Deliverable 5-5

REPORT ON DESIGN, CONSTRUCTION AND INSTRUMENTATION OF PARTIALLY VENTED EXPLOSION TUBE (PET)

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Introduction

Introducing hydrogen as fuel for land vehicles makes it necessary to consider not only the benefits of this fuel but also possible safety risks arising from hydrogen. While hydrogen has been used in many industrial applications with well controlled risk for a long time, the new applications are characterized by a different user group and a possibly much larger user base. Safety considerations must now take into account untrained personal and accidents in an unknown environment. In safety studies of hydrogen vehicles explosion events are considered which involve accidental release of hydrogen into a partially vented, partially confined geometry. This can be the engine compartment, the passenger compartment, the trunk or the vicinity of the vehicle. Explosion accidents in transport vehicles are thus mostly likely expected to take place in a semi-confined environment or in heavily congested areas.

If a combustible mixture is formed and ignited during an accident, the consequences of an accident strongly depend on the ability of the flame to accelerate resulting in fast combustion processes. In the case that the flame acceleration is weak, resulting in a benign combustion, the blast effect of such an accident would be insignificant and the only thermal damage could be expected. In the case that the flame acceleration is strong, significant overpressures and impulses can be generated. Transition to detonation can be also expected at a certain stage of the explosion process under appropriate conditions.

A number of experimental studies have been focused on determination of the critical conditions for strong flame acceleration (FA) and deflagration to detonation transition (DDT). Most of these studies were made in closed tubes with obstacles (Knystautas et al., 1982, Lee et al., 1984, Peraldi et al., 1986, Teodorczyk et al., 1988, Kuznetsov et al., 1999, and Dorofeev et al., 1999, 2000). The effect of semiconfined geometry was also addressed. Processes of FA and DDT in channels with transverse venting was studied by Sherman et al. (1989) and Ciccarelli et al. (1998). Most of these tests were made with relatively small vent ratio α (ratio of vent area to total surface area of the channel).

A study of critical conditions for FA and DDT with large vent areas was made recently by Alekseev, et al. (2000). Experiments were made in two obstructed tubes with inner diameters of 92 and 46 mm. Each of the tube was filled with a set of ring shaped obstacles spaced one tube diameter apart. The blockage ratio (BR) was equal to 0.6. The vent ratio α was varied from 0.1 to 0.4. Hydrogen-air mixtures of 9-70 % vol. H_2 and stoichiometric hydrogen - oxygen mixtures diluted with nitrogen (11-40 % vol. H_2) were used in the tests. Venting was found to have significant effect on characteristic features of turbulent flame propagation and on critical conditions for different explosion regimes. The greater was the venting percentage the more reactive mixtures were necessary for development of fast flames. The results showed that critical conditions for strong FA in cases of transverse venting may be expressed through the critical expansion ratio for strong FA in closed tubes, called here σ_{cr0}, and the vent ratio α: $\sigma_{cr}/\sigma_{cr0} \sim 1+2\cdot\alpha$. The critical conditions for detonation onset in vented tubes with a blockage ratio BR = 0.6 was found to be very close to that in closed tubes with the same obstacle configuration.

Studies of gaseous explosions in vented tubes with large vent ratios can be considered as a bridge between cases of explosions in closed tubes and cases of unconfined explosions in congested areas. The critical conditions for FA and DDT in the latter situation are much less understood compared to those in closed systems. At the same time they are important to for the understanding of explosion accidents in transport vehicles.

The following chain of model cases is suggested for experimental study (see Fig.1): 1) explosions in closed tubes; 2) explosions in vented tubes surrounded by air; 3) explosions in vented tubes surrounded by combustible mixture. The later case is close to the situation of unconfined explosions in congested areas. It represents any situation where hydrogen was released into a congested, partly confine environment and after some distribution period a weak ignition occurs inside the hydrogen-air cloud expanding from the leak location. The model case 3) thus is directly related to real applications involving the geometry of cars, fueling stations and infrastructure. The model case 2) can be also related to some accident situations, but it also serves as a bridge between the relatively well-studied case 1) and the main problem case 3).

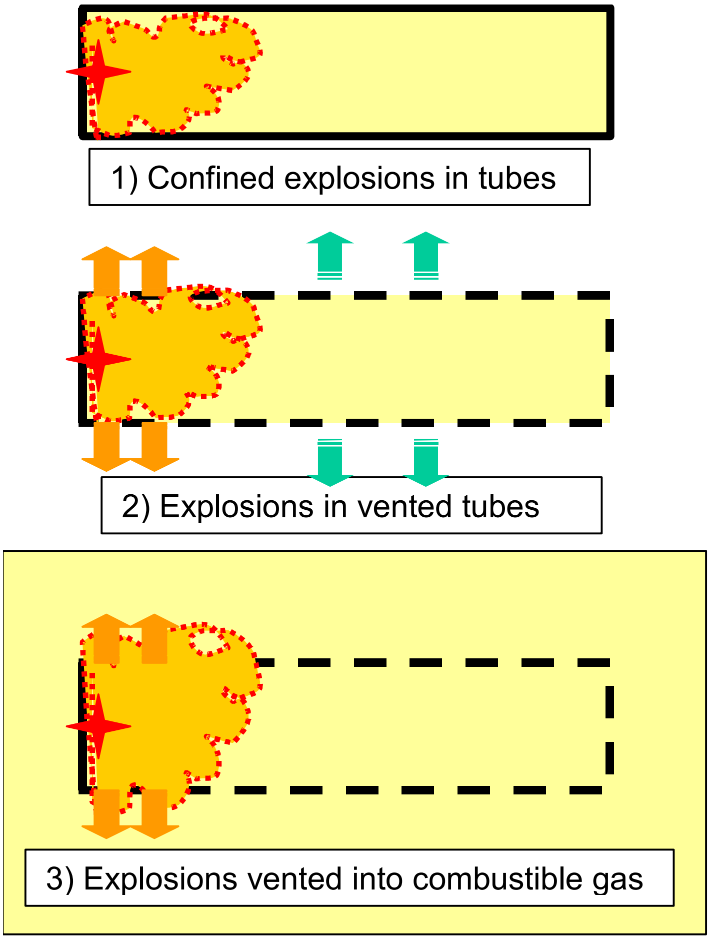

Figure 1. Schematic illustration of 3 model cases to bridge the confined explosions and unconfined explosions in congested areas.

A design of the experimental facility is suggested in the present report, which gives a possibility to study flame propagation and transition to detonation in model cases 2) and 3). The objectives of the experimental program include:

- Study of critical conditions for strong FA and DDT in vented tubes and semiconfined geometry;
- Comparison of explosion properties of hydrogen and typical hydrocarbon fuels in semi-confined geometry;
- Generation of the data necessary for validation of computer codes for simulation of gaseous explosions in semi-confined geometry.

The tests are planned as a continuation and supplementation of the experimental study of Alekseev et al., (2000).

Description of the experimental facility PET

CONFIGURATION 1

The facility consists of an explosion tube with movable brackets to adjust vent ratio, mechanism providing the opening of the vents, support construction, control system, and measurement system. A schematic of the facility in Configuration 1 (model case 2 – vented tube with combustible gas surrounded by air) is shown in Fig. 2.

The main part of the facility is a steel explosion tube of 100-mm i. d., which has a length of 7 m (see Fig. 3). It consists of three main sections, each 2.1-m long (see Fig. 4) and two additional sections 0.22-m long at each end. Each main section of the tube has 16 rectangular openings with dimensions and locations shown in Fig. 4. Two additional sections represent pieces of closed tubes. Circular orifice plate obstacles are installed along the entire length of the tube. The distance between the obstacles is equal to one tube diameter. Different sets of the orifice plates are available with blockage ratio BR equal to 0.3, 0.45, and 0.6.

The explosion tubes is supplemented with a pneumatically driven system, which provides opening of the vents just before the ignition of the mixture. This is achieved by rotation of brackets, which have an internal diameter close to the external diameter of the main tube. The brackets have rectangular windows (4 windows each), as shown in Fig. 5. These sections are mounted coaxial with the main tube (see Fig. 6), and can be rotated by a pneumatic mechanism. Variations of the rotation degree provide different vent ratios.

Test procedure

Two additional hermetic chambers are used to fill the tube with a combustible mixture. The mixture is prepared initially in the high-pressure chamber. This chamber is connected by valves to the main tube and then to the vacuum chamber at the other end. The filling is made with initially closed main tube having air inside. Simultaneous opening of the connecting valves results in the transport of the combustible mixture from high-pressure chamber through the main tube to the evacuated chamber. The volume of the mixture (at normal pressure) in the high-pressure chamber is approximately 5 times the volume of the main tube. This provides good uniformity of the gas composition in the main tube within the range of ± 0.15% vol. of fuel in air.

The experimental procedure starts with preparation of the mixture in high-pressure chamber by precise flow meters for different components. Then filling of the main tube is made, then the vents are opened to desired vent ration, and finally ignition is made.

Computational fluid dynamic simulations using the Fluent code have shown that significant amount of hydrogen-air mixture leave the opened tube within a time interval of about 0.25 second (see Fig. 7). The ignition should be initiated shortly before opening the tube, so that the flame arrives at the first vent location not later than 0.1 second after movement of the brackets to their final position. If this requirement cannot be satisfied for some of the vent ratios and mixture compositions, another option can be used, namely, additional covering of the vents with a thin (1 μm) “clean” film. This option was used in tests of Alekseev, et al. (2000). When a weak compression wave and following flame front reached the vents, the film was easily brokened. The overpressure of 5 Torr was sufficient to make the film broken.

CONFIGURATION 2

A schematic of the facility in Configuration 2 (model case 3 – vented tube inside the combustible gas) is shown in Fig. 8. In this configuration, the vented explosion tube with fixed vent ratio is placed into the cylindrical plastic bag. The diameter of the bag is about 400 mm. The supports of the tube are provided with two discs at the ends, which are used to fix the plastic bag hermetically. The discs are equipped with hermetic penetrations for the measuring cables.

Test procedure

In this configuration the explosion mixture is to be created in the whole volume inside the bag and the tube. Ignition is made after measurements of the mixture composition.

MEASUREMENTS

The measurement system consists of a subsystem for mixture composition measurements and a subsystem for measurements of explosion parameters. To measure the uniformity of the mixture composition the Rosemount-Fischer MLT4-gas-analyzer is used. Relative accuracy for differential measurements is about 1% of the mean value.

Measurements of explosion parameters include collimated time-of-arrival photodiodes and pressure transducers. The main tube is equipped with measurement ports located in the closed parts of the tube. The distances to the measuring ports from ignition location are shown in the lower part of Fig. 3. One pressure transducer and one photodiode are installed in each measuring location. This gives a total of 16 pressure transducers and 16 photodiodes along the main tube.

In Configuration 2, additional pressure transducers are installed outside of the tube at distances from 1 m to 15 m (Fig. 8). They are located at the same height (1 m above the ground level) as the axis of the main tube. These pressure transducers are use to record parameters of the air blast wave generated by semi-confined explosions.

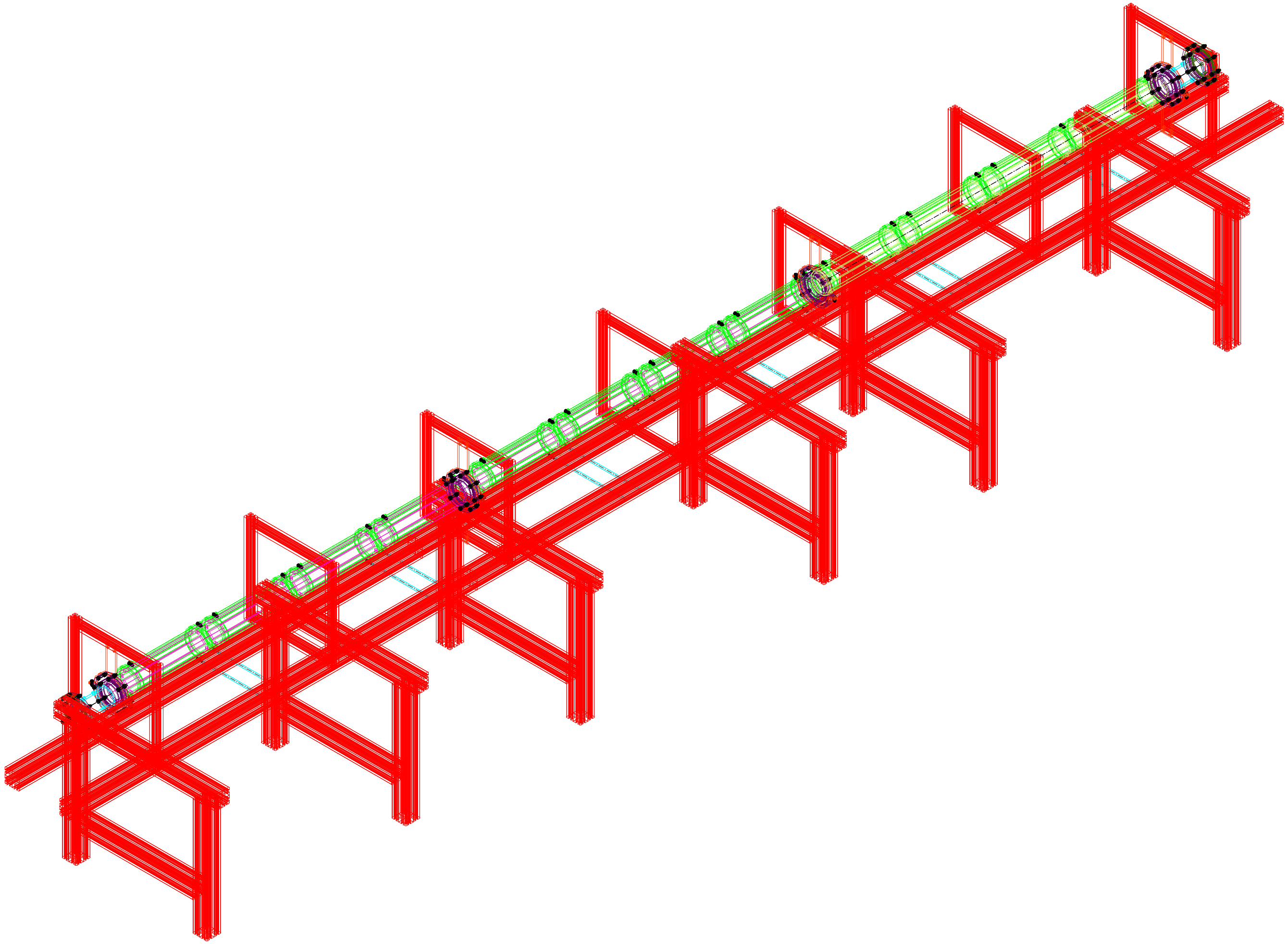

Figure 2. Schematic of PET facility in Configuration 1.

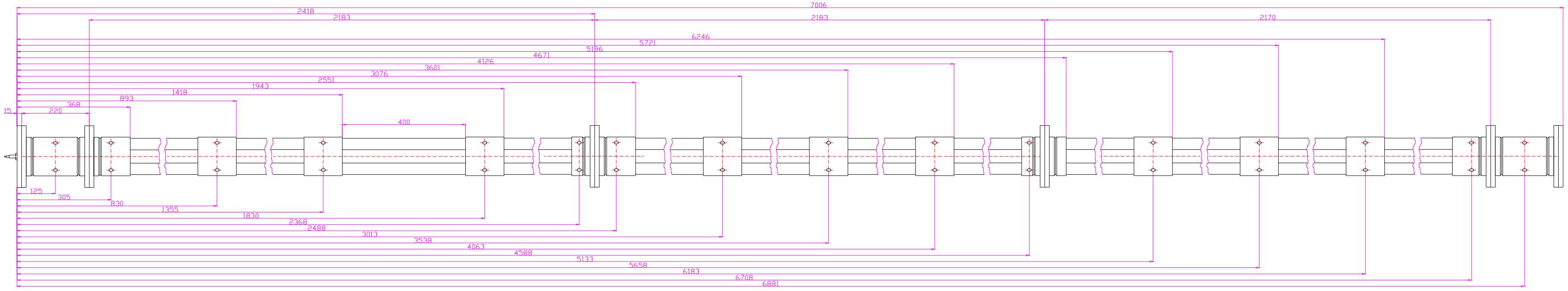

Figure 3. Dimensions of main tube

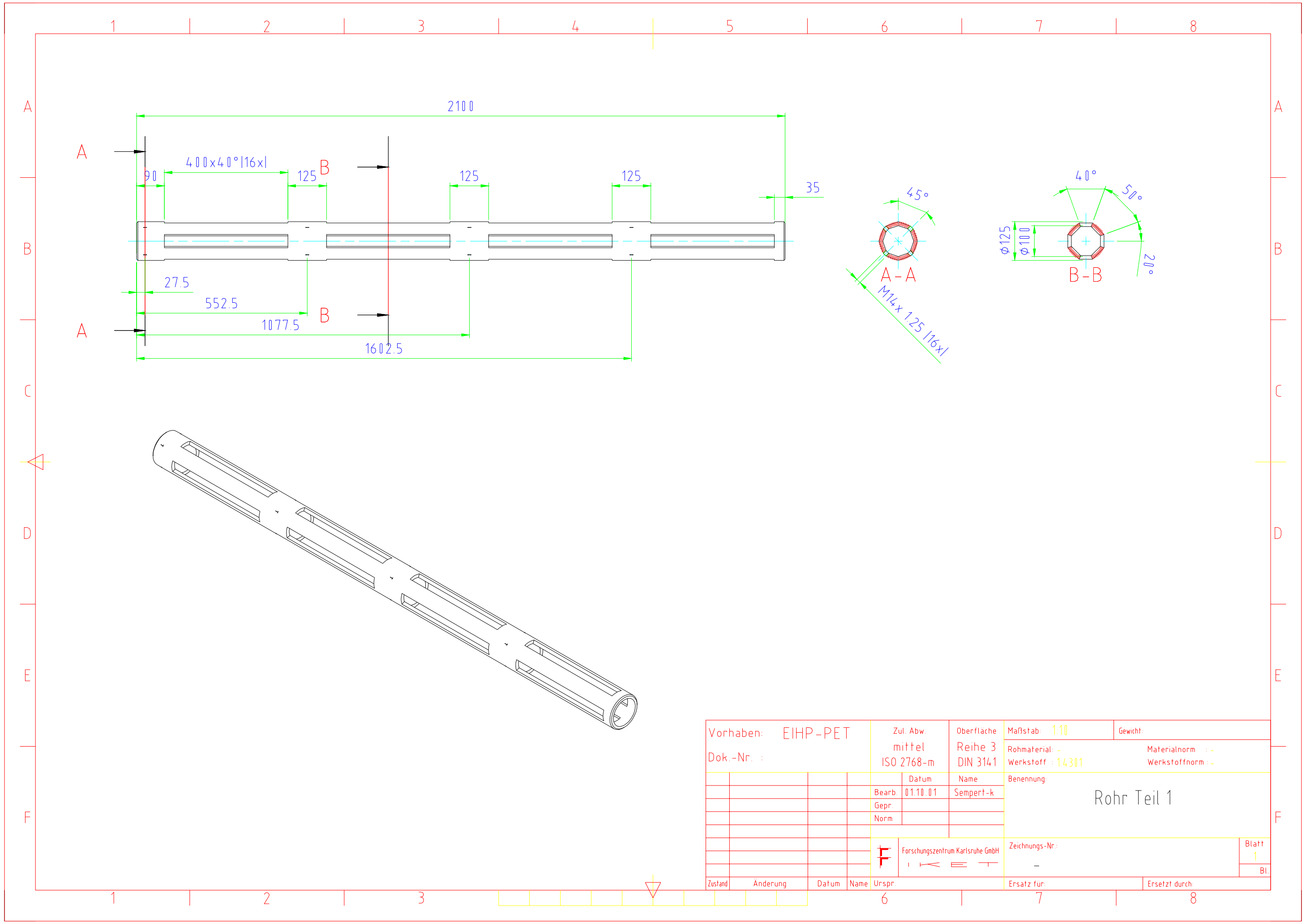

Figure 4. Detaile of the main tube section.

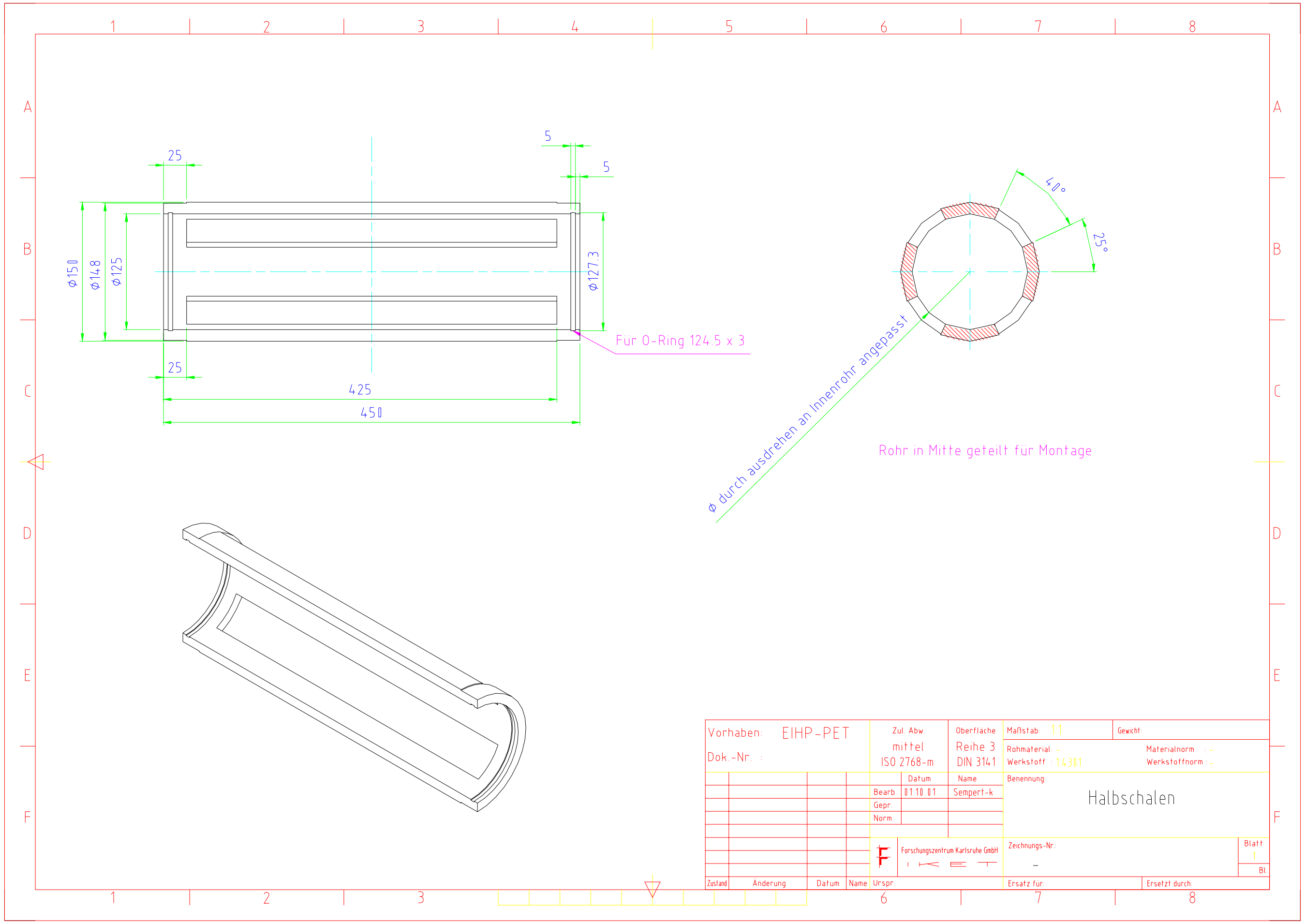

Figure 5. Dimencions of outer tube section.

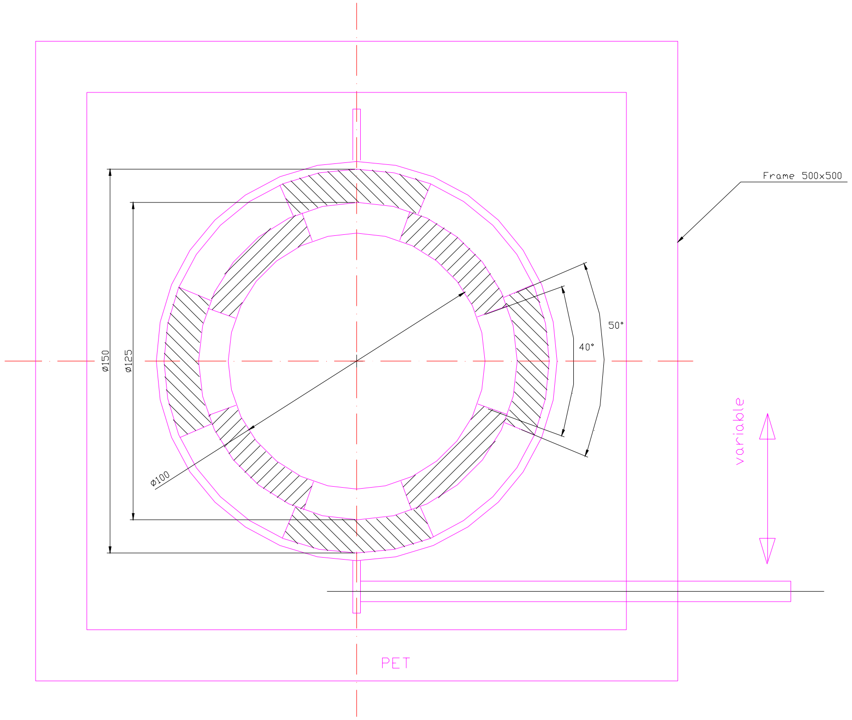

Figure 6. Mutual position of main tube, outer tube an supporting frame.

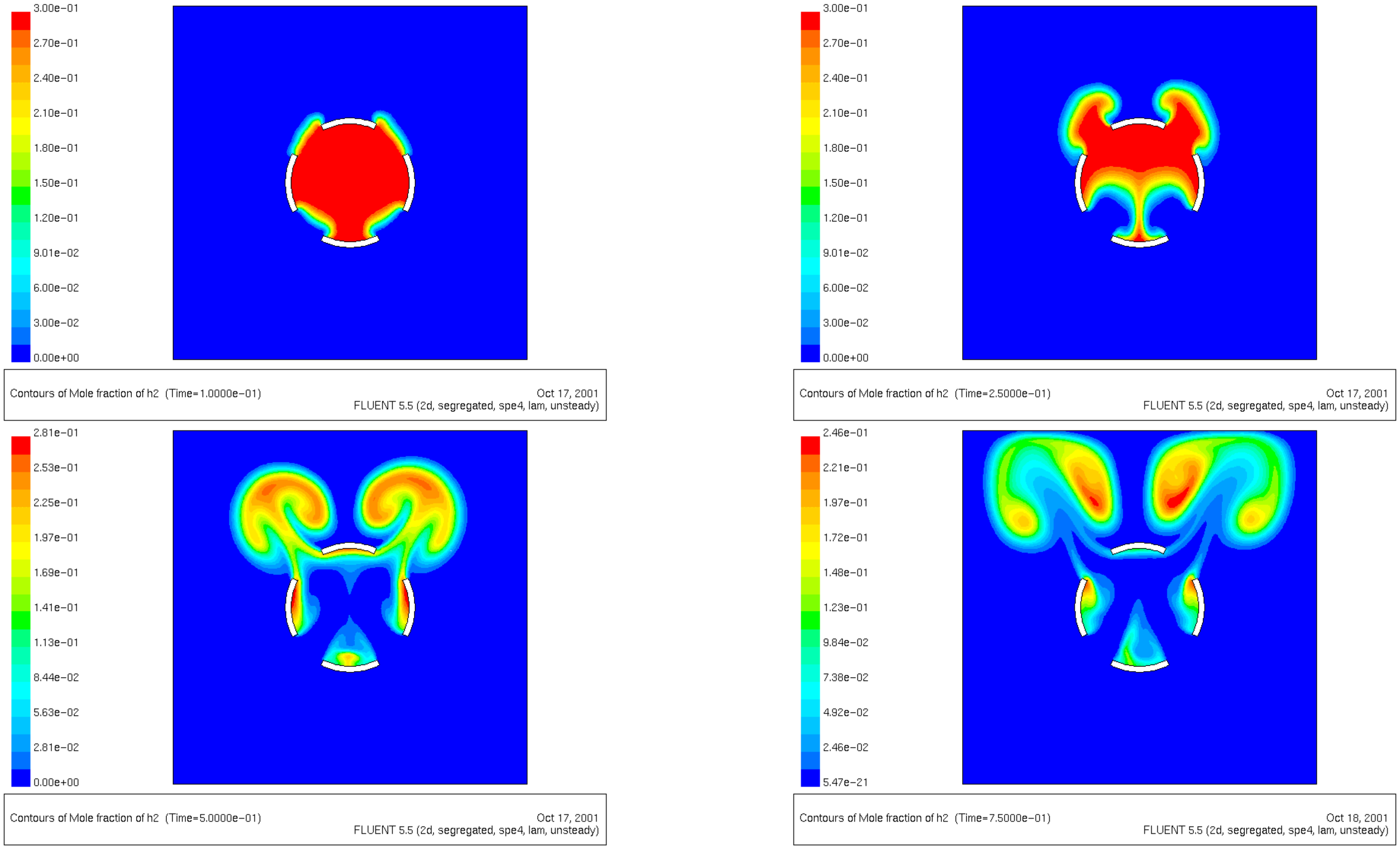

Figure 7. Results of calculations of hydrogen leak from vented tube due to byoancy. Initial mixture – 30% vol. of H2 in air. Distribution of hydrogen concentrations are shown for 0.1, 0.25, 0.5, and 0.75 s after opening of the vents.

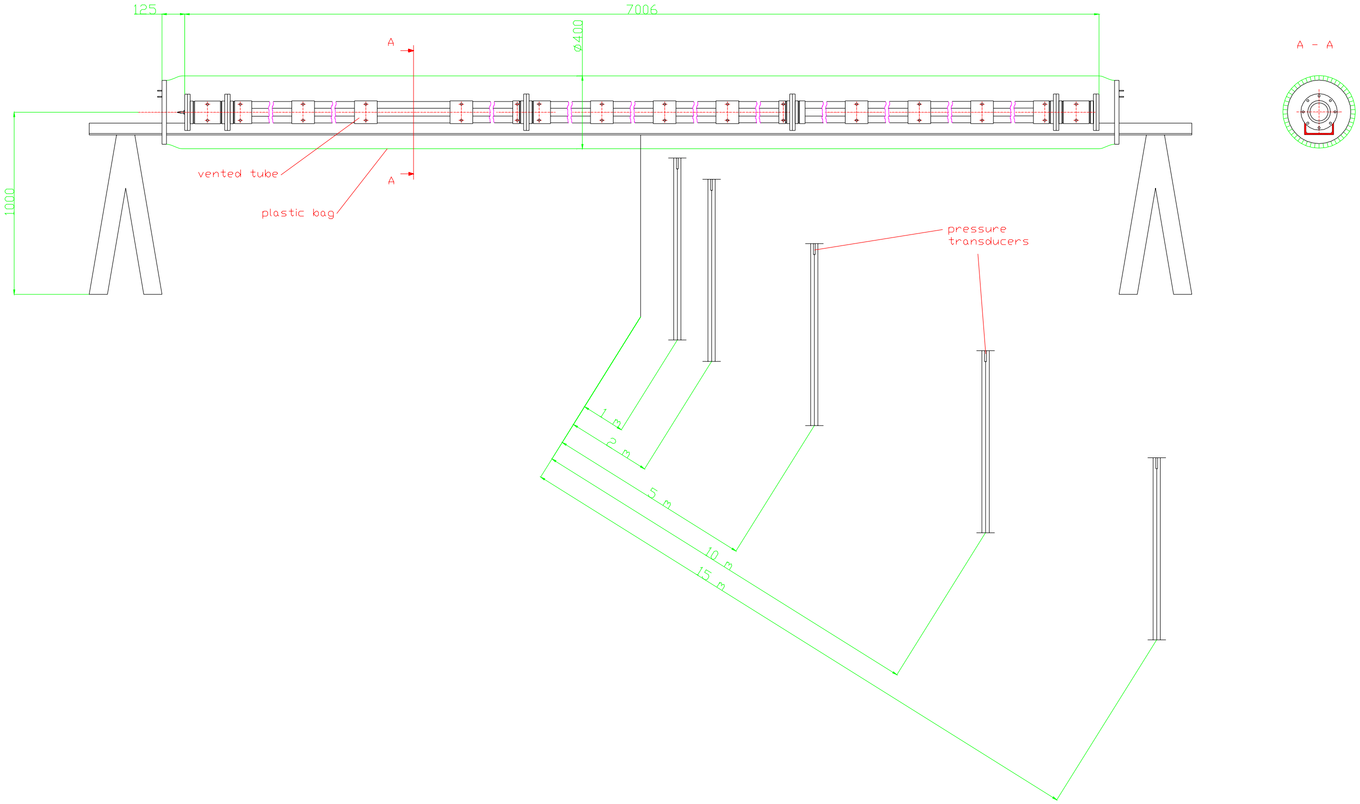

Figure 8. Schematic of PET facility in Configuration 2.

Test matrix

The results of Alekseev, et al. (2000), Kuznetsov et al. (1999), and Kuznetsov et al. (2001) can be used as valuable background information for the present experimental program. The study of Alekseev, et al. (2000) give first results on the effect of venting on critical conditions for FA and DDT. Only hydrogen mixtures were used in this study.

The results of Kuznetsov et al. (1999) and Kuznetsov et al. (2001) give the reference cases for critical conditions of strong FA in mixtures of hydrogen and hydrocarbon fuels in closed tubes. These results are summarized in Fig. 9.

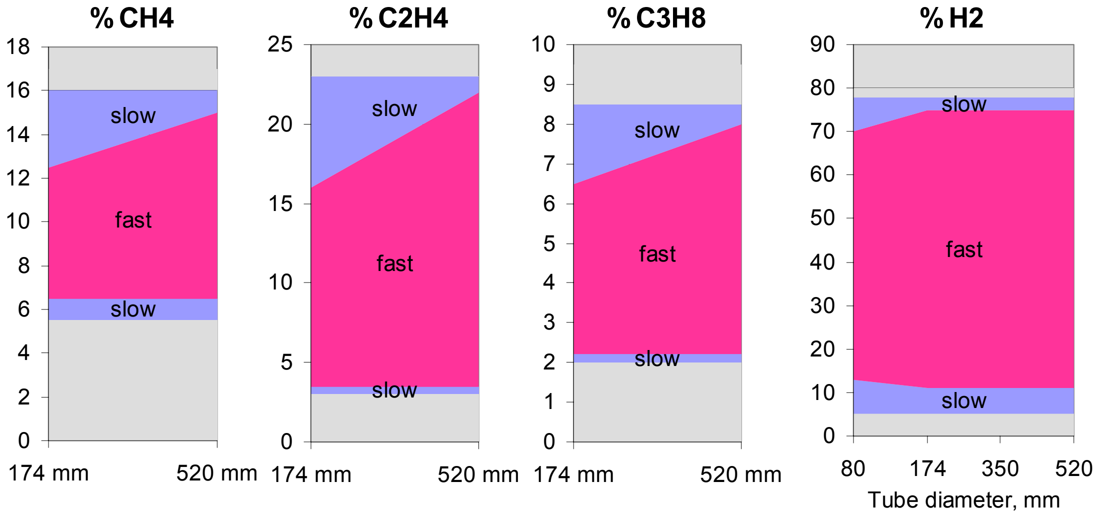

Figure 9. Limits for strong flame acceleration in mixtures of different fuels with air. Results obtained in closed tubes with different diameters are shown. Grey areas correspond to mixture compositions, where ignition was not achieved, blue areas to the cases of slow subsonic flames, red areas to cases of fast supersonic flames and detonations.

A limited number of tests in the PET facility were selected for each mixture, which should make it possible to meet the objectives of the EIPH-2program. All tests will be made with BR = 0.6, as the most effective configuration of obstacles for FA, according to the results of Alekseev et al. (2000).

The test matrix for experiments in Configuration 1 is presented in Table 1. A total of 45 tests are planned.

Table 1. Test matrix of PET experiments in Configuration 1

Mixture	Range of concentrations, % vol.	Number of tests with different concentrations	Vent ratio	Total number of tests
H_2-air	10 – 30	5	0.1, 0.2; 0.4	15
CH_4-air	5.5 – 16	5	0.1, 0.2; 0.4	15
C_3H_8-air	2 – 8	5	0.1, 0.2; 0.4	15

The preliminary test matrix for experiments in Configuration 2 is presented in Table 2. A total of 9 tests are planned. The details of the tests in Configuration 2 will be defined on the basis of the results in Configuration 1.

Table 2. Test matrix of PET experiments in Configuration 2

Mixture	Range of concentrations, % vol.	Number of tests with different concentrations	Vent ratio	Total number of tests
H_2-air	10 – 30	3	0.2 (0.4)*	3
CH_4-air	5.5 – 16	3	0.2 (0.4)*	3
C_3H_8-air	2 – 8	3	0.2 (0.4)*	3

*) to be defined after results in Configuration 1 are available.

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