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Preventing hydrogen detonations in road tunnels hydrogen trap concept

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ABSTRACT

During research of new possible sources of energy, hydrogen was identified as a very promising potential energy carrier. Because of its very good energy characteristics, it has received a lot of research attention while its safety features are the ones that were its drawback for potential use. Before it can be put in general use in transportation industry, there were safety problems identified as hazard which has to be further analysed. The main problem in the transport is the safe use of hydrogen in road tunnels where it should be safe in case of possible accidents where its release could end up in fire, deflagration and even detonation. In the article, concept of hydrogen trap on the ceiling is developed and described based on the available data and research results from which passive safety approach is suggested to be used in future designs of the road tunnels.

Introduction

Depleting resources of carbon fuels poses a threat against the mankind and calls for solutions which would enable commuting with vehicles using alternative source of energy. One possible solution is use of hydrogen which is a natural selection based on the quantity and its good features while the other features regarding the safety are not so appealing and just these features are the ones that prohibit the general use of this source at the moment. Based on these problems, wide number of experiments tries to determine all the areas where we do not know all the problems related to hydrogen. These experiments serve as the source of the mathematical and physical models, which could enable engineers to design safe solutions for the use of hydrogen. Using these models, we can conduct experiments, which would drive extensive costs in reality and for this reason we could make safe systems using hydrogen as an energy carrier. Models, however, require validation since we do not know if the models are describing the reality, which is established through the tests performed in different research facilities all over the world. Our aim was to leverage the present knowledge and to propose a safe solution for the mitigation of accidents involving hydrogen cars passing through a road tunnel.

Efforts regarding the problem of hydrogen release during the road accidents in tunnels. In the articles, we see that the scientists wanted to ascertain how the concentration of hydrogen mixed with air would spread under the ceiling of the tunnel [2,4,7,9,15,17,18,20,]. This was done by modelling with different CFD codes, which more or less resulted in different outcomes [13]. In addition, the problem with ignition of the

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mixture was modelled in different scenarios, which again lead to different consequences. Based on the results which are not of the same qualitative area, the recommendation is that there is a need for further investigation. Nevertheless, we need to have profound understanding of the problem, but on the other hand we need to stay pragmatic and direct the research towards possible safe solutions instead of broadening the research without the rationale behind it.

All the calculations with CFD models have certain amount of assumptions behind them, so by using different set of assumptions we can get different results in the end.

Safety concerns

Regarding safety, best results are achieved if the hydrogen is immediately ignited after the accident, if released. In this case, there is no potential for deflagration and detonation. If there is no immediate ignition, then there is the problem of mixing of the hydrogen with neighbouring air thus producing cloud within the explosion limits posing hazard to the people and infrastructure [8,10,14], In literature, we found that the probability for such delayed ignition is low but the research has been done to investigate the outcome of such delayed ignition events. Dealing with consequences and their mitigation is one problem, while preventing this to happen and reducing the probability of explosion is another problem. In our opinion, the latter is even more important than the former, so in our work we were dedicated developing approach which would work in any situation by reducing the probability of the explosion or reducing the size of it if the amount of hydrogen is too large for the system to be optimally effective.

Finding solution

When we search for a solution, we can use the knowledge from the experiments, which were performed during the different investigations and determine the proper solution for the problem. The advantage of such approach is that we do not need to additionally validate the results since they are based on the tests. At the end, we have to test the solution with the test which can provide us with a prompt answer to the question whether we have solved the problem or whether our reasoning was correct. This kind of approach could yield relatively fast and usable results, which can then be transferred into practical use.

Calculations that accompany the process are simple enough to present the problem while the test and possible CFD calculations can be done afterwards when we establish if the reasoning is sound and when we can expect possible solution to the problem.

Cars using new non-carbon technologies are now equipped with the containers filled by hydrogen sized 20 gallons with the pressure between the 350 and 700 bars. The mass of the hydrogen is around 2 kg, and the volume of the hydrogen released to the atmosphere pressure is approximately 50 m^3.

In case of an accident, this container can release the hydrogen to atmosphere although well protected within the car to avoid the damage. In open country conditions, this should not be problematic since the difference between the densities of hydrogen to that of the air is large and the rising of the hydrogen will be very quick. It can be problematic in a road tunnel where the released hydrogen can be trapped by the ceiling of the tunnel. The shape of the ceiling can produce concentration of the pressure in the case of delayed ignition of the hydrogen mixture. Since hydrogen has a very broad range of explosion concentrations, it is highly likely that, in some instance, explosion would occur.

Immediate ignition of the hydrogen has probably the lowest consequences for the accident but it cannot be obtained in all the cases. In the case of release without ignition, we should use passive systems to prevent possible detonation and with those systems we should be able to reduce the probability for detonation to the lowest possible limit.

Numerous experiments were performed over the years and a large amount of data collected related to gas explosions and hydrogen explosions in particular.

Based on the data, we can deduct that there are some geometries and instances where hydrogen would not detonate with high pressures. This is described in Gas explosion handbook [3]. The geometry is based on the tubes that have diameter less than $\lambda/3$ or with channels where height of the channel should be smaller than λ where λ is detonation cell size.

All the experiments were conducted with horizontal tube/channel alignment which is good for experiments but it is not good from practical point of view so the vertical tubes/channels are preferred. Buoyant force of the hydrogen in air mixture will tend to force hydrogen to collect in the upper part of the tube thus there forming high concentration of the hydrogen. The lower part of the tube/channel would have low concentration of the hydrogen in the air mixture.

The ignition of the material would be in any case from below and outside of the tube. The idea to compartmentalise hydrogen has several advantages:

- To reduce the mass of hydrogen in possible reaction/detonation.
- To design such geometry (diameter of the pipe or height of the channel) which would give deflagration/detonation with lowest possible overpressure or no overpressure at all.
- To prevent large fire from accident resulting in substantial consequences.
- To reduce consequences of an accident to the lowest possible extent.

During the last period, a lot of research has been carried out to study hydrogen mixtures with air explosions within the number of geometries and border conditions to learn how the environment and obstacles interfere with probabilities for explosion. It is interesting how much information can be obtained from articles and literature available. The problem is that all the research work is being done to improve and develop models with which we can later on, without large-scale experiments, foresee accidents and their consequences. Based on experiment models, we can provide close enough approximations, which can help design safe technology for use of hydrogen as a new energy carrier. To enable