

**Interest & Aim:**

coke oven gas (COG) is highly rated as a valuable by-product of coal carbonization to produce coke in the steel industry. Typically, a single ton of coke generates approximately 360 m<sup>3</sup> COG (Razzaq et al., 2013). Although COG is regarded as a non-standard gaseous fuel, it still has a reasonable energy content and calorific value, which depend on the nature of coal and the type of carbonization and have been widely used together with blast furnace gas and converter gas in the steel industry in Moravian-Silesian region of Czech Republic. For the assessment of process hazards and the safe design of process equipment handling coke oven gas, the knowledge of safety parameters, such as maximum pressure, maximum rate of pressure rise and burning velocity, is required. In this work, the explosion behavior of coke oven gas/air mixtures is studied. Experimental tests are carried out in a 1 m<sup>3</sup> closed explosion chamber adopted for the explosion tests.

**predictions:** The maximum pressure rise rate during gas explosions in enclosures,  $(dP/dt)_{max}$ , and the deflagration index  $K_{St}$ , are important explosion characteristics of premixture. They are used to quantify the potential severity of an explosion. The maximum pressure rise rate,  $(dP/dt)_{max}$ , depends not only on the mixture properties such as mixture composition, initial temperature and initial pressure) but also on the volume of the vessel in which explosion takes place. Unlike  $(dP/dt)_{max}$ , the deflagration index is an intrinsic property of the premixture and it is independent of the volume of the vessel used in experimental measurements. The relationship between  $K_{St}$ ,  $P_{max}$  and  $(dP/dt)_{max}$  is given by Eq(1-3):

$$\gamma = \left( \frac{dP}{dt} \right)_{\max} V^{1/3} = (36\pi)^{1/3} (P_{\max} - P_0) \left( \frac{P_{\max}}{P_0} \right)^{1/3} s \quad (1)$$

$$= \left(\frac{3V}{4\pi}\right)^{1/3} \left[ 1 - \left(\frac{p^0}{p}\right)^{1/\gamma} \left(\frac{\rho_{max} - p}{\rho_{max} - p^0}\right) \right]^{1/3} \quad (2)$$

$$= \frac{1}{(P_{\max} - P_0)^{1/3}} \frac{1}{3} \left( \frac{4\pi}{3V} \right)^{-1/3} \left( \frac{P}{P_0} \right)^{1/3} \left[ 1 - \left( \frac{P}{P_0} \right)^{1/3} \left( \frac{P_{\max} - P}{P_{\max} - P_0} \right) \right]^{-2/3} \frac{dP}{dt} \quad (3)$$

in which  $K_{St}$  is the deflagration index (bar.m/s),  $V$  is the vessel volume ( $m^3$ ),  $(dP/dT)_{max}$  is the maximum rate of pressure rise (bar/s),  $P_{max}$  is the maximum explosion pressure (bar),  $P_0$  is the initial pressure (bar), and  $\gamma$  the adiabatic coefficient of the unburned gas (-),  $s$  is burning velocity ( $m/s$ ),  $r_f$  is the flame radius ( $m$ ),  $P$  is the actual pressure (bar), and  $dP/dT$  is the rate of pressure rise (bar/s).

## Results and Discussions

According to standard EN 13673-1, the maximum explosion pressure is determined experimentally by preparing test mixtures of COG and air as oxidizing gas and conducting ignition tests at ambient conditions. Experiments are, however, expensive and time consuming, especially at elevated conditions of temperature and pressure, at which many industrial processes occur.

TABLE 1 Measured explosion parameters for COG/O<sub>2</sub>/N<sub>2</sub> mixtures of various compositions

Set	Fuel (vol.%)	Air (vol.%)	$P_{\text{air}}$ (bar)	$P_{\text{max}}$ (bar)	$P_{\text{air}}^*/P_{\text{max}}$ (bar)	$T_{\text{max}}$ (ms)	$(dP/dT)_{\text{max}}$ (bar/s)	$\alpha$ (ms)
1	5.2	94.8	4.01	1.04±0.020	2.97	12.67	0.34±0.034	1.83
2	7.0	93.0	4.87	2.38±0.047	2.51	7.75	0.62±0.062	0.05
3	8.7	91.3	5.62	4.30±0.086	1.32	4.01	3.22±0.032	0.07
4	10.0	90.0	6.15	5.45±0.109	0.68	2.04	17.90±1.790	0.24
5	15.0	85.0	7.85	7.57±0.151	0.27	1.50	178.5±17.851	1.28
6	20.0	80.0	8.58	8.19±0.163	0.39	1.50	180.12±18.012	1.11
7	22.5	77.5	8.47	7.84±0.156	0.63	1.70	97.15±9.715	0.85
8	25.0	75.0	8.25	7.00±0.140	1.25	1.99	41.78±4.178	0.35
9	35.0	65.0	7.02	4.45±0.089	2.57	6.84	26.94±2.694	0.55
10	35.2	64.8	6.59	1.72±0.034	4.87	10.85	0.47±0.047	0.10

TABLE 2 Measured explosion parameters for  $\text{CH}_4/\text{O}_2/\text{N}_2$  mixtures of various compositions

Test	Fuel (vol.%)	Air (vol.%)	$P_{\text{max}}$ (bar)	$P_{\text{max}}$ (bar)	$P_{\text{max}}$ (bar)	$T_{\text{max}}$ (ms)	$(dP/dT)_{\text{max}}$ (bar/s)	$a_1$ (m/s)
1	4.0	96.0	5.05	1.81±0.036	3.23	7.87	0.49±0.497	0.09
2	5.0	95.0	5.83	3.39±0.067	2.44	8.27	2.46±0.246	0.09
3	9.2	94.8	5.97	4.48±0.089	1.48	5.62	2.43±0.243	0.05
4	9.5	93.5	6.86	5.54±0.110	1.31	3.38	5.51±0.551	0.07
5	8.4	91.6	7.95	7.89±0.159	0.95	2.24	83.32±6.332	0.42
6	10.5	89.5	8.74	8.42±0.166	2.24	2.17	76.96±7.696	0.45
7	11.0	89.0	8.84	8.59±0.131	2.24	2.82	9.31±0.931	0.09
8	12.8	87.4	8.61	6.04±0.120	2.82	3.50	4.81±0.481	0.05
9	14.8	85.2	8.59	5.62±0.112	2.96	5.19	3.46±0.344	0.04
10	15.6	84.4	8.47	5.22±0.104	3.25	6.75	3.07±0.307	0.04

TABLE 3 Measured explosion parameters for  $H_2/O_2/N_2$  mixtures of various compositions

Fuel (vol.%)	Air (vol.%)	$P_{rel}$ (bar)	$P_{rel}^{max}$ (bar)	$T_{max}$ (ms)	$(dP/dT)_{max}$ (bar/s)	$c_s$ (m/s)
5.0	95.0	2.76	1.67±0.003	1.08	9.72	0.42±0.042
10.2	89.8	5.30	4.40±0.088	0.86	1.72	45.11±4.511
15.0	84.0	6.75	5.90±0.118	0.84	1.09	228.95±22.895
20.0	80.0	7.60	6.91±0.138	1.69	1.03	524.11±52.411
25.0	74.0	8.60	7.77±0.155	0.82	0.99	842.30±84.230
29.0	71.0	8.92	8.01±0.160	0.90	0.98	927.77±92.777
30.0	70.0	8.91	7.86±0.159	0.95	0.98	922.72±92.272
35.0	65.0	7.95	7.82±0.156	0.12	0.98	918.10±91.810
37.2	62.8	7.86	7.56±0.151	0.29	1.28	875.28±87.528
45.0	55.0	7.38	6.92±0.138	0.45	1.50	659.29±65.921

FIGURE 4 Development of the flames (4.5 vol. %  $H_2$ , 95.5 vol. % air) in the course of an explosion.

**Conclusion:** Scientific achievements of this article are new 1 m<sup>3</sup> experimental set-up description, validation and determination of COG explosion parameters at ambient conditions. Both gas explosion severity parameters and burning velocity have been determined. This work is aimed at fundamentally improving the understanding of gas phase oxidation processes of hydrocarbons mixtures, the risk assessment of such processes, their environmental efficiency and safety in chemical industry it refers to large-scale hydrocarbon (partial) oxidation processes. These processes form the basis of much of the (petro-) chemical process industry. These activities are of great importance to the improvement and extension of the applicability of standards for the determination of explosion indices such as the maximum explosion pressure, maximum rate of pressure rise and burning velocity.

## References:

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## Experiment:

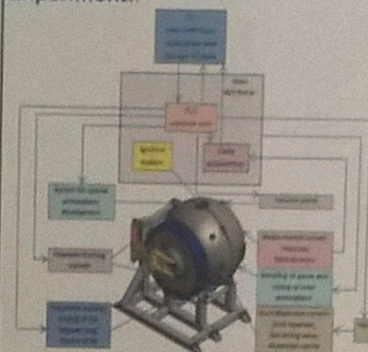


FIGURE 1. Representation of the experimental system

Spherical explosion chamber with the internal volume of 1.020 m<sup>3</sup> allows the measurement of parameters of explosive dust dispersion in accordance with the terms and specifications in EN 1839. Schematic representation of the explosion system is shown in Fig. 1. The mixing process proceeds inside the explosion chamber. The gases are dosed into the chamber from the dosing vessel equipped by three inputs: connection to cylinders with nitrogen and oxygen and line for free suction of air from outside. The explosion chamber is equipped with measurement of time depended dynamic pressure using pressure sensors (Kistler type 701A, accuracy 0.00125 MPa, sampling rate: 400 k/s) and also by the measurement of the flash duration. Control of the mechanical parts of the chamber, dispensing system control, ignition system, the system for the preparation of initial internal atmospheres other than air, including homogenization, data acquisition system is connected to the main distributor.



FIGURE 2 Development of the flames (10.0 vol.% COG, 90.0 vol.% of air) in the course of an explosion

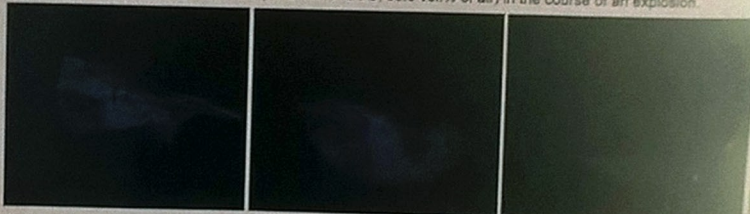


FIGURE 3 Development of the flames (4.0 vol. % CH<sub>4</sub>, 96.0 vol. % air) in the course of an explosion

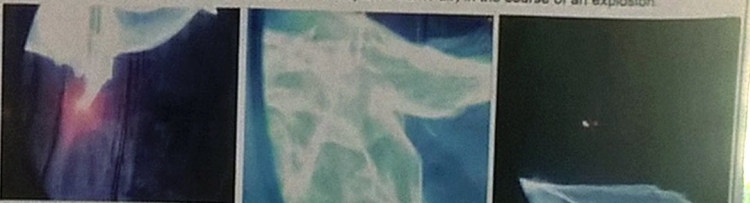


FIGURE 4 Development of the flames (4.5 vol. %  $H_2$ , 95.5 vol. % air) in the course of an explosion

