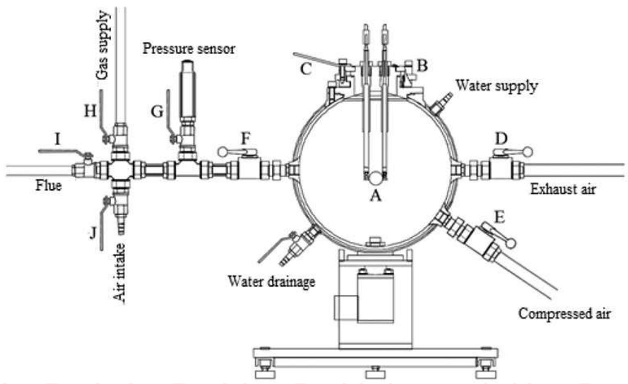

Figure 2. Scheme of 20-L apparatus.

4. Measurement results

Following chapters introduce the experimental results of measurement of explosion indices of methane, propane and hydrogen with air using the apparatus VA-20. The chemical igniter with ignition energies of 80, 160 and 240 J was used. The values of maximum explosion indices and lower explosive limit were determined in a range of minimum 0.5 vol.%.

4.1. Methane

Experimental results of the effect of the ignition energy on the explosion indices of methane are presented in **Table 3** and **Figures 3** and **4**. **Table 4** compares the maximum explosion pressure, maximum rate of explosion pressure rise and the lower explosive limit of methane for particular energies of ignition sources. Percentage changes related to the measurement with the lowest energy are also listed.

Concentration (vol.%)	4.5	5	6	7	8	9	10	11	12	13
					80 J					
p_m (bar)	0	2.2	4.3	5.3	6.1	6.8	7.2	6.8	6.3	5.8
$(dp/dt)_m$(bar s^{-1})	0	12	37	82	138	165	194	145	85	41
					160 J					
p_m (bar)	0	1.9	4.8	6.1	6.9	7.3	7.6	7.7	7.3	6.6
$(dp/dt)_m$(bar s^{-1})	0	12	58	155	209	228	280	218	146	76
					240 J					
p_m (bar)	0.1	0.1	3.0	4.7	6.1	6.7	7.2	7.6	7.3	6.9
$(dp/dt)_m$(bar s^{-1})	0	3	17	68	189	216	255	290	216	133

Table 3. Properties of tested gases (Material Safety Data Sheet—Methane, Propane, Hydrogen).

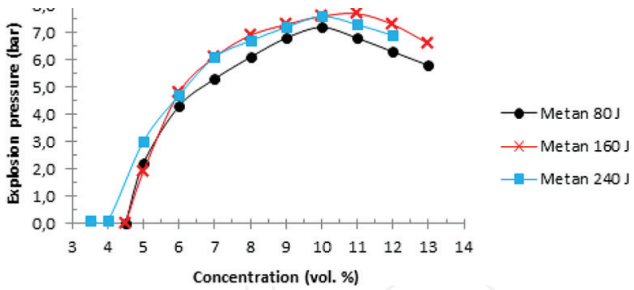

Figure 3. Graph of explosion pressure depending on methane concentration for various ignition energies.

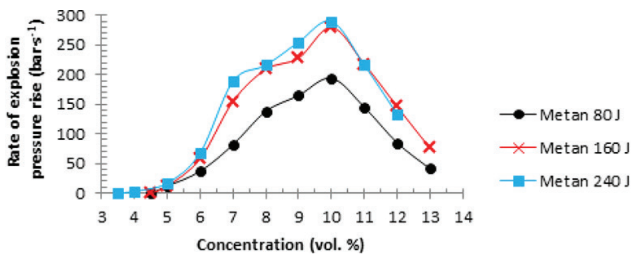

Figure 4. Graph of rate of explosion pressure rise depending on methane concentration for various ignition energies

	80 J	160 J	Methane percentage change (%)	240 J	Percentage change (%)
p_m (bar)	7.3	7.7	5.5	7.6	4.1
$(dp/dt)_m$ (bar s^{-1})	214	283	32.2	290	35.5
K_{Gmax} (bar m s^{-1})	58	77	32.2	79	35.5
LEL (vol.%)	4.5	4.5	0.0	3.5	−22.2

Table 4. Comparison of maximum explosion indices of methane.

4.2. Propane

Table 5 and **Figures 5** and **6** show experimental results of the effect of the ignition energy on the explosion indices of propane. **Table 6** compares the maximum explosion pressure, maximum rate of explosion pressure rise and the lower explosive limit of propane for particular energies of ignition sources. Percentage changes related to the measurement with the lowest energy are also listed.

Concentration (vol.%)	2	2.5	3	4	4.5	5	6	7
				80 J				
p_m (bar)	0	4.8	6.0	7.8	8.1	7.9	7.2	5.6
$(dp/dt)_m$ (bar s^{-1})	0	47	122	262	290	234	125	36
				160 J				
p_m (bar)	0	5.2	6.2	7.7	8.3	8.3	7.5	6.6
$(dp/dt)_m$ (bar s^{-1})	0	63	183	269	362	350	171	80
				240 J				
p_m(bar)	0.1	0.1	6.2	7.7	8.2	8.2	7.6	6.7
$(dp/dt)_m$ (bar s^{-1})	0	5	22	342	374	329	238	121

Table 5. Explosion indices of propane.

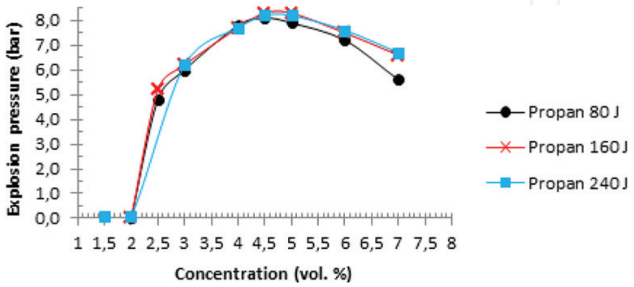

Figure 5. Graph of explosion pressure depending on propane concentration for various ignition energies.

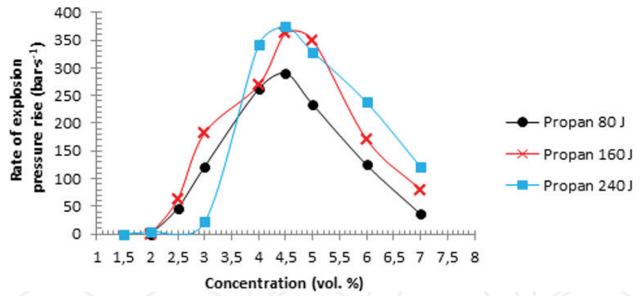

Figure 6. Graph of rate of explosion pressure rise depending on propane concentration for various ignition energies.

	80 J	160 J	Propane percentage change (%)	240 J	Percentage change (%)
p_m (bar)	8.2	8.3	1.2	8.2	0.0
$(dp/dt)_m$ (bar s^{-1})	305	366	20.0	377	23.6
K_{Gmax} (bar m s^{-1})	83	99	20.0	102	23.6
LEL (vol.%)	2.0	2.0	0.0	1.5	−25.0

Table 6. Comparison of maximum explosion indices of propane.

4.3. Hydrogen

Tables 7-A and **7-B** and **Figures 7** and **8** show experimental results of the effect of the ignition energy on the explosion indices of hydrogen. **Table 8** compares the maximum explosion pressure, maximum rate of explosion pressure rise and the lower explosive limit of hydrogen for particular energies of ignition sources. Percentage changes related to the measurement with the lowest energy are also listed.

Concentration (vol.%)	3.5	4	5	6	8	10	15
				80 J			
p_m (bar)	0	0.1	0.4	0.9	1.7	2.8	4.3
$(dp/dt)_m$ (bar s^{-1})	0	5	9	8	10	22	232
				160 J			
p_m (bar)	0	0.1	0.7	–	–	–	4.3
$(dp/dt)_m$ (bar s^{-1})	0	1	8	–	–	–	236
				240 J			
p_m (bar)	0.1	0.1	0.7	–	–	–	4.3
$(dp/dt)_m$ (bar s^{-1})	2	3	9	–	–	–	261

Table 7-A. Explosion indices of hydrogen.

Concentration (vol.%)	20	25	30	31	32	35
			80 J			
p_m (bar)	5.4	6.4	6.9	7.1	7.0	6.8
$(dp/dt)_m$ (bar s^{-1})	838	1566	1899	2166	2091	2105
			160 J			
p_m (bar)	–	6.4	7.0	7.0	7.0	6.8
$(dp/dt)_m$ (bar s^{-1})	–	1498	1880	2018	2203	2010
			240 J			
p_m (bar)	–	6.3	6.8	7.0	7.0	7.0
$(dp/dt)_m$ (bar s^{-1})	–	1546	2170	2183	2288	2295

Table 7-B. Explosion indices of hydrogen—part A.

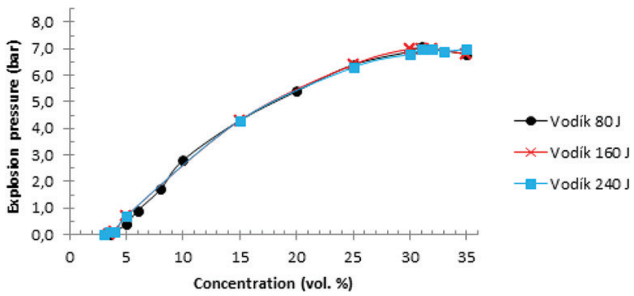

Figure 7. Graph of explosion pressure depending on hydrogen concentration for various ignition energies.

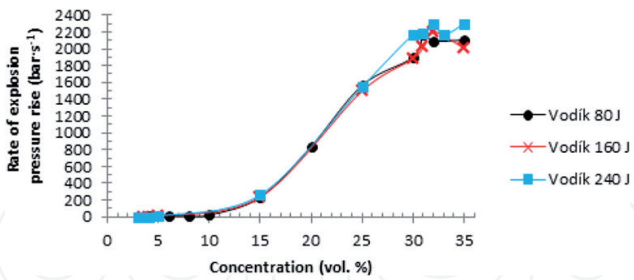

Figure 8. Graph of rate of explosion pressure rise depending on hydrogen concentration for various ignition energies.

	80 J	160 J	Hydrogen percentage change (%)	240 J	Percentage change (%)
p_m (bar)	7.1	7.0	−1.4	7.1	0.0
$(dp/dt)_m$ (bar s^{-1})	2324	2205	−5.1	2372	2.1
K_{Gmax} (bar s^{-1})	631	599	−5.1	644	2.1
LEL (vol.%)	3.5	4.0	14.3	3.5	0.0

Table 8. Comparison of maximum explosion indices of hydrogen.

5. Conclusion

While methane was measured, the rate of explosion pressure rise increased by 32.2% using double energy (160 J) and it increased by 35.5% using triple energy (240 J). Maximum explosion pressure increased by 5.5% using double energy (160 J) and it increased by 4.1% using triple energy (240 J). The lower explosive limit did not change at double energy (160 J). LEL decreased by 22.2% using triple energy (240 J).

While propane was measured, the rate of explosion pressure rise increased by 20.0% using double energy (160 J) and it increased by 23.6% using triple energy (240 J). Maximum explosion pressure increased by 1.2% using double energy (160 J) and it had not changed using triple energy (240 J). The lower explosive limit did not change at double energy (160 J). LEL decreased by 25% using triple energy (240 J).

While hydrogen was measured, the rate of explosion pressure rise decreased by 5.1% using double energy (160 J) and it increased by 2.1% using triple energy (240 J). Maximum explosion pressure decreased by 1.2% using double energy (160 J) and it had not changed using triple energy (240 J). The lower explosive limit increased by 14.3% at double energy (160 J). LEL did not change using triple energy (240 J).

According to experimental data, the inference was made that the size of ignition energy affects especially the rate of explosion pressure rise and the lower explosive limit. Its effect on explosion pressure is only minimal.

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