Ignition Temperatures of Explosive Atmospheres of CS_2 in Dependence on Spatial Orientation of the Hot Surface

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1 Introduction

The hot surfaces are an important ignition source that can cause explosions and fires in industry [1]. It must be safely mastered in equipment for use in potentially explosive atmospheres. The temperatures that cause ignition can be originated by various sources such as electrical currents, optical radiation, ultrasound or mechanical friction. The aim of this work is to investigate the ignitability of hot surfaces as a function of their temperature and their spatial orientation. The term associated with ignition by a hot surface is the safety characteristic AIT (autoignition temperature). It is determined by standard test methods (ISO/IEC 80079-20-1 [2]). It is the lowest temperature using the standard procedure, at which an explosive atmospheric mixture of vapors or gases with air is ignited [3]. AIT is used for classification of substances and of equipment into temperature classes (T1 to T6 acc. to IEC 60079-0 [15]). But it has limited application in a practical situation as the actual ignition temperatures (IT) are, except some specific cases, always higher than the AIT [3,4,5].

Ignition by a hot surface is a complex phenomenon which depends on the experimental condition, type of ignition source (like size, shape, material) and its orientation as well as the mixture composition [1,6]. Earlier experimental work was conducted with different ignition source like pipes, plates, glow plug [5,6,7] and different position of an ignition source [7,8,9]. Simulation work has been done for stoichiometric ethylene mixture for different orientations of a hot cylinder. The ignition temperature was found to be 128 K lower for horizontal orientation than for the vertical [8]. Experimental work on vertical hot pipelines resulted in ignition temperature 20 K higher than with a horizontal pipe [7]. This work can be used to understand the ignition mechanism in our experiment as in both cases natural convection has a strong influence on IT. Other experimental work using a U-shaped steel tube ignitor, gained an IT of CS_2 of 180 °C [10]. In most of the investigations small heating bodies are used in vertical and horizontal positions. There is lack of IT data available for larger hot surfaces as they may appear in electrical or mechanical equipment. This will be covered here, by using a hemispherical heating body of d = 100 mm in five different orientations of the heating body. The results shall be used for validation, modelling and future studies by numerical simulation.

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In another paper, hot surface ignition of a hydrogen-air mixture by glow plug (h = 9,3 mm, d = 5,1 mm) was investigated. According to the experimental results, heating rate affects the location where ignition is initiated. For a moderate heating rate (60 K/s), ignition occurs just above the top of the glow plug while at a higher heating rate (180 K/s), ignition occurs at the side of a glow plug. This happened due to non-uniform heating of the glow plug at a higher heating rate [11,12].

2 Mixture Preparation and Experimental Setup

Carbon disulphide has been chosen as it has the lowest ignition temperature (IT), a low boiling point and a low minimum ignition energy. This ensure that the real IT can be reached by the heating body and the time needed for the experiments remains low. The safety characteristics are taken from CHEMSAFE database [13]. They are shown in table 1.

Table 1: Safety characteristic data of carbon disulfide [13]

Substance	Boiling point	AIT	Temperature Class	Ex Group	Flash point	LEL	UEL	MIE
CS_2	46 °C	95 °C	T6	IIC	< -20 °C	0,6 vol% ± 10 %	60,0 vol% ± 5 %	0,01 mJ

From the selected concentration, we calculate the pump rate and the amount of required air supply. The KP2000 liquid pump (pumping rate 1 to 2000 ml/h) supplies CS_2 into the pipe. The air was taken from a compressed air network and passing through the drying cartridge. It consists of silica gel, which helps to get dry air for the experiment. The mixture of liquid and air pass through a heated evaporator coil. The coil is heated by the DC power supply. The premixed gas/ air mixture enters from the bottom of the cylinder. The experiment was done with quiescent gas/air mixture at atmospheric conditions (T = 21 °C, p = 1 bar). The mixture composition is supplied by the pump rate and is controlled by a gas analyzer (Oxymat), which work on the paramagnetic oxygen principle. A cylindrical glass vessel made of borosilicate and a volume of 37 l is shown in figure 1a. The cylinder is made of glass to record the ignition behavior with a high-speed camera. The material can withstand with a maximum of 1 bar overpressure, but explosion pressure is 10 bar which exceeded the specification for the material. So, an aluminum foil is used as a quick pressure relief rupture disk. The necessary diameter is calculated acc. to EN 14994 [14]. In the bottom of the cylinder convex spherical heating body (diameter 100 mm) is mounted in the center position. The heating body is installed in a stainless-steel ring in the bottom plate (aluminum). The bottom plate contains an insulation ring for thermal decoupling (fig. 1b).

The heating body is made of copper with a surface coating of gold to minimize the loss due to radiation (worst case) and to avoid catalytic effects. There are 7 heating cartridges attached to the heating body in such a way that heat will distribute evenly (fig. 1b and c). The power supply used for heating is a variable transformer (maximum output 230 V). The actual voltage is measured. For all experiments, voltage varies between 222 V and 226 V. The bottom plate consists of a continuous operating cooling system with a double flushing channel. The temperature of water maintained at 21 °C with the help of cryostat. The aim behind the insulation and cooling system is to achieve a steep temperature gradient between the heating body and bottom plate. Thus, it can be assumed that heating body and bottom plate are thermally isolated.

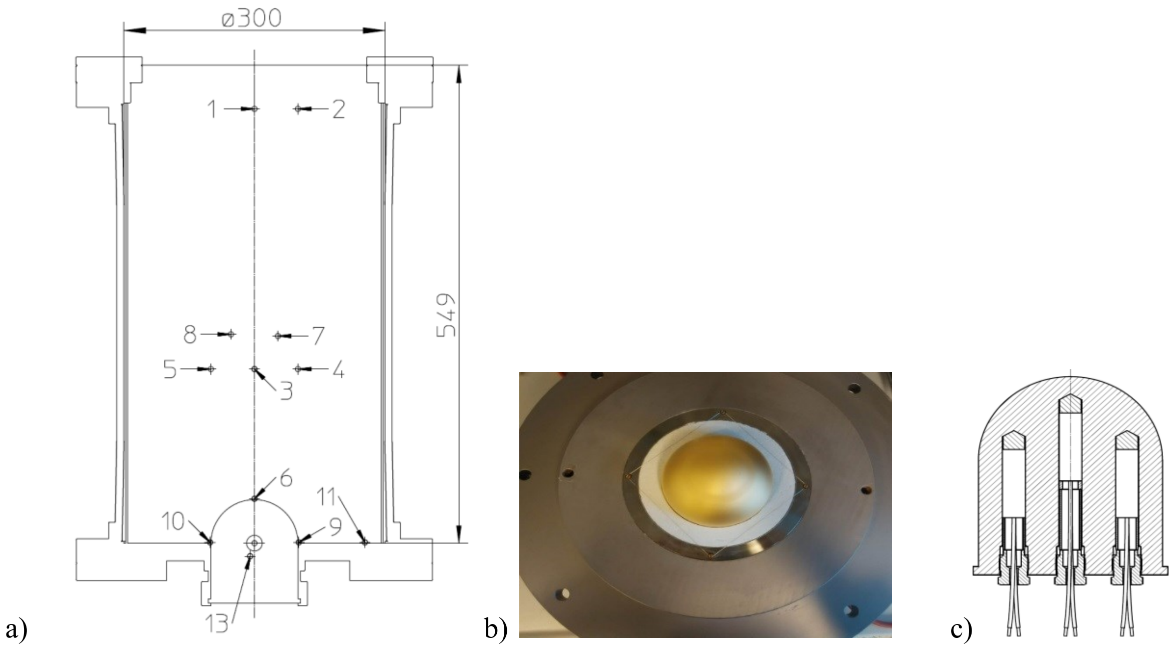

Figure 1: a) Cylindrical vessel with the hemispherical heating element and the positions of the thermocouples; b) Heating body with insulation ring; c) Heating body with heating cartridge

5 different positions of a heating body were used, counted from 0° (upright position, see fig. 1a) to 180° in steps of 45°. There are 13 type K thermocouples (T1 to T13; diameter 0,13 mm) mounted inside the vessel (tab. 2). T13 is inside the heating body and not in contact with gas mixture. The positions of the thermocouples can only be changed very time-consuming. They are chosen so that they can later be used for comparison with numerical simulations, mainly in the 0° position. They consider the resulting convective flow due to buoyancy. The temperature curves are recorded using a LabVIEW program and stored digitally. The experiment is performed in the fume hood with a continuous ventilation system to ensure safety at work. The concentration of the CS_2/air mixture was modified systematically. The measurement uncertainty of the ignition temperatures and the mixture compositions are ± 3 °C and ± 0,05 vol%, respectively. All experiments have been carried out twice and, in case of differing results, repeated a third time. The lowest value measured is assigned as ignition temperature (IT).

Table 2: Position of the thermocouples inside the cylindrical vessel
(x axis is along the symmetry axis of the vessel, the bottom of the vessel is zero; y and z axis form the plane parallel to the bottom of the vessel; y and z are exchangeable in the symmetric cylindrical configuration.)

	1	2	3	4	5	6	7	8	9	10	11
x coordinate/mm	+000	+050	+000	+050	-050	+000	+027	-027	+051	-051	+127
y coordinate/mm	+499	+499	+200	+200	+200	+051	+238	+240	+001	+001	+001
z coordinate/mm	+000	+000	+000	+000	+000	+000	+147	+147	+000	+000	+000

3 Results

The ignition temperatures of the CS_2/air mixtures for the different positions of a heating body are given in figure 2. For position 0°, 45° and 90°, the change in ignition temperature is very small. For the 90° position, IT remains 1 to 2 °C lower compared to the 0° position. In contrast, IT for 135° are close to IT for 180°. For 180° ignition temperatures are highest. From figure 2 we can see the ignition temperature of CS_2 increases with increasing concentration for all positions. This is in accordance with [10]. Here, we only discuss the results of the orientation 0° and 180° in detail. For 0.8 vol% (position 0°) and 1.5 vol% (180°), a cold flame generates as we are near to the lower explosion limit (0.6 vol%). For lower concentrations at 1 % to 1,5 %, after the ignition, flames will remain for a long time compared to a higher concentration. For 4 vol% (180°), IT is 271 °C, which is like IT at stoichiometric mixture (6.5 vol%) in position 0°. Near the stoichiometric mixture ignition becomes faster. We did not conduct the experiment higher than a stoichiometric mixture to ensure safe operation. During all experiments at 0°, we observed the temperature rise of thermocouple 1 and 2 initially, which indicate convection flow generates inside the vessel. For 180°, we did not observe temperature rise of thermocouple 1 and 2 initially which indicates the flow is very low. The different flow pattern for both orientations is a principal reason for the difference of the IT at the 0° and 180° position.

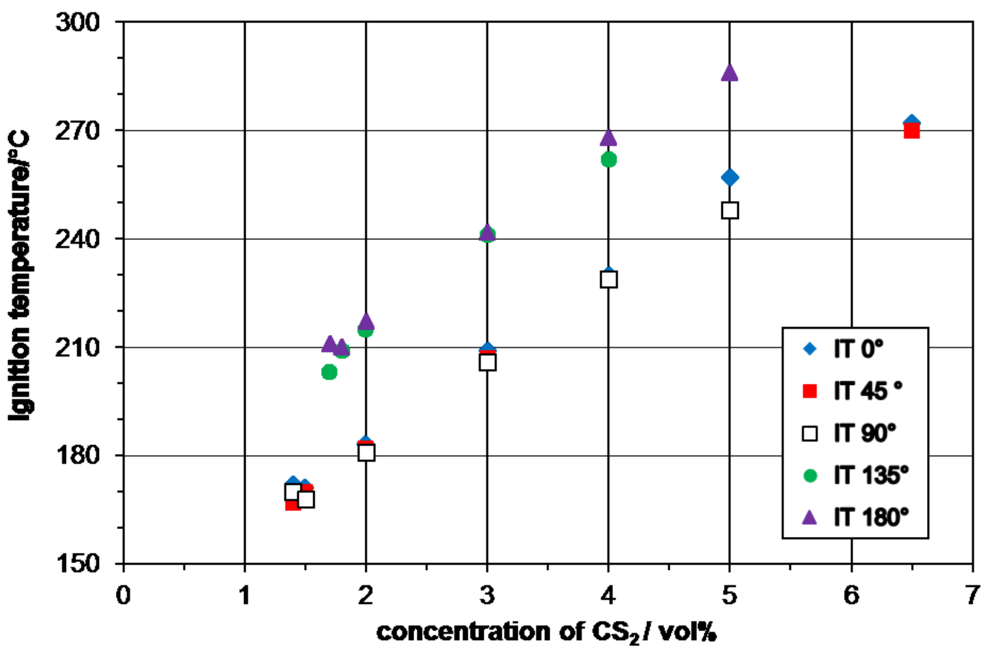

Figure 2: Ignition temperature vs concentration for the positions 0°, 45°, 90°, 135°, 180°

In figures 3 and 4, temperature curves are given for position 0° and position 180°, respectively. The total time of ignition is 0,48 s for 0° and 0,66 s for 180°. From both diagrams, we can see the maximum temperature rise at thermocouple 1, 3 and 6 for both orientations which justifies the position of the thermocouples. For 0° (figure 3, image 1), ignition occurs at the top of the heating body. In this area the velocity is low, and the temperature is high. Thus, the gas volume will find stable conditions for a longer residence time compared to other volume elements. For 180° (figure 4, image 1), ignition occurs again at the highest part of the heating body where, in this case, the flow forms a ring-shaped stagnation zone near the wall [8].

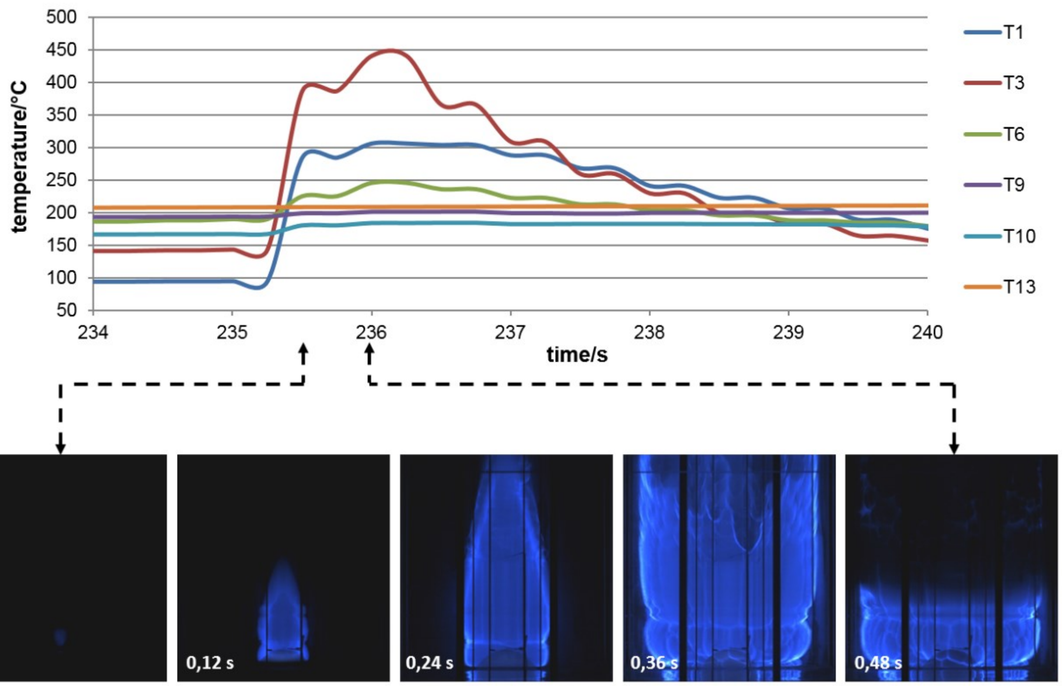

Figure 3: Temperature vs time diagram with an image sequence for 3 vol% of CS_2; position 0°

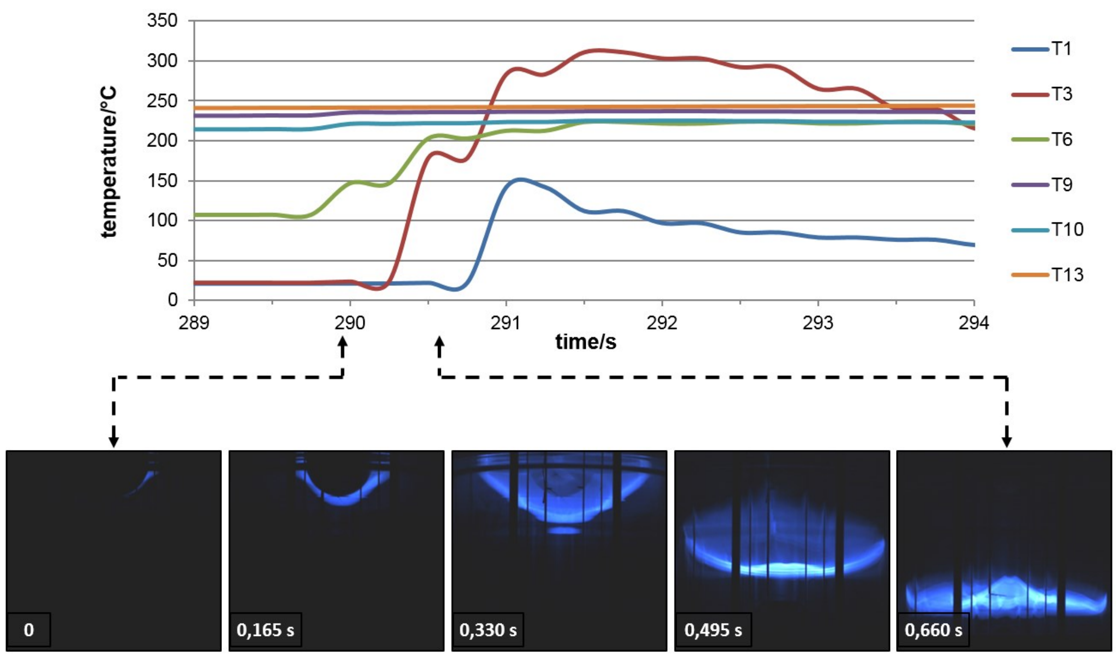

Figure 4: Temperature vs time diagram with an image sequence for 3 vol% of CS_2; position 180°

4 Conclusions

In agreement with [10] the ignition temperature below the stoichiometry of carbon disulfide decreases with decreasing concentration. For spherical convex hot surfaces, the lowest ignition temperature occurs near the LEL. The minimum ignition temperature is 160 °C in the 0° position and 211 °C in the 180° position. At all CS_2 concentrations, the difference in ignition temperatures between the two positions remains nearly the same at about 30 °C. This is due to the resistance to the natural convection current in the cylinder. In this experimental study, natural convection plays a key role in the ignition process. The influence is not significant at 0°, 45° and 90° and approximately equal at 135° and 180°. This must not be quantitatively transferred to other forms of ignition source, since then change the flow conditions in the different positions.

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