Comparison of Different Natural Gas Flow Rates in Pipelines and their Effect on Odorant Concentration

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Abstract— *The article deals with the problem of adding and spreading an odorant in a high-pressure pipeline. Briefly describes the basic properties of odorants added to natural gas. Furthermore, it mainly focuses on the odorant concentration in natural gas at different natural gas flow rates. By using the ANSYS CFX software, simulations were carried out on the pipeline models representing the selected section of the distribution network at the maximum, minimum and zero flow of natural gas.*

Keywords— CFD Simulation, High-Pressure Pipeline, Odorization Techniques, Natural Gas.

I. INTRODUCTION

Natural gas is a mixture of gaseous hydrocarbons. Among its main components is mainly methane, which makes up approximately 93% to 99% of its content. In addition, natural gas also contains propane, butane and other substances. Natural gas serves mainly as a natural fuel for heating and DHW, further for cooking, or in the form of CNG as a fuel for cars. Among its advantages are good controllability and distribution, there is also no need to provide storage space for the customer.

Natural gas is lighter than air, it is flammable, colorless, tasteless and has no natural smell. Although it is not a poisonous gas, it is non-breathable. It is the absence of odor that appears to be problematic from the safety point of view. For this reason, natural gas odorization is necessary. The importance of odorization lies in the early warning of people in the event of an accidental gas leak either from a gas pipeline or from a delivery point. Thanks to early detection of a natural gas leak, an explosion, fire or suffocation can be prevented.

II. ODORANTS PROPERTIES

An odorant is defined as a characteristically odorous substance added to other odorless, usually hazardous substances in order to signal their presence. The role of odorants is to ensure gas leak detection without the need to use any equipment. The end user must be able to detect a possible leak with his own sense of smell. Odorants therefore enable the detection of gas leaks even in places where the placement of special detectors would be complicated or completely impossible.

The ideal odorant should be an easily recognizable specific odor with a strong enough intensity that the use of a low concentration of the odorant in the gas is sufficient. The odorant used in natural gas should have a good ability to penetrate the ground so that in the event of a pipeline breach in the ground and a subsequent leak, it can warn people on the surface. At the same time, however, it cannot penetrate through an intact pipeline, nor can it disturb it by its own action. It must also not change the physical and chemical properties of natural gas, except for adding an odor.

There are two basic groups of odorants, namely sulfur-based and sulfur-free odorants. Sulfur-based odorants are traditional odorants. This group includes, for example, mercaptans, sulfides and sulfur-containing heterocycles. Mercaptans, also called thiols with the formula R–SH, are sulfur analogs of alcohols and phenols. They react similarly but are more acidic. They are insoluble in water, but they are soluble in ethanol or diethyl ether. They cause a very strong, pervasive and unpleasant smell. Instead of an oxygen atom, their molecules contain a sulfur atom. The functional group of mercaptans is –SH. Mercaptans are mostly liquid substances, except for methanethiol, which is in gaseous form. These types of odorants are also commonly found in the wild nature. In practice, however, various mixtures of several types of odorants are currently used to take full advantage of their positive properties. In this way, the optimal properties of the odorant can be achieved.

III. PIPELINE MODEL IN THE EXAMINED SECTION

The model of the pipeline section was created using CAD software PTC Creo. The simulation of the natural gas and odorant mixture spreading in the investigated section was subsequently carried out in the ANSYS CFX software. The examined pipe section is shown in Fig. 1 when viewed from above.

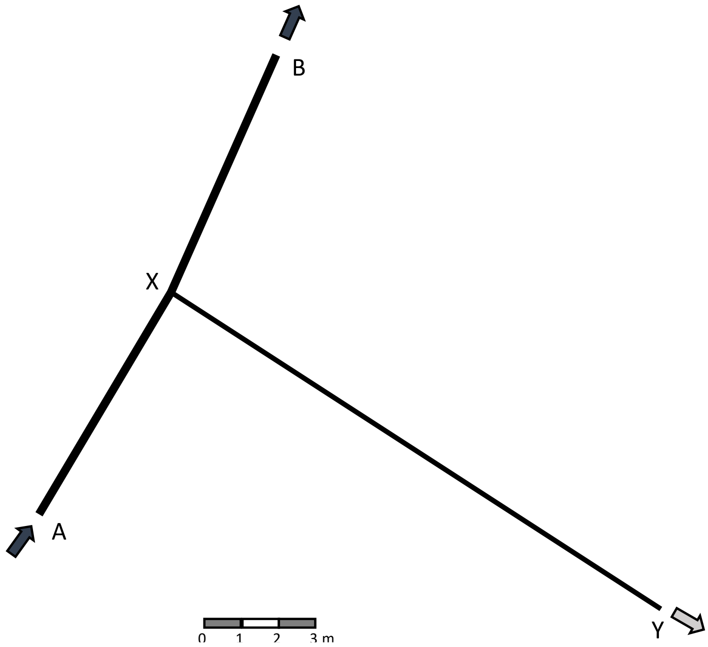

FIGURE 1: The examined section of the distribution network

The section between points A and B represents the main pipe with a diameter of D = 200 mm, while natural gas enters point A. A secondary pipe with a diameter of D = 80 mm is connected to the main pipe at point X. Due to the negligible value of elevation on the selected section of the main pipeline, and no elevation of the secondary pipe, it is possible to consider this section of the pipe network as horizontal. The distances between individual points of the section are defined in Table 1.

TABLE 1
PIPE LENGTH OF SELECTED SECTIONS

Section	Length (m)
A – X	7
X – B	7
X – Y	16

Due to the low partial pressure of the odorant in the pipeline, it can be assumed that the odorant added to natural gas in liquid form always evaporates even at high operating pressures and normal temperatures. This statement is also confirmed by long-term observation of the behavior of odorants added to natural gas in practice. Thus, a homogeneous mixture of natural gas and odorant occurs in the pipeline.

IV. ODORANT CONCENTRATION AT THE DELIVERY POINT AT MAXIMUM FLOW

Before the simulation, it was necessary to set the boundary conditions. At the time of maximum flow through the main pipeline, Q_{mA1} = 0.1034 kg·s^{-1} of natural gas entered point A of pipeline. At delivery point Y, the amount of taken gas was Q_{mY1} = 0.0036 kg·s^{-1}. As the natural gas in the main pipe flowed further from point B, it was necessary to define the relative pressure p_{rel} = 0 Pa at this point. The pressure at point A at maximum flow is p_{A1} = 3.164 MPa. Odorant volume fraction φ_{THT} = 1.0447·10^{-5}. The gravitational acceleration g = 9.81 m·s^{-2} was also considered.

In addition to boundary conditions, it was also necessary to define the material properties of natural gas and odorant. The molar mass of natural gas was calculated according to its current composition. Its density and dynamic viscosity were defined using the .ccl file as a function for temperatures in the range 0-20 °C and pressures in the range 2-4 MPa. This file was subsequently imported into the ANSYS program. The molar mass and dynamic viscosity of the odorant was read from the safety data sheet. Odorant density was defined as a function using equation (1) derived from the equation of state:

$$\rho_{\mathrm{THT}} = \frac{p_{\mathrm{THT}} \cdot M_{\mathrm{THT}}}{\mathrm{R} \cdot T} \tag{1}$$

where p_{THT} is the partial pressure of the odorant (Pa), M_{THT} – molar mass of the odorant ($\mathrm{kg \cdot mol^{-1}}$), R – universal gas constant ($8314\ \mathrm{J \cdot kmol^{-1} \cdot K^{-1}}$), T – thermodynamic temperature (K).

The simulation results show in Fig. 2 the natural gas flow velocity and in Fig. 3 the odorant volume fraction when viewed from above on the XY plane in the pipeline axis at maximum flow:

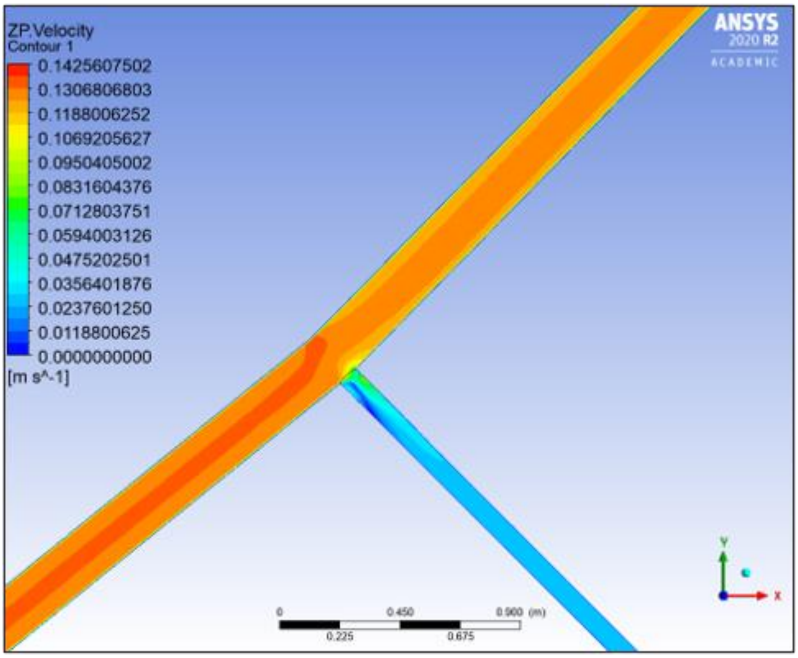

FIGURE 2: Natural gas velocity at max. flow rate

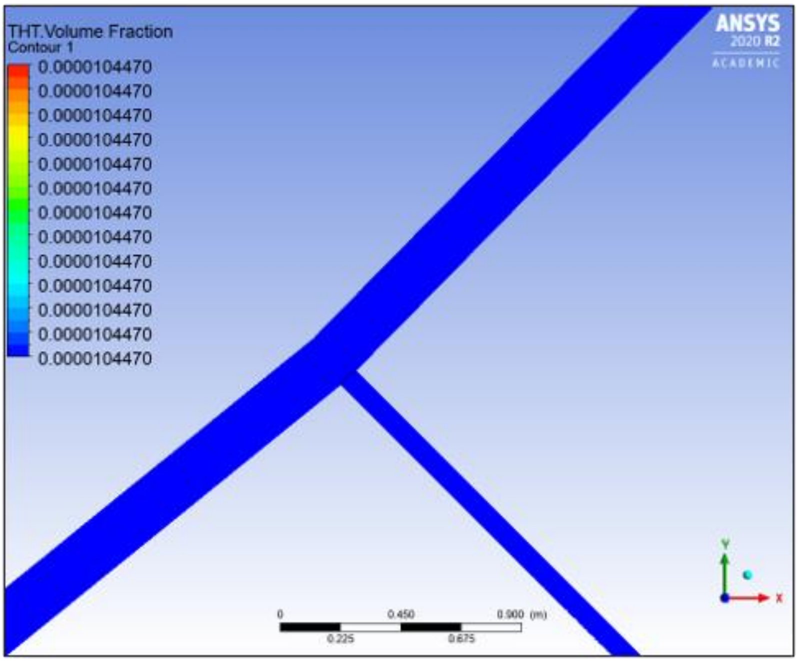

FIGURE 3: Odorant volume fraction at max. flow rate

The result shows that at the maximum flow rate of natural gas, there is no change in the concentration of the odorant in the pipeline along its length in the axis of the pipeline. Using the AreaAve function in the ANSYS program, it was also verified that the concentration does not change even in the cross-section of the pipe at the delivery point Y.

V. ODORANT CONCENTRATION AT THE DELIVERY POINT AT MINIMUM FLOW

At the minimum flow rate at point A in the main pipe $Q_{mA2} = 0.0038$ kg·s^{-1}, the pressure at this point of the pipe was $p_{A2} = 3.179$ MPa. The flow rate at delivery point Y was $Q_{mY2} = 0.0007$ kg·s^{-1}. The volume fraction and material properties were defined as in the simulation at maximum flow. The results of the simulation show in Fig. 4 natural gas velocity and in Fig. 5 volume fraction of the odorant when viewed from above on the XY plane in the pipe axis at minimum flow rate:

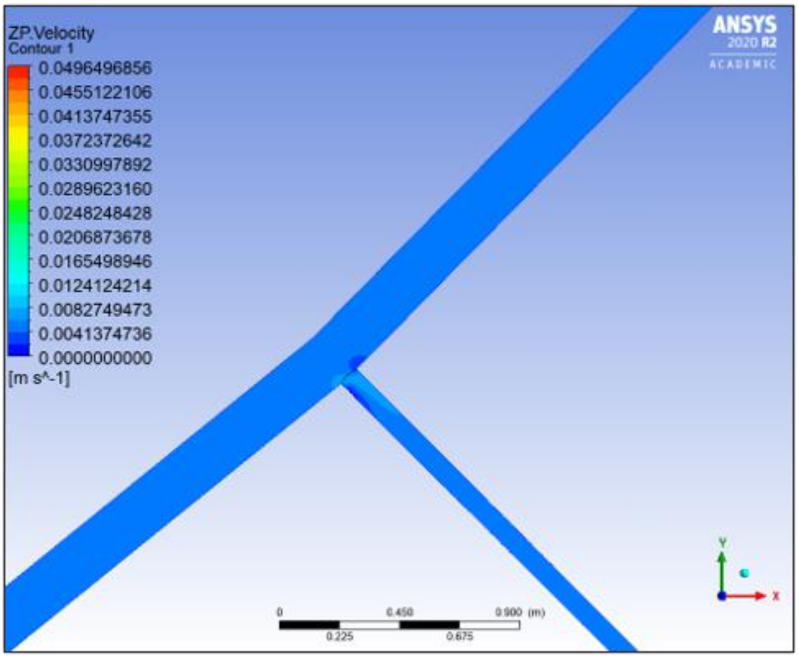

FIGURE 4: Natural gas velocity at min. flow rate

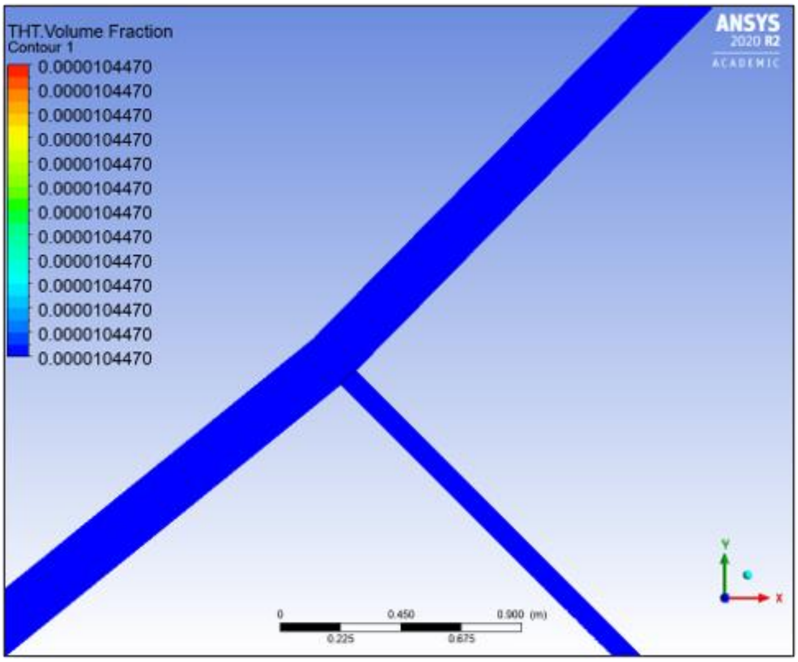

FIGURE 5: Odorant volume fraction at min. flow rate

As in the previous simulation, even in the case of minimum flow, there is no change in the odorant concentration in the natural gas in the axis of the pipe, nor in its cross-section at the delivery point.

VI. ODORANT CONCENTRATION AT THE DELIVERY POINT AT ZERO CONSUMPTION AND MAXIMUM FLOW RATE IN THE MAIN PIPELINE

In this simulation, the goal was to verify a possible change in concentration in an extreme theoretical situation, when at the maximum flow of natural gas in the main pipeline, a state of zero consumption would occur at the delivery point Y. The flow rate and pressure at point A were the same as in the first simulation, the flow rate in delivery point Y was $Q_{mY3} = 0$ kg·s^{-1}. The other parameters remained same as in the previous simulations.

Fig. 6 shows the velocity of natural gas and Fig. 7 shows the odorant volume fraction at zero consumption.

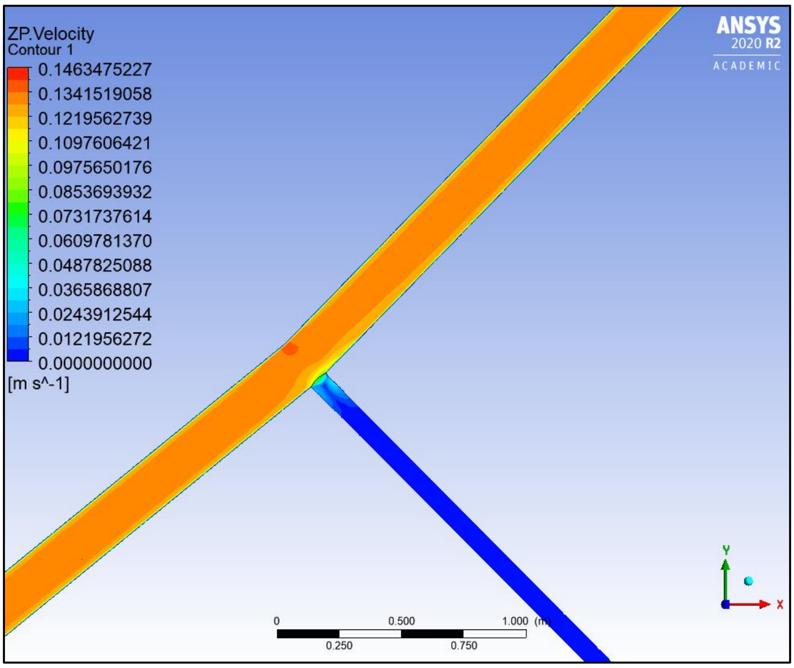

FIGURE 6: Natural gas flow rate at max. flow rate and zero consumption

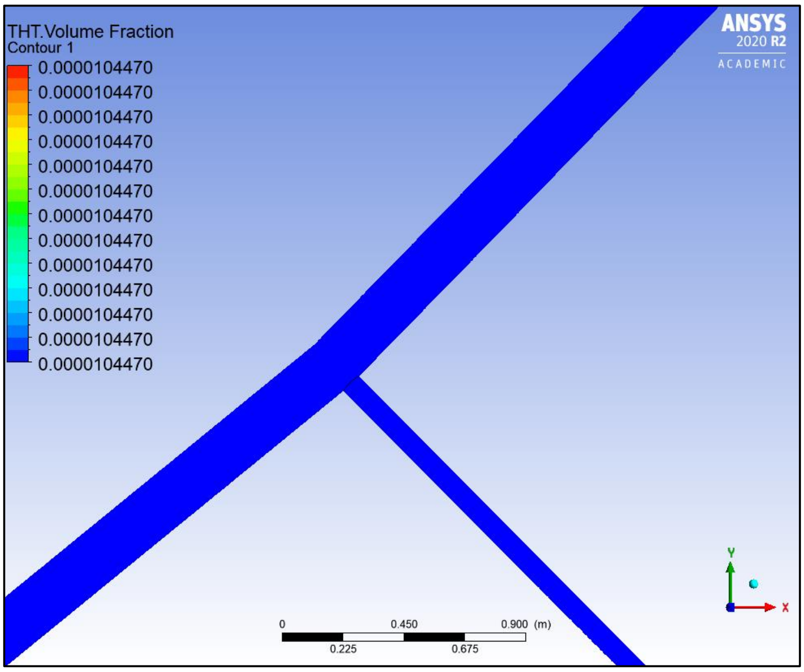

FIGURE 7: Odorant volume fraction at max. flow rate and zero consumption

As can be seen from the results, even in this extreme situation there was no change in the concentration of the odorant in the natural gas.

VII. CONCLUSION

Describing the behavior of an odorant in natural gas is quite complicated, since in addition to physical processes, it is also affected by chemical processes such as adsorption, absorption and oxidation. As a result of these processes, the odorant concentration in natural gas may decrease after a certain period of time. In this article, the focus was on the actual flow of the mixture of odorant and natural gas without the influence of chemical processes. The simulations confirmed the assumption that after the vaporization of the odorant in the pipe, an unchanging homogeneous mixture is formed, regardless of the gas flow rate in the pipeline.

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