POSSIBILITIES FOR THE USE OF HYDROGEN IN THE NATURAL GAS DISTRIBUTION NETWORKS IN THE GREEN ENERGY SEGMENT

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ABSTRACT. The article describes the possibilities for the transport of hydrogen in gas networks mixed with natural gas. Options are described for hydrogen production using alternative energy to meet the Green Deal criteria. The specifics of the transport and distribution gas pipelines in Bulgaria are examined. According to their technical parameters, with the aim of high safety, a scheme of mixing hydrogen with natural gas is proposed. Based on the materials of the pipelines and the technical means of management and maintenance, the permissible concentrations of hydrogen are given. To achieve the possibility of a simplified assessment of the influence of hydrogen, a SWOT analysis was made regarding its impact on gas distribution and transport systems.

Key words: hydrogen, natural gas, green energy, networks, SWOT analysis.

ВЪЗМОЖНОСТИ ЗА ИЗПОЛЗВАНЕ НА ВОДОРОД В ГАЗОРАЗПРЕДЕЛИТЕЛНИТЕ МРЕЖИ В СЕГМЕНТА ЗЕЛЕНА ЕНЕРГИЯ

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РЕЗЮМЕ. В статията се разглежда възможността за транспортиране на водород в газоразпределителните мрежи. Описани са варианти за производството на водород с използване на алтернативни енергии за спазване на критериите за зелена сделка. Разгледани са спецификите на транспортните и разпределителните газопроводи в България. Според техни технически параметри с цел висока безопасност е предложена схема на смесването на водорода с природен газ. На база на материалите на тръбопроводите и техническите средства за управление и поддръжка, са дадени допустимите концентрации на водород. За постигане на възможност за улеснена оценка на влиянието на водорода е направен SWOT анализ по отношение на въздействието му върху газоразпределителните и транспортни системи.

Ключови думи: водород, природен газ, зелена енергия, мрежи, SWOT анализ.

Introduction

In the European economy, a key factor is the implementation of the ambitious goals of the European Green Pact (“The European Green Deal,” 2019) for an energy transition to climate neutrality by 2050 through the decarbonisation of the economy. By 2030, CO_2 emissions in the EU must be reduced by at least 55% (Metalova, n. d.). Very shortly, similar requirements are expected to be enshrined in Bulgarian legislation, given the fact that the Bulgarian society, as part of the European family, is a party to the so-called Green Deal.

As a result of these global changes, many countries have started actions to decarbonise their energy. On a global scale, the share of renewable energy sources (RES) is growing (Alhorr et al., 2014; Mitkov et al., 2022). This process is long with a requirement for the development of new technologies and devices, respectively their digitisation, which makes it financially intensive (Basu et al., 2023). After successfully implementing technologies for the production of electricity and heat from solar, wind, and water sources (Georgiev and Lakov, 2011; Karadjov, 2021), the trend to replace natural gas with hydrogen fuel are imposed. This leads to the entry of technologies for the use of hydrogen. Generated by electrolysis using green energy (photovoltaics, wind generators, etc.), it is injected in different concentrations into the gas supply network. The concentration can vary widely between 5 and 50% depending on the system into which it is injected (*Implementing the repower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets*, 2022).

In this regard, the possibility of using the existing gas supply networks in combination with hydrogen generated by renewable energy sources is on the agenda (“How pink hydrogen could add to the nuclear renaissance,” n.d.).

In support of the introduction of hydrogen technologies is their presence as an energy measure for decarbonisation alongside the recycling of raw materials and materials, the application of zero-waste technologies, smart technologies, clean food, affordable education, and clean, affordable and secure energy (Ejdys and Szpilko, 2022). Statistically speaking, from all types of measures, the share of research to achieve improvement of the energy efficiency of gas supply networks by using hydrogen generated by using the already listed RES and its application in the existing constructed network infrastructure is currently increasing (Gondal et al., 2018; *The European Green Deal*, 2019). In addition, the convergence of different ecological energy sources in search of the synergistic effect of their joint work exists. Globally, the European Union requires not only the use of hydrogen in gas supply networks but also the digital tracking of flows not only of gas, but of all resources from the utility sector ("Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC," 2009). Open projects and programs convince the public of the safety and reliability of the technology, helping to achieve the criteria of sustainable development ("European Hydrogen Safety Panel"). This leads to an increase in the share of hydrogen use in gas supply networks in many European countries through the construction of mixed hydrogen-gas supply systems.

That is why the purpose of the article is to investigate the possibilities of applying hydrogen in pipelines in Bulgaria, clearly describing their advantages, disadvantages, threats, and prospects using the SWOT analysis method.

Specifics of mixed hydrogen-gas supply systems

The application of hydrogen in networks is technically carried out through the creation of "mixed systems". They aim to improve or replace existing gas supply systems with ones using a mixture of hydrogen and natural gas. Therefore, hydrogen can feed the existing gas supply networks, in different concentrations, so that a substantial reconstruction of the networks leading to significant resources is not required.

The efficiency of the functioning of the systems depends on the correct synergistic influence of the different energy sources according to the requirements of the standard, environmental conditions, and economic and infrastructural factors.

For a real assessment of the effectiveness of this technical solution, an adequate analysis of a working network on the territory of all European countries is necessary through digital measurement and tracking of the main parameters. The aim is to examine the benefits and efficiency for consumers and suppliers when changing the share of hydrogen in the networks. This will lead to the reduction of the consumption of fossil energy resources and the negative impact on nature, by the criteria for sustainable development of the European Union ("European Hydrogen Safety Panel").

A major problem in achieving this goal is convincing consumers and a large proportion of small suppliers in the benefits of this investment. A SWOT analysis can show the strengths of implementing hydrogen in gas supply and gas transport networks, while also pointing out the dangers. In addition, society must be aware of the development opportunities and threats in the construction of mixed hydrogen-gas supply systems. The reason is that the injection of hydrogen is related to the study of its possibilities for use in urban distribution networks at a low risk to the population. To achieve the set goals, the gas-dynamic changes resulting from changes in the flow rate and pressure of the fluid due to an increase in the concentration of hydrogen in the network were analysed according to its characteristics. Based on this research, a SWOT analysis is presented.

State of the gas distribution and gas transport system in Bulgaria

The distribution systems in Bulgaria, as well as the networks, are subdivided according to the Ordinance on the device and safe operation of the transmission and distribution gas pipelines, and the facilities, installations, and appliances for natural gas according to their pressure into high, medium and low pressure (PMSN№171/16.07.2004, n.d.). At the same time, the material from which they are built can be steel, high-density polyethylene, copper and/or steel for internal installations, or another material, according to the requirements of the regulation, which are strictly specific to the transport of natural gas (Karadjov, 2022).

The systems also contain adapters, valve units, gas regulating and measuring stations, filters, pressure regulators and temperature and pressure correctors, solenoid valves, measuring devices, compensators, casings, and candles. These are complex facilities, the indicators of which need to be registered and controlled using a CAD system of the main parameters - pressure, flow rate, and temperature. All this is to ensure the security and safety of the system and third parties.

The study of hydrogen deployment methods has many specifics, such as properties of hydrogen, method of injection into the network, concentrations, and others, which is also part of the central topic of this article. The focus of these studies brings us to five aspects: gas transport; storage; type of distribution system; application to the end user; measurement and regulation (Ekhtiari et al., 2022). For safety, it needs to know the permitted amount of injected hydrogen in the system, and it is necessary to determine the permissible concentrations and the "neuralgic" points that are sensitive to this, i.e. the most vulnerable places. Limits on hydrogen levels vary widely by legislation, with up to 17% hydrogen content in natural gas being a feasible target without changes to existing technologies (Clegg and Mancarella, 2016). Briefly, for the sake of clarity, the following categories of factors reflecting the behavior of changing hydrogen concentration can be distinguished: material of the equipment and pipelines, their functions, method of injection, and the type of equipment at the end users.

Types of material

Steel pipes. It is known that hydrogen is lighter than air and the molecule has a small size, therefore it causes high diffusion not only in the gas distribution but also in the pipe walls based on the pressure variation due to the transient gas flow (Hafsi et al., 2018). This, in turn, leads to the ageing of the material, an increase in the brittleness of the steel, and the risk of leaks in the network. Such materials are the steel elements of the type API X52 and API X80, which are mainly used for the transportation of natural gas. They have low tensile plasticity, and the cracks grow at temperatures that are also characteristic of Bulgaria (Khwaja and Paul, 2022). Before using hydrogen in pipelines, a compatibility and corrosion resistance test should be performed because of the danger of overpressure and hydrogen corrosion. A suitable material to explore is nitrided steel or the use of higher-grade steel pipes, which would also increase safe working conditions, and reduce accidents and the possibility of leaks (Hristova, 2017).

Plastic pipes. Regarding the ageing parameter of high-density polyethylene, as well as PVC for some countries, larger amounts of hydrogen could be injected, namely over 15% to 50%, for domestic 20%, given the corrosion resistance of the material (Ekhtiari et al., 2022). The reason is that these thermoplastic plastics have a higher ductility than metals. Unfortunately, there is an increased mobility of hydrogen, which is also the reason for the increased permeability of the pipe walls made of these materials. Permeability per day is reported, which depends on the pressure, but the difference between the amounts of methane and hydrogen is significant:

- Methane: 1.1 liters/km/day,
- Hydrogen: 2.3 liters/km/day (Melaina et al., 2013).

In the same study, the durability of these materials was reported to be increased compared to metallic ones, and their values are shown in Table 1. Therefore, it is imperative to study their compatibility with hydrogen in the transfer after a careful economic and technical analysis of the losses in the system from the point of view of its diffusivity compared to the high pressure polyethylene brands.

Table 1. *Percentage of a blend of H2G for different materials pipes.*

St pipes Up to 10-20% presence of H2 in the system, manufacturers recommend up to 7%.	**PEHD 100** Up to 35-50% presence of H2 in the system, manufacturers recommend up to 30%
Cu Up to 10% presence of H2 in the system, up to 7% is recommended	**PEHD 80** Up to 40% presence of H2 in the system, up to 10% is recommended

Types of network

Transportation systems. The transportation system includes components such as pipelines, gas turbines, compressors, compressor stations, etc. Their characteristics mainly depend on the material from which they are made, and for pipes it is steel. When tested in hydrogen mixed gases, they show the ability to work with up to 30% hydrogen-natural gas (H2G) mixture, while any increase in these amounts above these levels or at levels of 50% lead to critical corrosion activity towards the system components (Ekhtiari et al., 2022).

Turbines and compressor stations operate with a 10-20% H2G mix. However, manufacturers recommend lower hydrogen concentrations in the order of 1 to 5%, or of 5% to 7% at most (Ekhtiari et al., 2022). Major turbine manufacturers such as General Electric recommend H2G of up to 5%, while Siemens mandates 15%, and Mitsubishi Hitachi Powers report the highly efficient operation of their turbines of up to 30% ("How pink hydrogen could add to the nuclear renaissance," n.d.).

In compressor systems, up to 20% concentration of hydrogen in the composition of natural gas does not negatively affect the system, but requires a degree of suitability in terms of the materials used and the ability of hydrogen to migrate. Therefore, lower concentrations in the order of 7-10% are recommended (Ekhtiari et al., 2022).

In general, the transport system in which mixtures between injected hydrogen and natural gas will be used requires material replacement and the use of alloyed and nitrided steels for the resistance of the material when working with the hydrogen-containing mixture (Melaina et al., 2013).

An important factor is the calorific value of the mixture, as that of hydrogen-natural gas is lower than that of natural gas. This parameter leads to the need for adjustments, regarding the appliances at the end customers. (ibid).

It was found that density changes significantly above 20% H2G. The lower density affects the flow rate by increasing it and with it the pressure. The delivery of larger quantities is necessary to satisfy the required flow rates of consumers, which is directly related to the ability of pipes and appliances to withstand the new pressures (Gondal, 2019; Gondal et al., 2018).

Gas distribution and supply networks

Gas distribution and supply networks made of high-density polyethylene do not show activity about the concentration of hydrogen in the H2G mix and there is no major corrosion hazard. Rather, in networks, the risk is of diffusion, migration, and leakage of gas into the atmosphere (Gondal, 2019; Gondal et al., 2018). Therefore, the implementation of systems to detect hydrogen leakage and create explosive conditions is of great importance, and it is necessary.

Table 2 shows the effect of hydrogen on the various elements of the system at different percentages of hydrogen in the systems (Ekhtiari et al., 2022; Gondal, 2019; Topolski et al., 2022).

Table 2. *Impact of H_2 in NG on the elements of gas supply systems*

Element	Percentage content H2	Need for action
Pipelines stee PE	0-20 % 31-50 %	unaffected Suitability adjustments
Gas compressors in transmission pipelines	10%	Suitability adjustments
Turbines	5-7% 10-20%	unaffected Suitability settings
Compressor stations low	0-7% 7.5-10%	unaffected Suitability adjustments
Boilers	0-7% 7-25%	unaffected Suitability settings
Gas burners sensors	0-7% 7-48% 10%	unaffected Suitability settings

Hydrogen injection methods

The injection is carried out by a group of hydrogen bottles in a system, the quantity being controlled by a computer system recording the flow parameters. The system in Fig.1. contains solenoid valves, taps, flowmeters, manometers, and regulators.

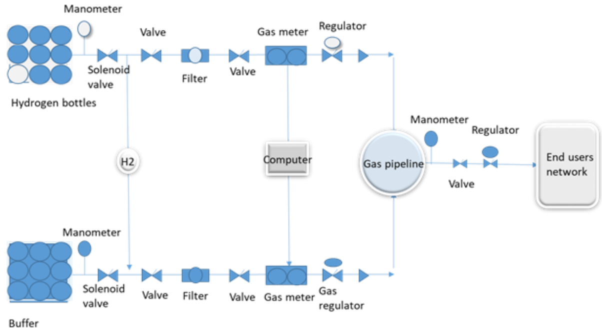

Fig. 1. Figure of hydrogen injection in the system

Another type of possible system is connected as shown in Fig.2 using RES to generate energy for hydrogen hydrolysis.

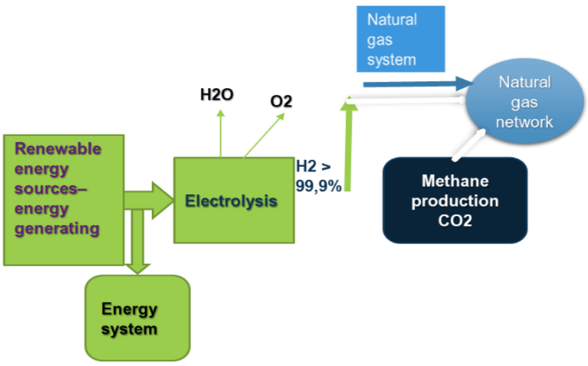

Fig. 2. Scheme of hydrogen generation and injection into the natural gas system, using RES to generate energy for hydrogen hydrolysis

The advantages of the first scheme are the possibility of stockpiling when increased supplies are needed, and the disadvantage is a risk in supplies, storage, and trouble-free operation with a requirement for technical supervision and storage. In the second scheme, there is no need for a warehouse, but there is no possibility of producing extraordinary quantities except in the presence of another installation. A detailed study of the injection capabilities and schemes will be the team's next study.

Devices at the end users

The devices at the end customers are also sensitive to the effects of hydrogen on the metal parts as they corrode, become brittle, and breakable. Their material must be compatible with the characteristics of the gas, iron, and specific conditions.

In terms of appliances, the Wobbe index is of utmost importance. This index shows the heating capacity of gases and their interchangeability. It is expressed as the calorific value of the fuel divided by the square root of its specific gravity. The Wobbe Index (WI) or Wobbe number is an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and town gas and is often specified in the specifications of gas supply and transport services. The higher the index, the more calorific the gas and the greater the heat-generating capacity. Values of 48-58 MJ/nm^3 indicate the calorific value of natural gas, which defines it as having a high calorific value. For gases less rich in methane, the value is lower and is between 41-47 MJ/nm^3 (Gondal et al., 2018).

Table 3 shows the dependence of the WI index on the hydrogen content in the mixture (Gondal, 2019; Topolski et al., 2022).

Table 3 *Calorific value ratio in relation to the Wobbe index and the presence of hydrogen in the mixture*

	Wobbe IndexMJ/nm3	
H2 %	Low callorific value gas	High callorific value gas
0	48	58
10	47	57
20	46	56
30	45	51
40	44	50
50	43	49
60	42	48
70	41	46
80	40	45

Fig. 3 shows how the parameters of the Wobbe index change about the presence of hydrogen in natural gas at a concentration of 60%. The dependence then changes with increases (Zhao et al., 2019), but these values are not the subject of the present analysis.

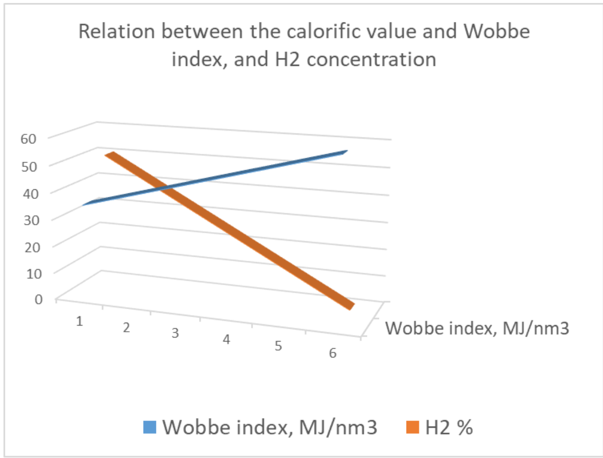

Fig. 3. Wobbe index in relation to the presence of hydrogen

The presence of hydrogen in the system decreases the Wobbe index as its concentration increases. The presence of hydrogen, depending on the percentage content, also determines the calorific value levels, as they move inversely proportional to the injected amounts of hydrogen in percentages compared to the natural gas in the system.

Regarding the natural gas flame, many authors claim that a 5% increase in flame speed and a rise in flame height are observed when hydrogen is introduced into the mixture up to 20%. For turbulent regimes in turbines, the authors claim that with a larger increase in speed of about 20%, the flame speed is also increased (Topolski et al., 2022).

SWOT analysis

Despite all the evidence for the perspective of hydrogen injection in transport and distribution systems, there are known technical parameters that show increased flame, permeability, and reduced calorific value. This leads to a certain amount of mistrust among consumers. Since a regulatory framework is in place and large companies have developed solutions and grant financial means, a method of convincing the public is needed. For this purpose, the presentation of this innovative idea using the SWOT analysis method is suitable in Table 4. It gives a clear idea of the advantages and disadvantages, development trends and opportunities, as well as expected threats.

The concrete explanation of the processes in the introduction of new technologies is a starting point for public approval and support, referring not only to consumers, but also to a large part of the business, i.e. future investors. Therefore, SWOT is presented regarding the interaction of pipe materials with hydrogen in the mixture of mixed hydrogen-natural gas systems and the resulting deployment opportunities. (Gürel, 2017; Sammut-Bonnici and Galea, 2015).

Undescribed matters and issues in the work are pressure variation as the H2G mix varies with pipe diameter, maintainability, the usability of cathodic protection, injection methods, and others, which will be future work of the team.

Table 4. *SWOT analysis*

	Internal factors	
System	**Strong points**	**Weak points**
Gas distribution, polyethylenes	Achieving decarbonisation; They have no activity towards hydrogen; Tolerate high concentration; Availability of patents and technically competent personnel; Good partnerships with local, regional, and national organisations; Improved customer service; High-quality information; Systematic control;	Hydrogen release; Reduced calorific value and low Wobbe index; High diffusion; Possible accidents; Lack of trained service personnel
Transport systems, Steel	Achieving decarbonisation; Persistent behaviour at the indicated concentrations; Increased diffusion; Production available; Investment and technical experience; Availability of patents and technically competent personnel; Systematic control	Reduced resistance to high concentrations; Corrosion; Accidents; Cracking of the steel; Lack of trained service personnel; The reduced caloric content and low Wobbe index;

	External factors	
Systems	**Possibilities**	**Threats**
Gas distribution and transport	Digitalisation; High traceability of parameters; Ability to analyze; Predictability of behavior; Changing technological parameters; The rapid development of technological opportunities in the field; Creation of a monitoring system; Availability of European programs for the introduction of hydrogen; The price per unit of energy is expected to decrease; Investment experience; Opportunity for scientists and businesses to participate in common projects;	Accidents; Increased funding; Need for staff training; Need for digital surveillance; Monitoring the regulatory base and its change; Lack of trust Increased flow rate requirement;

Conclusions

To reduce the carbon footprint, achieve increased efficiency, and meet the criteria for sustainable development, it is possible to use hydrogen in natural gas systems. The available regulatory framework, financial interest, and solutions from the major companies have been established. Despite some inconveniences in the application of hydrogen, such as increased diffusion and slightly reduced calorific value, there is indisputable evidence of its effectiveness and a major role in reducing the carbon footprint.

The complex technical parameters in presenting this innovation comprehensibly are overcome by a SWOT analysis, in which not only the advantages are explained, but also the risks and development opportunities and threats in the application of hydrogen. Such an analysis was made based on the types of networks, materials, facilities, and devices inherent in their operation. The clear, accurate, and categorical presentation of the latter is a factor in convincing the public of the benefits, as well as an opportunity to prepare a comparative analysis with other proposals. The presented SWOT analysis uses parameters, such as material resistance, corrosion resistance, permeability, flow rate, calorific value, safety, leakage losses, and the Wobbe index.

The comments and conclusions made are not final and definitive, because they can be enriched and developed as the number of applications of this technology increases.

Acknowledgements. The authors thank Project NI SEVE contract MON Do1-160/28.08.18, for the support in projects for the use of hydrogen technologies.

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