

Influence of Pressure and Temperature on Safety Characteristics of Syngas-air Mixture Produced by Autothermal Gasification Technology

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Most safety characteristics published so far are valid for specific and limited conditions. No explosion characteristic exists for synthesis gas which cover all conditions occurring in “real life” and resulting conditions. This requires more information and systematic investigation of the explosion parameters of synthesis gas in air under various conditions. The paper presents the results of an experimental evaluation of the safety characteristics for synthesis gas multi-component (CO-H₂-CH₄-C₃H₈)-O₂-(CO₂-N₂) mixture at temperatures of 323 K, 373 K and 423 K and at elevated pressures of 0.50 bar, 0.75 and 1.00 bar.

1. Introduction

The production of syngas using agricultural waste and the use of wind and solar energy in combination with water electrolysis is one way to substitute natural gas. Therefore, the number of synthesis gas (syngas) plants is growing very fast (Knoef et al., 2012).

On the other hand, the operation of such plants could be responsible for a significant number of accidents. The focuses of this contribution are the explosion characteristics and hazards arising from the synthesis gas. In order to prevent explosions when storing and handling syngas it is necessary to know the explosion limits of individual gas components and its gas mixtures in mixture with air. However, syngas from gasification unit can vary significantly in its composition. Therefore, for each gas composition the explosion limits would have to be determined. This would require a considerable amount of time and effort. Due to this fact, the explosion limits of syngas are frequently referred to only by the hydrogen fraction of the gas mixture in the safety-relevant literature. In reality as syngas consists of hydrogen, methane, carbon monoxide, carbon dioxide and further residual gases the explosion limits are generally over or underestimated (Skrinsky et al., 2015).

These explosion characteristics are important for design of safety devices (e.g. relief systems, vents), able to ensure active protection of pressure vessels where flammable mixtures are formed. Beyond safety devices, the values of these parameters are useful for emergency planning especially for developing scenarios where emergency relief or external heat transfer may be inadequate. At the same time, the maximum explosion pressure that the explosion reaction can generate is one good measure of the magnitude of the hazard associated with the reaction (CCPS, 1995).

2. Autothermal gasification technology

The autothermal gasification technology at the Energy Research Centre was developed as a result of the Project “Biomass Gasification for Cogeneration”. The aim of the Project was using the generated gas in a cogeneration unit with a piston combustion engine for the electric energy and heat production. Base of this technology is a fixed-bed gasification generator. The fuel is supplied to the grate of the gasification reactor from a fuel bin by the two screw conveyors. The fuel is supplied to the reactor’s lower part automatically based on a measured temperature in the gasification reactor. The generated gas is transported to the hot filter, where are removed dust particles. Behind the filter are gas cooler, exhaust fan and combustion chamber, in which the producer gas is combusted (Skrinsky et al., 2015).



Figure 1: Autothermal gasification technology: a) gas cleaning devices - hot filter, gas cooling and exhaust fan; b) fuel bin and fuel transport into autothermal gasifier.

The technology is operated in the low under pressure and it is provided by a necessary measurement and control technological units. Thermal output of the autothermal gasifier is 100 kW. As a fuel for testing was used wood pellets with diameter 6 mm. Gas for analysis was sampled from sampling point 2 depicted in Figure 2.

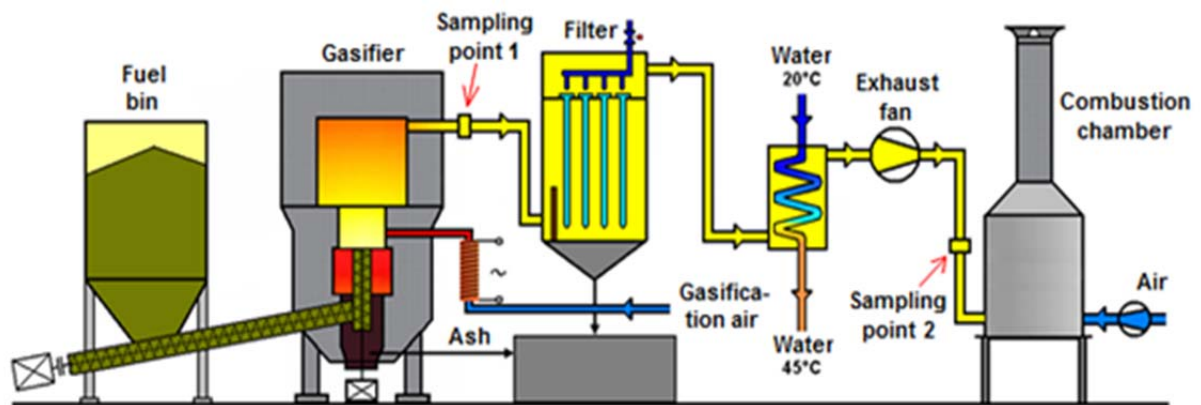


Figure 2: Autothermal gasification technology: a) gas cleaning devices - hot filter, gas cooling and exhaust fan; b) fuel bin and fuel transport into autothermal gasifier

Table 1: The average composition of syngas produced for the experiments (dry basis)

Ingredients	H ₂	CH ₄	CO	C ₃ H ₈	O ₂	CO ₂	N ₂
Content %	15.9	2.1	20.2	1.0	0.1	11.8	48.9

3. Problem Formulation

Most explosion characteristics published so far are valid for pure compounds and limited experimental conditions, mostly ambient. There have been no explosion characteristic exists for synthesis gas-air mixtures which cover industrial conditions up to 423 K and initial pressures 0.50 bar, 0.75 bar and 1.00 bar.

4. Experiment

The experiments were performed with the experimental setup adopted in previous studies (Skrinsky et al., 2016a) where detailed description has been given. Measurements of the p_{max} and $(dp/dt)_{max}$ have been performed in the 0.020 m³ explosion chamber with working pressure up to 30 bar. The experimental set-up according to EN 15967 consists of pressure acquisition system, heating system, and a constant volume vessel with the ignitor centrally located. During explosions, the pressure in the combustion vessel was tracked by the

pressure transducer (Kistler 701A) and recorded together with a Charge Amplifier (Kistler 5011). The pressure transducer works at a sample rate of 100 kHz. The air is supplied as the mixture of 79% N₂ (>99.95%) and 21% O₂ (>99.95%). A series of induction sparks generated between stainless steel electrodes was used as an ignition source. The tips of the electrodes were positioned at the centre of the vessel. The distance between the tips was (5 ± 0.1) mm. The mounting of the electrodes was resistant to the heat and pressure generated during the tests and provided adequate electrical resistance from the test explosion vessel. A high voltage transformer (root mean square: 13–16 kV; short circuit current: 20–30 mA) was used for producing the series of ignition sparks. A timer was used to set the required discharge time of 0.2 s. Explosion tests have been performed at different initial concentration of SYNGAS-air at standard initial temperature and pressure ($T_{init} = 298.15 \text{ K}$, $p_{init} = 1 \text{ bar}$) and elevated temperature and pressure ($T_{init} = \text{up to } 423 \text{ K}$, $p_{init} = 0.5\text{-}1.0 \text{ bar}$).

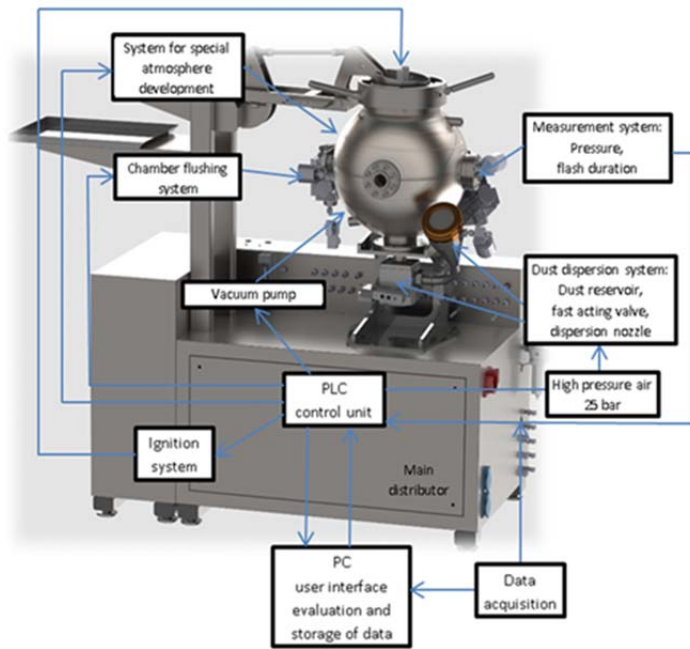


Figure 3: General diagram of the testing system adopted for the explosion tests

The experimental procedure was as follows: (a) the air in the explosion vessel was evacuated to a vacuum of 0.1 mbar; (b) mixing gases were added into the vessel at different ratios; (c) the mixture was admitted at the desired pressure, then ignited at once; (d) after ignition and the capture of the signals by the acquisition system, the burned gas was completely evacuated. Then, a new cycle was repeated. Care was taken not to warm up the equipment by explosions by temperature control unit Presto A30, (JULABO GmbH).

5. Results and discussion

Figure 4 gives the variation of normalized explosion pressure with equivalence ratio for syngas-air mixtures at atmospheric pressure and four initial temperatures. At normal pressure as shown in Figure 4, the peak explosion pressure decreases in the order of 298 K, 323 K, 373 K and 423 K giving approximate values. The difference of peak explosion pressure among the different temperatures is more significant for rich mixtures than for lean mixtures. Particularly, flame speed is quite low at the extremely rich mixture, causing large heat loss to the vessel wall and greatly reducing p_{ex}/p_0 .

Figure 5 shows the effect of initial pressure. The change in the initial absolute pressure of the degas-oxidant mixture at an atmospheric initial temperature produces a proportionate change in the maximum pressure developed by a deflagration of the mixture in a closed vessel (NFPA, 2002).

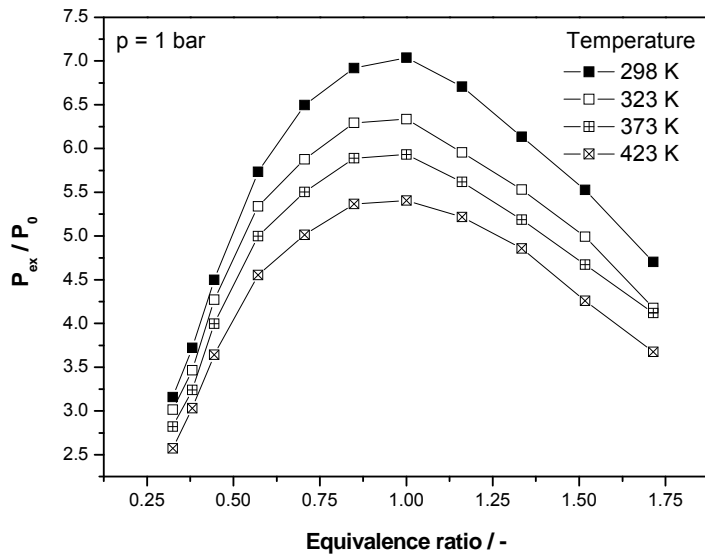


Figure 4: Normalized peak explosion pressure (p_{ex}/p_0) versus equivalence ratio at atmospheric pressure and four initial temperatures.

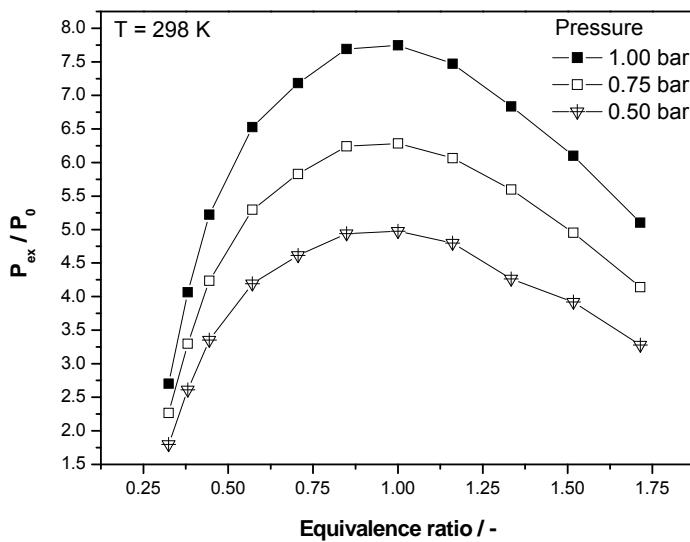


Figure 5: Normalized peak explosion pressure (p_{ex}/p_0) versus equivalence ratio at atmospheric temperature and three initial pressures.

Figure 6-7 show the maximum rate of pressure rise, $(dp/dt)_{max}$, and deflagration index, K_G , versus equivalence ratio at elevated temperatures and pressures for the syngas-air mixtures. Maximum rate of pressure rise and deflagration index reach their peaks at around 1.0, and they decrease at both lean and rich mixtures. As shown in Figure 6, $(dp/dt)_{max}$ and K_G give an approximate value at varied initial temperatures, indicating that $(dp/dt)_{max}$ and K_G are less sensitive to the variation of temperature than p_{ex}/p_0 . Rate of pressure rise is affected by both flame speed and heat release. Flame speed increases monotonically with the increase of temperature but the decrease of total fuel mass results in the decreased heat release and offsets the effect of flame speed on the explosion pressure.

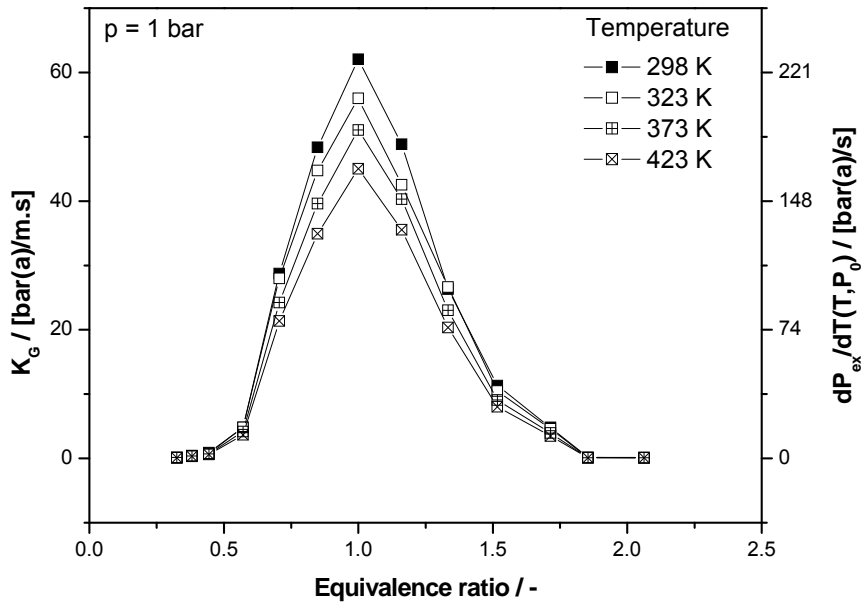


Figure 6: Rate of pressure rise, $(dp/dt)_{ex}$, and deflagration index, K_G , versus equivalence ratio at atmospheric pressure and four initial temperatures.

With the increase of initial pressure as shown in Figure 7, $(dp/dt)_{max}$ and K_G increase dramatically, especially around equivalence ratio of 1.0. This differs from the flame speed, but agrees with the mass burning flux when taking into account of the effect of density. It is noted that deflagration index is less than 199 at $\Phi = 1.0$ and the initial pressure of 0.5 bar, belonging to the first class of $(dp/dt)_{max}$ and low potential of explosion hazard, i.e. ≤ 200 bar.m/s (NFPA, 2002). However, K_G exceeds 30 bar around the stoichiometric ratio at the pressures equal, lower than 0.5 bar, and enters the lowest class of deflagration index.

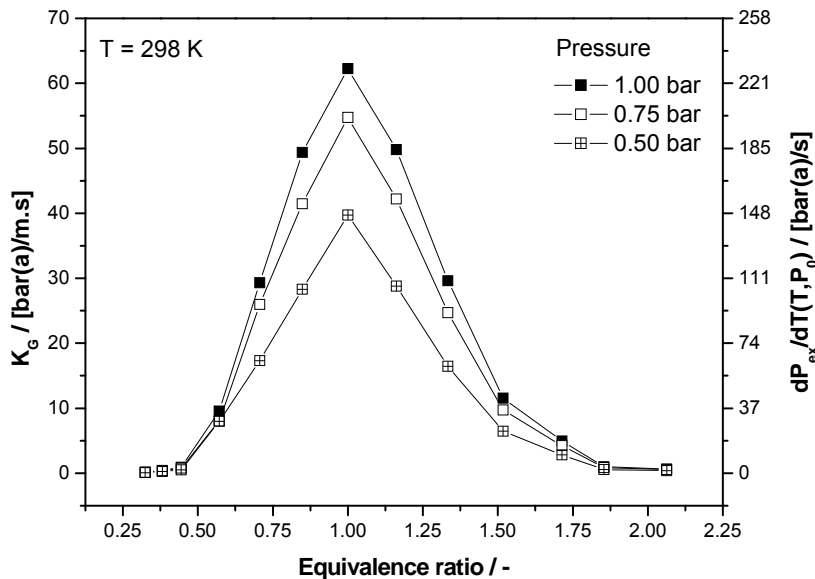


Figure 7: Rate of pressure rise, $(dp/dt)_{ex}$, and deflagration index, K_G , versus equivalence ratio at atmospheric temperature and three initial pressures.

6. Summary

Table 2 and 3 give the values of the normalized explosion pressure, p_{ex}/p_0 , explosion pressure rise rate $(dp/dt)_{max}$ and deflagration index, K_G , for different initial temperatures and pressures of the synthesis gas -air mixture. Table 2 and Table 3 show average values and measurement deviations calculated from three experimental data values measured under identical initial conditions.

Table 2: Average values of the explosion characteristics at $\Phi = 1,0$ and $p_0 = 101$ kPa

Characteristic	Unit	$T_0 = 298$ K	$T_0 = 323$ K	$T_0 = 373$ K	$T_0 = 423$ K
P_{max}/P_0	[-]	7.0±0.4	6.3±0.3	5.9±0.3	5.4±0.3
$(dp/dt)_{max}$	[bar/s]	62,0±6.1	55.9±5.7	51.0±5.2	45.0±4.7
K_G	[bar·m/s]	16.8±1.5	15.2±1.4	13.8±1.2	12.2±1.1

Table 3: Mean values of the explosion characteristics at $\Phi = 1,0$ and $T_0 = 298$ K

Characteristic	Unit	$p_0 = 0.50$ bar	$p_0 = 0.75$ bar	$p_0 = 1.00$ bar
P_{max}/P_0	[-]	4.9±0,2	6.3±0.3	7.0±0.4
$(dp/dt)_{max}$	[bar/s]	39.7±4.1	54.7±5.5	62,0±6.1
K_G	[bar·m/s]	10.8±1.1	14.8±1.4	16.8±1.5

7. Conclusions

Energy Research Centre, VŠB-TU Ostrava is aimed at fundamentally improving the understanding of synthesis gas oxidation processes, the risk assessment of such processes, their environmental efficiency and safety (Skrinsky et al., 2016b). The focus of this paper is to quantify the explosive properties of the gas mixture produced by autothermal gasification for different initial temperatures and pressures (Tables 2-3). The main conclusions are summarized as follows:

1. Explosion pressure, rate of explosion pressure rise and deflagration index of the synthesis gas mixture reach maximum values near the stoichiometric concentration with an equivalent ratio $\Phi = 1$ within the studied range, i.e. 0.3-2.1 at temperatures of 323-423 K and pressures of 0.5-1.0 bar.
2. The explosion pressure, the rate of explosion pressure rise and the deflagration index of the synthesis gas mixture increase with increasing initial pressure and decrease with the increasing initial temperature for the given measurement conditions.

Acknowledgments

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Reference

- CCPS: Center for Chemical Process Safety, 1995, Guidelines for Safe Storage and Handling of Reactive Materials. Center for Chemical Process Safety.
- Eckhoff, R., 2015, Explosion Hazards in the Process Industries, 1st ed. Gulf Publishing Company.
- EN 15967, 2012. Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours. European Standard, Beuth Verlag, Berlin Wien Zurich.
- Knoef et al., 2012, Handbook biomass gasification – second edition, BTG Biomass Technology Group BV; 2nd edition.
- NFPA 68, 2002. Guide for Venting Deflagrations. National Fire Protection Agency
- Skrinsky J., Veres J., Peer V., Friedel P., Travnickova J., Dalecka, A., 2016b, Explosion parameters of coke oven gas in 1 m³ explosion chamber, Chemical Engineering Transactions, 53, 7-12, DOI: 10.3303/CET1653002
- Skrinsky J., Veres J., Peer V., Friedel P., 2015, Explosion characteristics of syngas mixtures at elevated temperatures and pressures, Journal of Safety Research and Applications, 8.
- Skrinsky J., Veres J., Travnickova J., 2016a, Explosions caused by corrosive gases/vapors, Materials Science Forum, 844, 65-72, DOI: 10.4028/www.scientific.net/MSF.844.65.