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Numerical analysis of hydrogen and methane propagation during testing of combustion engines

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Abstract

The research of gas-fuelled combustion engines using hydrogen or methane require accordingly equipped test benches which take respect to the higher dangerous of self ignition accidents. This article deals with numerical calculations of flow in laboratory during simulated leakage of gas-fuel from fuel system of tested engine. The influences of local suction and influences of roof exhausters on the flow in the laboratory and on the gas propagation are discussed. Results obtained for hydrogen and for methane are compared. Conclusions for design and performance of suction devices and test benches are deduced from these results.

Keywords: hydrogen, methane, suction hood, gas propagation

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1. Introduction

The development and research of gas-fuelled combustion engines require accordingly equipped test benches which take respect to the particular chemical and physical properties of given fuel gas. Local suction and sufficient air exhaustion of test rooms are recommended as well as gas sensors of higher sensitivity. Also higher air change rate in the test room especially in vertical direction is required [1]. This article then deals with special requirements for suction and ventilation of the test room, where hydrogen and methane are used as a gas fuel in combustion engines. Numerical computations of air flow and gas-fuel propagation in the laboratory of Department of Vehicles and Engines in Technical University of Liberec are made for hydrogen and methane to find out differences in gas propagations and requirements for ventilation.

2. Methods

Drawing of the test engine laboratory is in fig. 1. The laboratory has rectangular ground plan, it is 36 meters long, 8.65 meters wide and 6.5 meters high. The reflected test bench is placed in the front part at the outside wall near the iron-plate gate. These gates are not able to be hermetically closed and allow the air to flow through. It is thought that the gate closer to the test bench will be opened during testing of the engine. Accordingly to these assumptions no other entrances to the laboratory are reflected in computations. The laboratory is already equipped by three exhausters placed on the top wall. The new suction device, the suction hood, will be installed just above the test engine. Earlier calculation proofed that suction are not efficient if the suction hood is placed 2 meters above floor and so it is lowered to one meter. Square suction hood are suggested to be 0.8 meter width.

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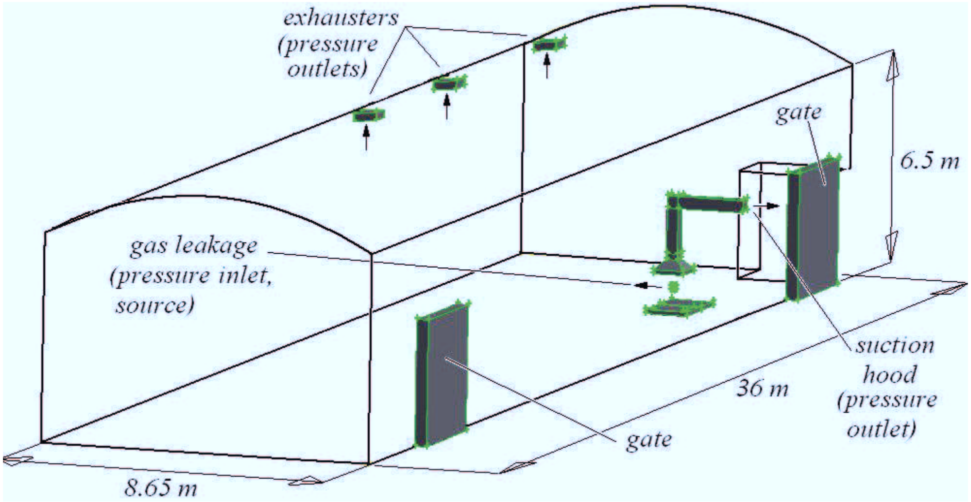


Fig. 1: Model for calculation of gas propagation in test engines laboratory.

All mediums are supposed to be ideal gases with stagnation temperature 300 K. It is air in the laboratory, hydrogen H_2 and methane CH_4 which represents natural gas. The gravity acceleration $g = 9.80655$ m/s^2 is reflected in computations, because especially propagation of very light hydrogen in the air is influenced by lifting forces and proceeds mainly in vertical direction. Fluent 6.1 software were used for computation. Coupled steady solver, turbulence model k-epsilon realizable with enhanced wall treatment and second order upwind of all variables were chosen. The convergence criteria were stable values of residuals. Three-dimensional model consists from hexahedral cells around the gas leakage inlet and suction hood and the rest of model is meshed by tetrahedron cells, as we can see in fig. 2. Total amount of cells in computation domain is 320 thousands. Pressure outlet boundary conditions were used to setup suction of exhausters and of suction hood, while pressure inlet boundary is used for gas leakage. The gas leakage is speculated to be in the center of the test benches, half meter above the floor and half meter below the suction hood. The cross section of inlet of gas leakage 1 cm^2 and overpressure 100 Pa correspond to the mass flow rate of hydrogen 0.3 g/s and mass flow rate of methane 1 g/s.

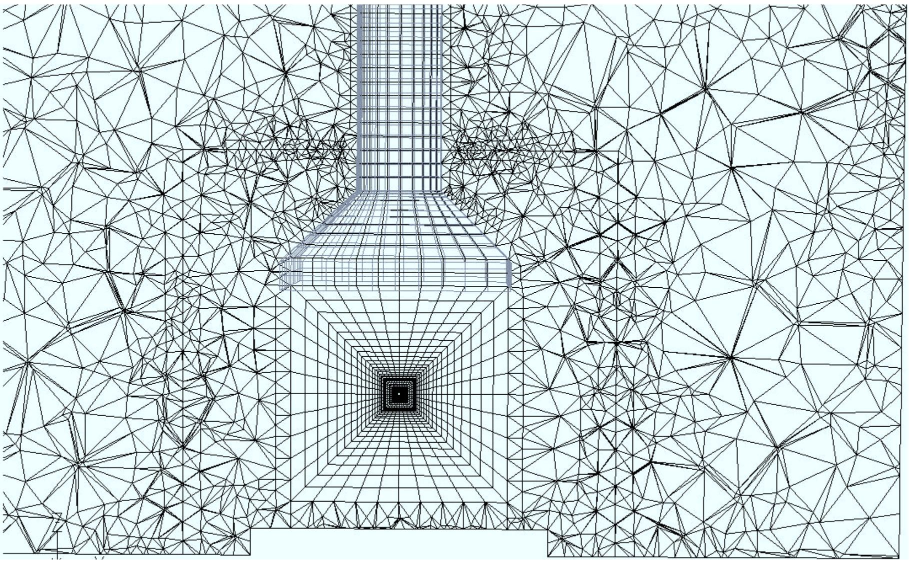
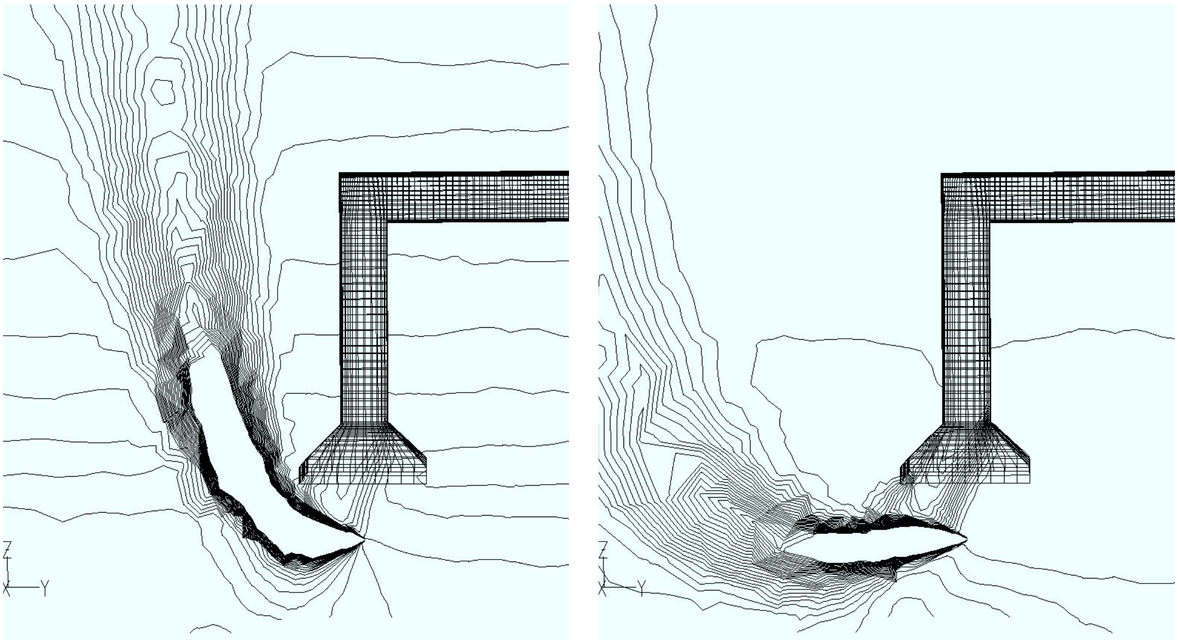


Fig. 2: Detail of computational mesh near the suction hood and gas leakage.

3. Results

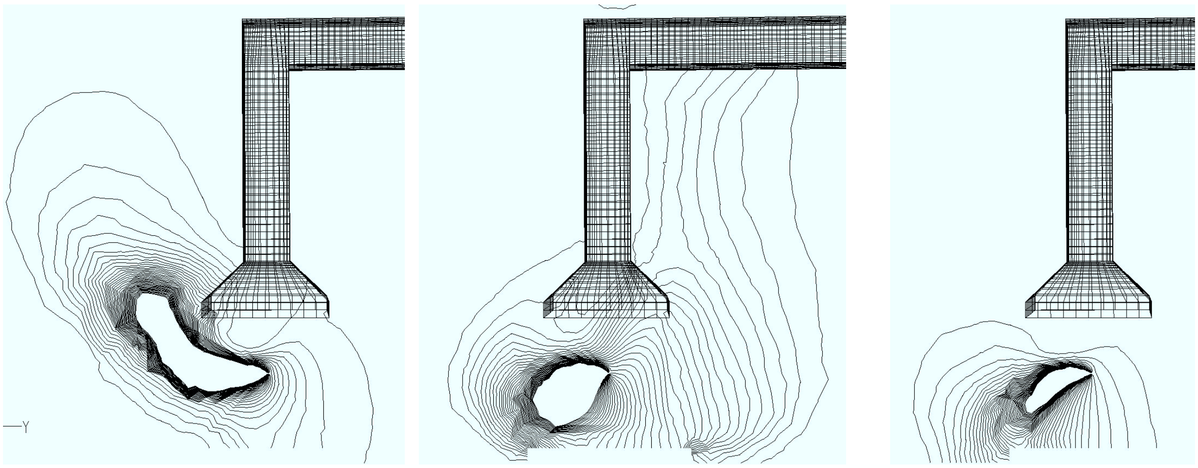
Following cases of suction of both gases were investigated: Gas propagation in the laboratory without any suction. Influence of suction by roof exhausters. Influence of suction hood operating with various performance and conditions, with or without roof exhausters. Gas leakage is suggested to be in horizontal direction, which is more unfavourable situation than uniform source of gas spreading to all directions. Results of computations are portrayed in vertical plane, parallel to the initial direction of gas leakage. Variants are compared with help of contours of volume concentration of the leaked gas. Note that lower ignition limit for mixture of air and hydrogen H_2 is 4% of volume, i. e. 3.3 grams of hydrogen in one cubic meter of air and the ignition energy is only 10 mJ and decreases with concentration [2, 3]. Lower ignition limit for mixture of air end methane CH_4 is 4.4%, i. e. 29 grams of hydrogen in one cubic meter [1]. Displayed volume concentrations are in range from 0.04% to 4%. The white area inside contours means that the concentration is above lower ignition limit.



Hydrogen H_2, 0.32 g/s. Methane CH_4, 1.06 g/s.

Fig. 3: Gas propagation with no suction in operation. Contours of volume concentration displayed in vertical plane parallel to the inlet direction of gas leakage. Maximal displayed volume concentration is 4%.

Differences between propagation of hydrogen and methane in the laboratory without any suction in operation are obvious from fig. 3. In both cases the leakage gas escapes from below the standing suction hood because of initial inlet velocity in horizontal direction and then the flow turns up. The gases than propagate mainly in vertical direction and cumulate below the top wall, while small part of gas escapes through standing exhausters. The concentration rises with vertical position. In the case of hydrogen the flow turns from horizontal direction to vertical direction sooner than in the case of methane, because of its lower density. The area of dangerous concentration of hydrogen, where the lower ignition limit is getting over, is larger than it is for methane. Those areas of exceeded lower ignition limits even reach the outside of the test bench region, which is below the suction hood. Test operating without any suction is hazardous, even because the hydrogen spreading in the air could not be noticed by human senses. Next computations answer questions how the suction by roof exhausters can influence the flow in the test room, propagation of gases and area with dangerous concentrations.



H_2, 0.32 g/s.
One exhauster, 6.9 m_3/s.

H_2, 0.32 g/s.
Three exhausters, 18.5 m_3/s.

CH_4, 1.06 g/s.
Three exhausters, 18.5 m_3/s.

Fig. 4: Gas propagation, while roof exhausters are working. Contours of volume concentration, maximum 4%.

It is obvious from fig. 4 that the ventilation of test room realized in vertical direction by roof exhausters solves accumulation of leaked gases below the top wall and the air in the laboratory is cleaner. Further we can observe that if three roof exhausters are operating, the leaked gases propagate downwards to the floor and then spread horizontally. As a result the effected area is larger, because the gases have more time to spread around the suction hood. These effects are caused by the standing suction hood, which now forms a curtain and makes the gas to flow down. On the other hand these effects are negligible when the suction performance is lower and only one roof exhauster is in operation, as we can see in fig. 4. But the area of dangerous concentration is then larger.

The flow in the laboratory illustrated by pathlines if all three roof exhausters are working is in fig. 5. We can observe how the incoming air flow through the gates, aerate the laboratory and enter exhausters. We can also see that air around the test bench on the left side of the laboratory is effected by two nearest exhauster, while the farthest exhauster sucks air from the rest of laboratory. Ventilation realized by only one nearest exhauster seems to be sufficiently efficient and could be even more useful than using three exhausters. It is obvious that without local suction the area with dangerous concentration could not be reduced.

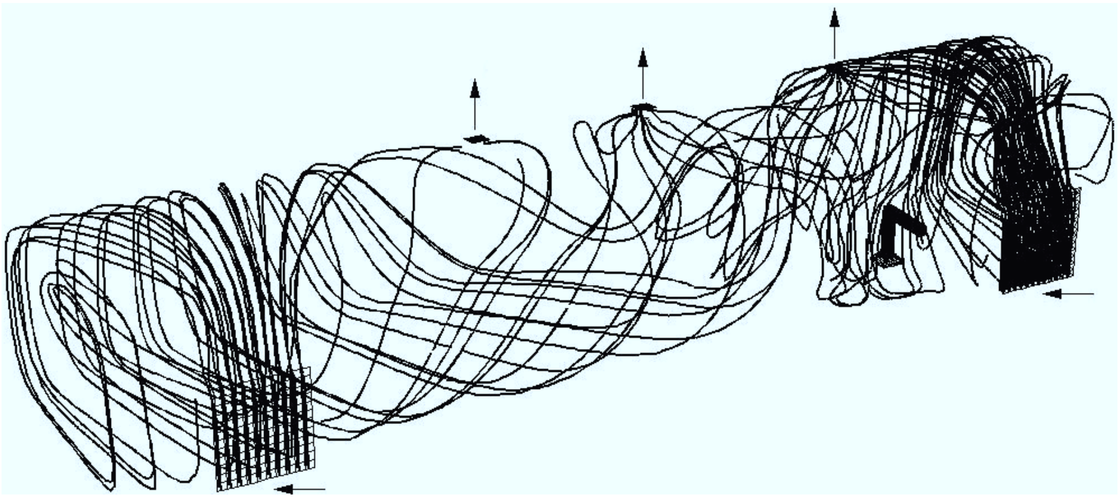
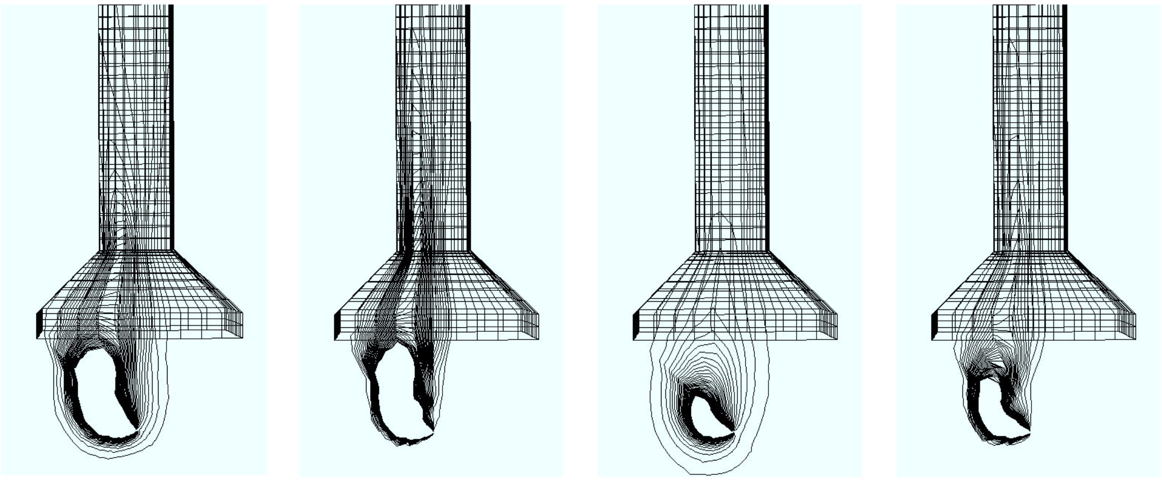


Fig. 5: Flow in laboratory illustrated by pathlines coloured by volume concentration of H_2, all roof exhausters are working and suction hood is standing.

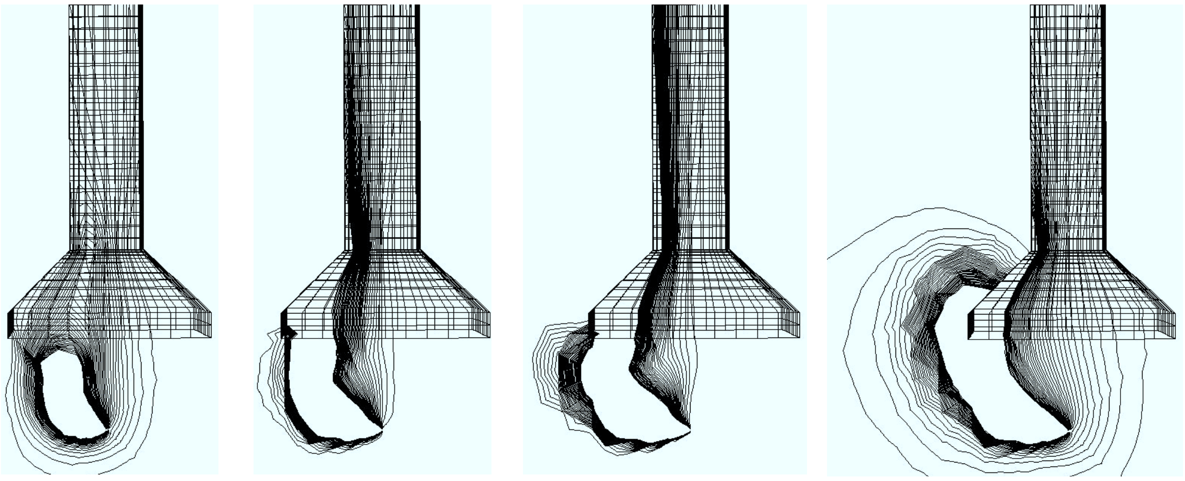


without roof exhausters | with roof exhausters | without roof exhausters | with roof exhausters

H_2, 0.32 g/s. | CH_4, 1.06 g/s.

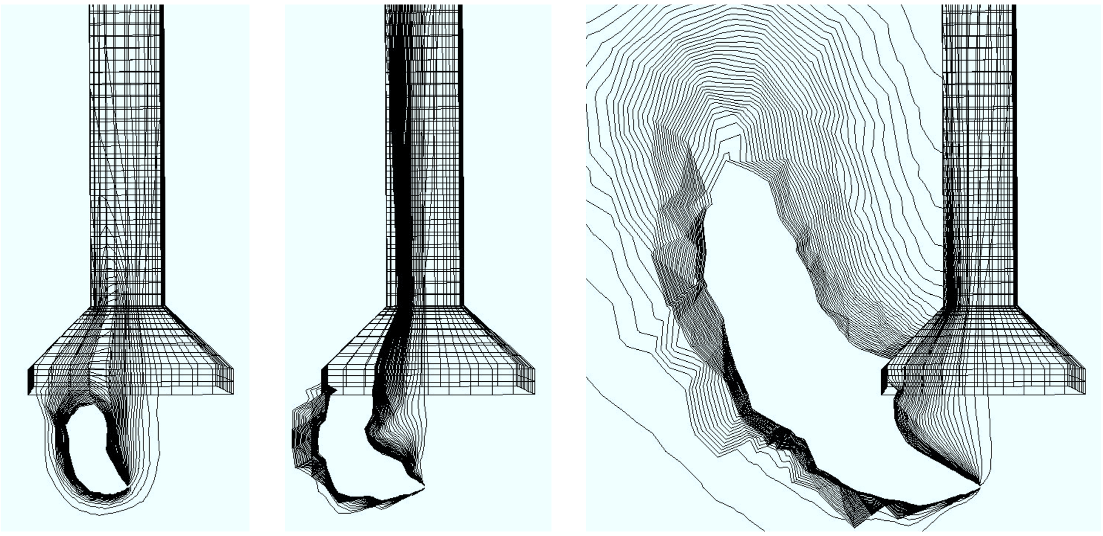
Fig. 6: Gas propagation, suction hood is working at 1.5 m^3/s. Contours of volume concentration, maximum 4%.

Fig. 6 shows results of computations made for local suction by suction hood. If the volume flow of suction hood is quite high, 1.52 m3/s, all leaked gas is sucked out and the formation of an explosive atmosphere is prevented. The influence of roof exhausters is negligible. Horizontal ventilation could be even turned off, because no gas spread outside the test bench. Others computations in fig. 7 show influence of suction hood performance on hydrogen propagation. We can see that reduction of suction flow increase concentration of hydrogen inside the suction tube. For low suction flow the hydrogen can spread outside the test bench, but finally most of leaked gas is sucked out. Similar situation appears when the mass flow of hydrogen is increased on 0.64 g/s, as is illustrated in fig. 8. But if the mass flow rate of hydrogen is 1.29 g/s the suction hood flow 1.52 m^3/s is no longer sufficient. In this case, for pressure inlet 1600 Pa, the inlet velocity 200 m/s overcomes the suction flow and hydrogen escapes from below the hood and propagates further vertically in the laboratory. We should notice that in all cases of gas leakage, some gas escapes from testing bet and should be exhausted by roof ventilation.



Suction hood volume flow 1.07 m^3/s. | Suction hood volume flow 0.75 m^3/s. | Suction hood volume flow 0.53 m^3/s. | Suction hood volume flow 0.26 m^3/s.

Fig. 7: Propagation of hydrogen, 0.32 g/s, suction hood is working while roof exhausters are not. Contours of volume concentration, maximum 4%.



H_2, 0.32 g/s. H_2, 0.64 g/s. H_2, 1.29 g/s.

Fig. 8: Propagation of hydrogen, suction hood is working at 1.52 m^3/s. Contours of volume concentration, maximum 4%.

4. Conclusion

Numerical computations of gas propagation and of flow in the laboratory for combustion engine tests were performed. Cases of gas leakage of hydrogen and methane were investigated. Calculations proofed that especially hydrogen spreads mainly in vertical direction. It was find out that the influence of vertical ventilation realized by roof exhausters without local suction could be even disadvantageous and should not be excessive powerful. On the contrary the local suction in vertical direction did by suction hood is sufficient to prevent the formation of an explosive atmosphere. The needful performance of local suction and requirement of additional roof ventilation were discussed too.

Acknowledgement

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