Theoretical Analysis of the Natural Separation of Hydrogen and Natural Gas in the Pipelines of An Apartment Building

Romana Dobáková[1*]; Natália Jasminská[2]; Marián Lázár[3]

Department of Energy Engineering, Faculty of Mechanical Engineering, Technical University of Košice, Slovakia
*Corresponding Author

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Abstract— *Due to the current development of the state of fossil resources, efforts are being made to replace extractable energy sources with renewable sources that would have less impact on the environment during the production, transport and consumption processes. Hydrogen is a promising universal energy carrier that could gradually replace the currently used fossil fuels to a large extent. The article discusses the problem of mixing hydrogen into natural gas using simulation in the ANSYS CFX program into the proposed distribution network, as well as its behaviour in a mixture with natural gas in the case of reduced consumption by the consumer, or during downtime or repairs, when the flow in the intake pipe is reduced or completely stopped.*

Keywords— ANSYS CFX, hydrogen, natural gas.

I. INTRODUCTION

Fossil fuels are found in nature only in limited quantities, and with today's dependence of humanity on their excessive use, it can be assumed that within the horizon of several decades, society will reach a point when the reserves of these energy sources will reach a critical point and demand for them will exceed production.

Experiments are currently taking place that deal with the use of the already existing distribution network for the implementation of hydrogen economy in current gas systems and explore the possibilities of transporting hydrogen to the final consumer without the need for significant technological interventions in the natural gas distribution network (ZP). In many countries, the process of mixing different proportions of hydrogen into natural gas is already underway to achieve a reduction in the production of greenhouse gases, and research is also underway into the behaviour of the mixture of hydrogen and natural gas during transport in the pipeline network.

II. MIXING HYDROGEN INTO NATURAL GAS

In addition to high potential, the use of hydrogen hides the need for a total change in infrastructure. Among other things, technical, economic and institutional changes are needed to create a full hydrogen economy, the implementation of which may take decades. These changes concern all individual segments of the energy system, namely production, distribution, storage and use by end consumers. For end users, measures are required due to the change in the properties of the burned mixture of hydrogen and natural gas, considering aspects such as backflow, unintended gas release, efficiency, service life and safety of gas appliances. Among other things, hydrogen can also affect the material properties of the pipeline system, which have an impact on overall safety.

The service life of some types of pipes can be reduced if they are exposed to hydrogen for a long time, especially at higher concentrations and at high pressures. Hydrogen can cause damage to steel pipes even under normal operating conditions in natural gas distribution systems. Hydrogen encounters the pipe material, diffuses through the structure of this material, causes its embrittlement and subsequent degradation of its mechanical properties and the formation of microcracks.

The advantage of mixing hydrogen into natural gas is a significant reduction in greenhouse gas emissions, provided that the hydrogen is produced from low-carbon energy sources, for example using solar, wind, nuclear energy or from fossil energy sources with carbon capture and storage. Mixing hydrogen into natural gas improves air quality in urban areas by reducing the amount of sulphur dioxide and carbon dioxide produced during the natural gas combustion process.

When hydrogen is mixed with natural gas, similarly to when other gases of different densities are mixed, a phenomenon called stratification of the gas mixture can occur. In such a case, different vertical layers of these gases with different representation of individual components may occur in the pipeline, in which there are gases with different densities. A gas with a lower bulk density rises compared to a gas with a higher bulk density. In addition to the influence of gravity on the separation capabilities of gases with different densities, diffusion acts in a mixture of two or more gases. Thanks to the free movement of particles in the pipe, the gases diffuse each other, and thus, under ideal conditions, a homogeneous mixture is created. For low mixture flow conditions that raise concerns about imperfect mixing, injection methods are used to maximize mixing.

III. THE EFFECT OF HYDROGEN ON THE SAFETY OF HOUSEHOLD APPLIANCES

To be able to replace todays commonly used natural gas with a mixture of natural gas and hydrogen in household appliances, the condition of the possibility of safe combustion without the need for structural modifications of the appliances must be met. If it were not possible to burn such a gaseous mixture in already existing facilities, it would mean extensive costs for modification or replacement of appliances for many households.

At the same time, there is a general agreement in publications of renowned companies that a hydrogen content of up to 10% does not represent any or negligible technical risk for existing household appliances [1].

Mixing hydrogen into the mixture with natural gas affects the performance of the burner or power consumption of the appliance, as the combustion heat and calorific value of the given mixture decreases with the increasing proportion of hydrogen in the mixture, and when the pressure parameters of the mixture are maintained, it causes a decrease in the performance of the burners and thus also the power consumption of the appliance. The increasing amount of hydrogen causes a decrease in the density of the entire mixture and, consequently, an increase in the flow rate and thus the amount of mixture flowing through the burner nozzle.

When burning mixtures of natural gas with hydrogen, the values of adiabatic temperatures and actual combustion temperatures in the burners of household appliances are higher than in the case of burning pure natural gas, because hydrogen has higher combustion temperatures than natural gas under the same combustion conditions. Since the combustion of a mixture of natural gas and hydrogen leads to an increase in the stoichiometric volume of the combustion air and thus to a decrease in the temperature of the flue gases, an increase in the combustion temperatures of mixtures of natural gas and hydrogen should not have any effect on the functionality of domestic gas appliances [1].

0% H_2 10% H_2 20% H_2

FIGURE 1: Flame from the burner of a gas appliance at different proportions of hydrogen mixed with natural gas [2]

When mixing hydrogen into a mixture with natural gas, it is necessary to assess its impact on safety in the event of its leakage, either in the event of an accident of the given gas equipment or during a long-term shutdown of the equipment using the combustion of the natural gas mixture treated in this way. Hydrogen is generally easily flammable and therefore when it escapes from the pipe or there is a risk of ignition from the device under pressure due to the turbulent mixing of hydrogen and the surrounding air.

IV. BOUNDARY CONDITIONS FOR SIMULATION IN PROGRAM ANSYS CFX

In order to assess the behavior of hydrogen in a mixture with natural gas, a simulation was carried out in the ANSYS CFX program in the proportional representation of 20% hydrogen and 80% methane. The selected pipe section on which the simulation took place represents the main pipe with four sampling points in a four-story apartment building, where gas was used only for cooking. There was one collection point on each floor. The distance of the sampling points from the main vertical pipeline is 1000 mm, and the distance between the individual floors on which the sampling points are located is 2500 mm. The diameter of the main pipe located vertically is 56 mm, and the diameter of the supply pipes to the gas measuring devices is 32 mm. The inlet of the gas mixture to the pipeline system is located at the lowest point set as OPENNING with the relative pressure at the inlet set to 0 Pa (fig.2).

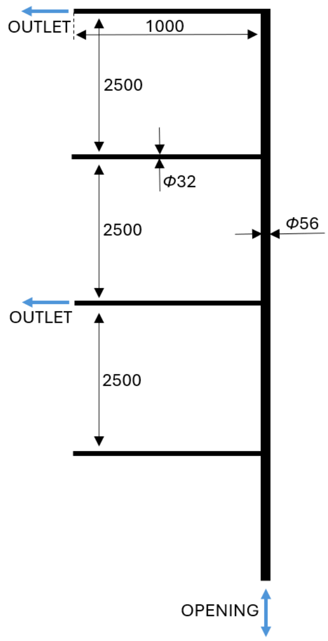

FIGURE 2: Location of individual collection points in a four-story apartment building

Solving the problem of the behaviour of hydrogen in a mixture with natural gas was carried out under two boundary conditions. In the first case, there was no sampling from the main pipeline at any sampling point. This variant represents a period of inactivity during the night hours or during periods with reduced consumption of natural gas, or shutdowns. Assessing the behaviour of hydrogen in a mixture with natural gas at zero consumption is important, as due to their different densities, hydrogen tends to separate from the rest of the mixture. The accumulation of hydrogen in the upper layers of the pipeline during long-term shutdowns can cause undesirable circumstances, such as hydrogen leakage, which can be difficult to detect, since hydrogen is not odorized, or a decrease in the mechanical properties of the pipelines. In the second assessed state, the sampling was realized only on the fourth and second floors, on the remaining two floors the sampling was zero, as shown in fig. 2. Subsequently, the intake of the gas mixture was closed on the highest floor and, after a time interval of 5 minutes, also on the second floor. In the case of consumption, the proposed maximum consumption of a gas stove when using four burners is 2.13 $m^3 \cdot h^{-1}$. Initialization conditions are set to 0 Pa overpressure. After the implementation of the active gas mixture extraction, the simulation time of zero extraction was chosen to be 8 hours, which represents approximately the time of night rest.

In both cases, the development of the distribution of the gas mixture in the pipeline system as well as the possible stratification of individual components along the pipeline height are subsequently investigated.

V. EVALUATION OF THE EXPERIMENT USING SIMULATION IN THE ANSYS CFX

The results of the simulation experiment show the possible probability of the formation of a layer of highly concentrated hydrogen in a mixture with a small proportion of methane in the highest parts of the pipeline distribution system. With increasing time at zero flow in the supply horizontal pipelines to the sampling point of the gas mixture, it is possible to observe a gradual increase in the proportion of hydrogen in the mixture at the expense of the proportion of methane. The longer the shutdown of the gas mixture intake, the larger the area with the increased proportion of hydrogen. The formation of areas can be observed at the highest points of the distribution pipeline system (fig.3, 4).

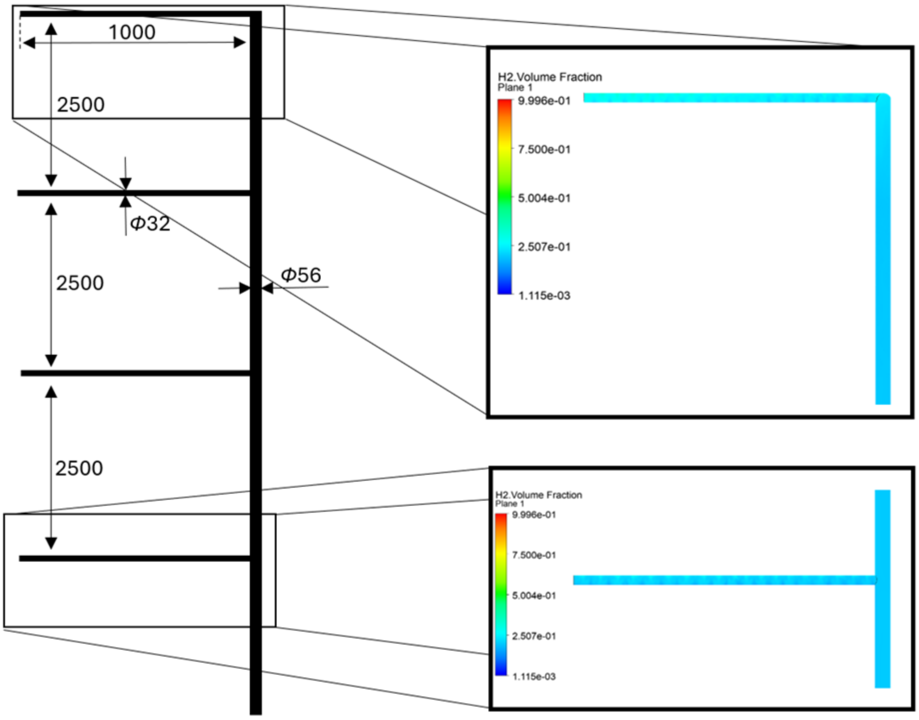

FIGURE 3: Distribution of hydrogen concentration in the distribution system after 2 hours

The separation of hydrogen from natural gas occurred in approximately the same way in the case of the simulation with and without withdrawal. After a period of approx. 15 minutes from the stop of withdrawals, the course of the simulation was roughly the same. In fig. 3 shows the state after two hours from the closing of the withdrawals. It is possible to observe the gradual increase of the hydrogen concentration in the highest intake pipe. The total concentration of hydrogen in this pipeline was around 25-30%.

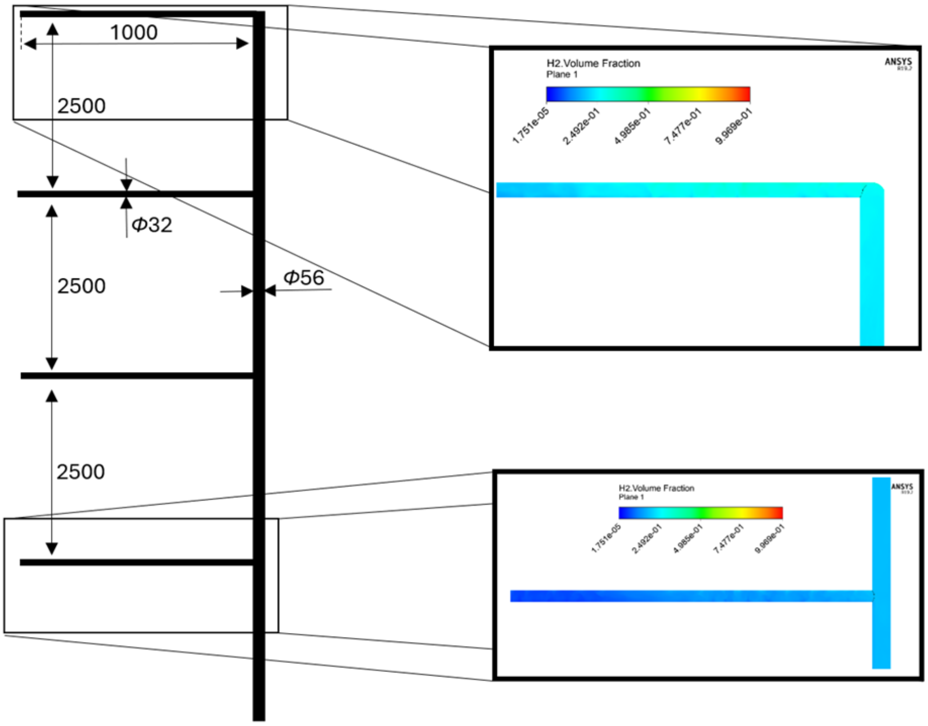

FIGURE 4: Distribution of hydrogen concentration in the distribution system after 8 hours

If the gas withdrawal period exceeds a certain critical time limit, a continuous layer of hydrogen may form, as can be seen in fig. 4. In the case of a longer shutdown of appliances in the highest levels of the distribution of the gas mixture, which may be caused by the non-occupancy of the premises, or the holiday season, the layer of hydrogen in the gas distribution can reach a height of several meters. Such a phenomenon can occur because of the constant supply of fresh gas mixture due to the use of gas appliances in the lower levels of the distribution system and subsequent shutdowns during the night.

Due to the influence of diffusion, continuous mixing of hydrogen with natural gas occurs within the vertical pipeline, but the diameter of the intake horizontal pipes probably impairs the ability of hydrogen to diffuse into the natural gas, resulting in its gradual separation. Despite diffusion, hydrogen is gradually transported to higher parts of the pipeline distribution system. In fig. 4 it is possible to observe that hydrogen concentrations locally reached a limit exceeding 35-40%. At the same time, it is possible to observe that the concentration of hydrogen in the lowest horizontal pipe dropped significantly below the 20% limit. The local increase in hydrogen concentration in the pipeline is primarily influenced by time and mainly by the total amount of hydrogen present in the distribution pipeline system. In places with an increased concentration of hydrogen, damage to distribution systems can occur due to hydrogen embrittlement.

VI. CONCLUSION

Even though the results of simulation experiments cannot be considered as accurately describing the processes that take place in gas pipelines for the distribution of a mixture of natural gas and hydrogen, it would be appropriate to focus on the experimental solution of the problem described in of this article. The formation of areas with a significant presence of hydrogen in the mixture in the pipeline system ensuring the transport of such a mixture can mean a potential danger in case of stoppages of gas mixture intakes.

From the simulation experiments, it is possible to assume the formation of layers with an increased concentration of hydrogen in both horizontal and vertical pipelines, while the probability of the formation of such zones with a higher concentration of hydrogen also increases with increasing height within the distribution system of a mixture of hydrogen with natural gas.

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