INFLUENCE OF HYDROGEN CONTENT IN GAS MIXTURES WHEN DETERMINING THE COMPRESSIBILITY FACTOR

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ABSTRACT. The report presents a methodology for determining the compressibility factor at different hydrogen contents in gas mixtures. Based on the presented methodology, the change of the compressibility coefficient of gas pipeline mixtures, with different hydrogen content, under different thermobaric conditions and the characteristics of gas distribution networks, is determined. Attention is paid to the influence of the exact determination of the compressibility factor when considering the consumption of gas hydrogen mixtures by consumers, as well as to the hydraulic dimensioning of the gas distribution networks, through which the gas-hydrogen mixture will be transported.

Key words: hydrogen, gas mixtures, compressibility factor.

ВЛИЯНИЕ НА СЪДЪРЖАНИЕТО НА ВОДОРОД В ГАЗОВИ СМЕСИ ПРИ ОПРЕДЕЛЯНЕ НА КОЕФИЦИЕНТА НА СВРЪХ СВИВАЕМОСТ

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РЕЗЮМЕ. В доклада е представена методика за определяне на коефициента на свръх свиваемост при различно съдържание на водород в газови смеси. На база на представената методика е определено изменението на коефициента на свръхсвиваемост на газопроводни смеси с различно съдържание на водород и при различни термобарични условия, характерни за газоразпределителните мрежи. Обърнато е внимание на влиянието на точното определяне на коефициента на свръхсвиваемост при отчитане потреблението на газоводородните смеси от потребителите, както и за хидравличното оразмеряване на газоразпределителните мрежи по които ще се транспортира газо-водородна смес.

Ключови думи: водород, газови смеси, коефициент на свръхсвиваемост.

Introduction

Natural gas is a mixture of hydrocarbons of light components from methane to propane (Nikolov, 2007; Boyadjiev, 2023). With the advent of decarbonisation and low carbon footprint requirements, the deployment of hydrogen in natural gas distribution and delivery systems is increasingly coming. (“A European Green Deal,” n.d.) The requirements are for an energy transition to climate neutrality by 2050. The ambitious goal set by 2030 is to reduce CO2 emissions in the EU by 55% (Metalova, n.d.). This will reflect that in future, similar requirements will also be set in the Bulgarian legislation as part of the European legislation and as a party to the GREEN DEAL.

The world is changing and more countries are taking action to implement hydrogen in their energy sector. The share of renewable energy sources (RES) occupies an increasing percentage of the total energy distribution (Alhorr et al., 2014; Mitkov et al., 2022). The development of new technologies and facilities becomes a key factor for the development of enterprises in the new era. Production is becoming more and more financially intensive and innovative (Basu et al., 2023).

Successful implementation of technologies for the production of electricity and heat from solar, wind, and water sources is one of the factors of development (Georgiev and Lakov, 2011; Karadjov, 2021), with the trends of replacing natural gas with hydrogen fuel increasingly being imposed.

The use of hydrogen is increasingly being introduced by the European institutions and short deadlines oblige companies to apply programs for the implementation of RES, hydrogen, and other technologies that reduce the release of carbon dioxide into the atmosphere. Hydrogen is introduced into the natural gas supply networks, being generated by electrolysis using green energy (photovoltaic, wind generators, etc.) and/or injected in different concentrations into the gas supply network, in different concentrations within the proven possibility for operation without change in the system and users' devices - between 5 and 20% depending on the system in which it is injected (*Cmplementing the repower EU action plan: investment needs, hydrogen accelerator and achieving the bio-methane targets*, 2022).

Gas supply networks in combination with hydrogen generated by RES are already being considered for use by Bulgarian energy companies or households, and such a practice is gaining popularity (Karadjov, Hristova (2023), “How pink hydrogen could add to the nuclear renaissance,” n.d.).

There are tendencies to increase the share of research to achieve improvement of the energy efficiency of gas supply networks by using hydrogen generated by RES and its application in the existing constructed network infrastructure (Gondal et al., 2018; *The European Green Deal*, 2019).

The requirement of the European Union for the use of hydrogen in gas supply networks sets tasks related to the accounting of the passed energy, and this is directly related to the digital tracking of the flows of mixtures of hydrogen and natural gas (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; Hristov P, Hristova T, 2019).

More and more European programs are being implemented, such as hydrogen deployment projects, and scientific research on the safety and reliability of cogeneration technology is carried out (“European Hydrogen Safety Panel,” n.d.). That is why the share of hydrogen use in gas supply networks in many European countries through the construction of mixed hydrogen-gas supply systems is steadily increasing.

The purpose of the study is to present the variation of the compressibility factor devitiation from an ideal gas z factor, at different input data of the systems. The parameters: pressure, hydrogen concentration and temperature are important when consider the consumption of gas-hydrogen mixtures by consumers, as well as for the hydraulic dimensioning of the distribution networks. The test for compressibility factoris done according to the Standing-Katz method. The research done gives a clear idea of the changes of the compressibility parameter, as an important factor for the correct accounting of the change in the behavior of the gases from the ideal case and their accounting, as a flow in the networks.

Specifics of the compressibility coefficient for hydrogen in gas mixtures

The injection of hydrogen into networks is technically carried out by creating "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 state of gases is defined primarily by the volume, temperature, and pressure of the system. Accounting for the deviation from the state of ideal gases from real gases requires the determination of the dimensionless value of the coefficient of compressibility Z, under different thermobaric conditions.

Here, the following equation is in force:

$$PV=z.n.R.T, \tag{1}$$

where:

P is the pressure in Pa;
T – temperature in ^{o}C;
R – universal gas constant in J/kmol.K;
V – volume in m^3;
Z - compressibility factor;
n – number of molls in kmol.

According to the Standing–Katz diagrams, the reduced and critical values of the thermobaric conditions under which the gas is present play a role in determining the z factor.

$$\mathrm{Ppr} = \frac{\mathrm{P}}{\mathrm{P}cr}; \tag{2}$$

$$\mathrm{Tpr} = \frac{\mathrm{T}}{\mathrm{T}cr}; \tag{3}$$

where Pcr and Tcr are pseudocritical pressure and temperature, in MPa and K, respectively, and P and T are the pressure and the temperature in MPa and K.

$$\mathrm{Tcr} = \sum_{k=0}^{n} \mathrm{y}i.Tcri; \tag{4}$$

$$\mathrm{Pcr} = \sum_{k=0}^{n} \mathrm{y}i.Pcri; \tag{5}$$

For a real estimate of the coefficient of overcompressibility, the Standing-Katz plots give a certain accuracy of about 5% under certain conditions of the gas mixture as follows: $P < 12$ MPa, $T < 70$ ^{o}C, H_2S and $CO_2 < 5\%$ mol, content of N_2 ip to 10% mol (Nikolov, 2007).

To calculate the coefficient of deviation from ideal gases, an approximation of the graphs can be used the Latonov-Gurevich dependence (Nikolov, 2007), according to the formula:

$$\mathrm{z} = [0{,}4\lg Tpr + 0{,}73]^{\mathrm{P}pr} + 0{,}1\ \mathrm{P}pr \tag{6}$$

where:

z is the compressibility factor;
Tpr – brought down temperature in K;
Ppr – brought down pressure in MPa.

The composition of the gas is essential in determining the reduced and critical temperatures, and pressures. Therefore, calculations were made at different composition ratios in terms of the percentage of hydrogen to methane, varying from 0 to 100%.

The analysis of the variation of the compressibility coefficient, in relation to the different hydrogen content, aims to show indirectly what would be the variation of the volume in relation to the composition of the gas under the different thermobaric conditions. The goal is to investigate and predict the possible changes that occur when the content of methane in the mixture is changed, as well as to perform the necessary recalculations with a view to the accurate digital measurement of the flows in the networks and their main parameters. (“European Hydrogen Safety Panel,” n.d.).

The main problem here is the properties of hydrogen and its specifics. Safety makes serious demands to achieve this goal. From the resulting new hydrogen injection mixtures, the strengths of the implementation of hydrogen in gas supply and gas transport networks can be shown, but the weaknesses of the system can also be seen, which at the same time are the dangers that could arise. The reason is that hydrogen injection is related to a number of factors changing the working conditions of urban distribution networks where a low risk to the population is sought. To achieve this, it is necessary to analyse the gas-dynamic changes resulting from changes in the system parameters, such as temperature, flow, and pressure, as well as fluid composition, due to an increase in the concentration of hydrogen in the network.

Methodology for determining the coefficient of compressibility of gas-hydrogen mixtures

Calculation of compressibility coefficients and gas law deviation coefficients is performed using a modified Equition SGERG-mod-H2 (Report PK 1-5-3 Dr. Peter Schley, 2021).

When choosing a option in relation to the main operating conditions, technical parameters of the gas distribution systems and networks in Bulgaria, as subdivided in the Ordinance on the device and safe operation of transmission and distribution gas pipelines and natural gas facilities, installations and appliances, were selected according to the pressure~~,~~ (PMSN№171/16.07.2004, n.d.). That is why high, medium and low pressure was considered, and taken as characteristics of the pipelines.

Another parameter is the temperature. Natural gas in the country is traded under standard conditions, which means at T = 20^{0}C and P_{atm} = 101 325 Pa, while in Europe standard conditions are set at T = 15^{0}C.

For the compressibility coefficient, another important parameter is the critical pressure and temperature Pcr (Pa) and Tcr (K), according to formulae 4 and 5.

The SGERG-88 equation was developed by Jaeschke et al. described in the international standard ISO 12213-3 "pipeline quality gas". For the application of hydrogen in the systems, it is necessary to ensure against the corrosive effects on the material, as with the increase in the mole fraction of hydrogen, the replacement of the material of the pipelines and the equipment to them is also required. In view of the safety of applying higher concentrations of hydrogen in the systems and providing protection against corrosion activity, the following measures are recommended, with up to 17% not requiring replacement of the types of pipes used according to the authors (Clegg and Mancarella, 2016):

The limit for the hydrogen content was set at 20 mol %, as an acceptable content for safety reasons from the point of view of the immutability of the pipe material. The density is in the range of $0.55 \leq d \leq 0.80$; the density range under standard conditions is from $0.711\ kg/m^3 \leq \rho n \leq 1.034\ kg/m^3$. (Technical report PK 1-5-3 Dr. Peter Schley, 2021). Therefore, the calculations performed are based on hydrogen percentage, pressure, and temperature.

The flowchart of the methodology for determining the coefficient of compressibility factor of gas-hydrogen mixtures is shown in Figure 1.

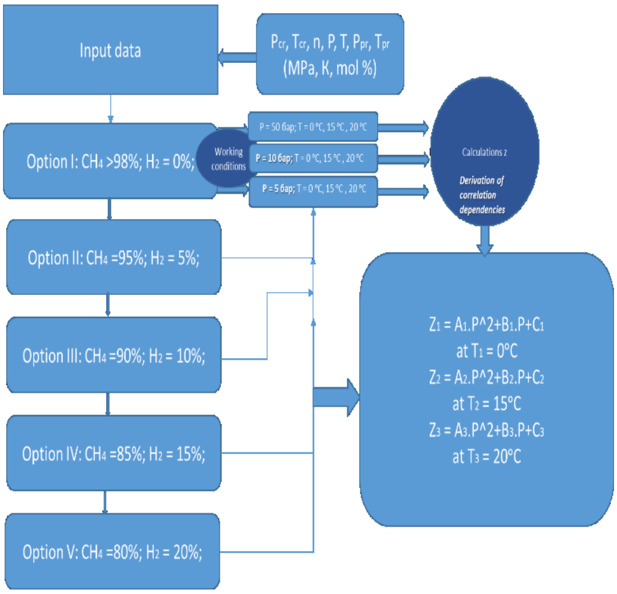

Fig. 1. Flowchart for calculating the coefficient of the compressibility factor

Results

The results obtained from the calculations at pressures of 50, 10, and 5 bar for the five options at different temperatures 20 ^{0}C, 15 ^{0}C, and 0 ^{0}C and content in the gas of H_2=0%, H_2=5%, H_2=10%, H_2=15%, and H_2=20%, are given in Table 1 below. In view of the fact that gas distribution and supply networks of high density polyethylene exhibits activity in relation to the concentration of hydrogen in the H_2G mix, there is no major corrosion hazard within up to 20% presence of hydrogen in the system. Rather, in networks, the risk is of diffusion, migration, and leakage of gas into the atmosphere (Gondal, 2019; Gondal et al., 2018).

Table 1. Change in the coefficient of compressibility

Option	CH4 %	H2 %	P bar	T=20^{0}C Z	T=15^{0}C Z	T=0^{0}C Z
I	~100	~0	50	0,9117	0,9055	0,8835
			10	0,9817	0,9806	0,9765
			5	0,9909	0,9903	0,9880
II	~95	~5	50	0,9228	0,9172	0,8976
			10	0,9838	0,9827	0,9790
			5	0,9919	0,9913	0,9895
III	~90	~10	50	0,9332	0,9282	0,9108
			10	0,9858	0,9848	0,9814
			5	0,9929	0,9924	0,9907
IV	~85	~15	50	0,94295	0,9385	0,9231
			10	0,9877	0,9868	0,9838
			5	0,9938	0,9934	0,9918
V	~80	~20	50	0,95205	0,9481	0,9345
			10	0,9895	0,9887	0,9860
			5	0,9947	0,9943	0,9929

Figure 2 shows the variation of the coefficient of compressibility factor for option I, at pressure from 5 to 50 bar and temperature from 0 ^{0}C to 20 ^{0}C. Correlation dependences have been derived for express stepwise determination of the coefficient of compressibility factor in the analysed thermobaric range, with content of 100% of methane in the gas.

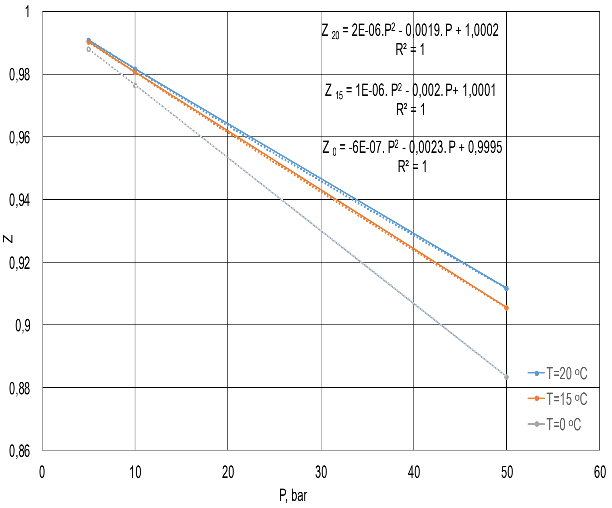

Fig. 2. Variation of the coefficient of compressibility for option I

Figure 3 shows the variation of the coefficient of compressibility factor z for option II, at pressure from 5 to 50 bar and temperature from 0 ^{0}C to 20 ^{0}C. Correlation dependences have been derived for express stepwise determination of the compressibility coefficient in the analysed thermobaric range, with a content of 95% of methane and 5% of hydrogen in the gas mixture.

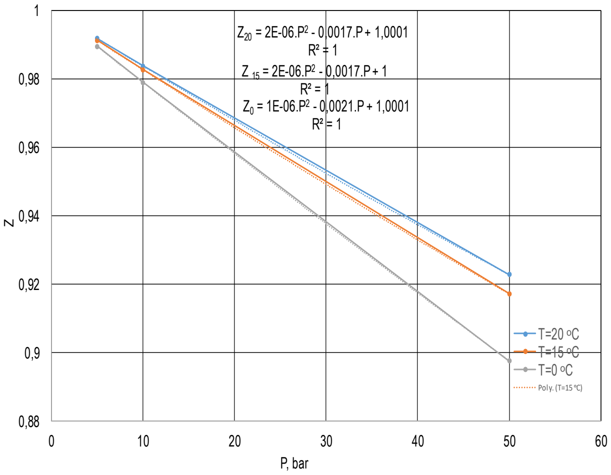

Fig. 3. Variation of the coefficient of compressibility for option II

Figure 4 shows the variation of the coefficient of compressibility factor for option III, at pressure from 5 to 50 bar and temperature from 0 °C to 20 °C. Correlation dependences have been derived for express stepwise determination of the coefficient of compressibility factor z in the analysed thermobaric range when the gas mixture contains 90% of methane and 10% of hydrogen.

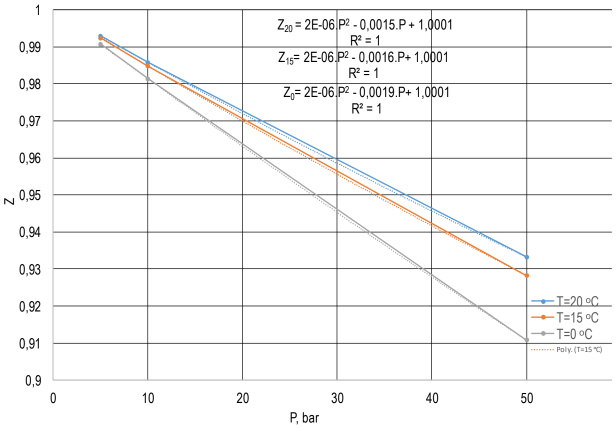

Fig. 4. Variation of the compressibility factor for option III

Figure 5 shows the variation of the coefficient of compressibility factor for option IV at pressure from 5 to 50 bar and temperature from 0 °C to 20 °C. Correlation dependences have been derived to express stepwise determination of the compressibility coefficient in the analysed thermobaric range with a content of 85% of methane and 15% of hydrogen in the gas mixture.

Figure 6 shows the variation of the coefficient of compressibility for option V at pressure from 5 to 50 bar and temperature from 0 °C to 20 °C. Correlation dependences have been derived for express stepwise determination of the compressibility coefficient in the analysed thermobaric range with a content of 80% of methane and 20% of hydrogen in the gas mixture.

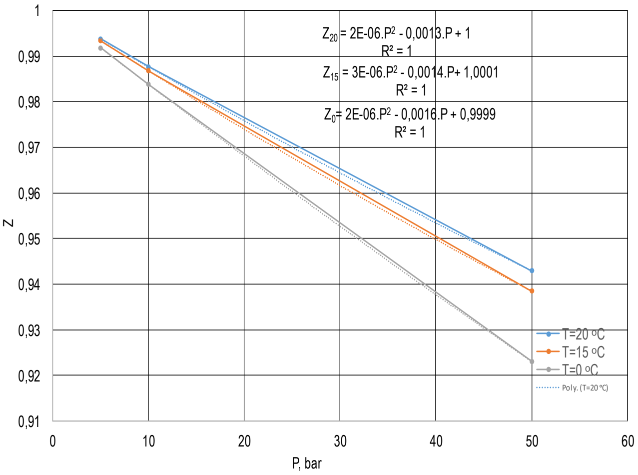

Fig. 5. Variation of the coefficient of compressibility factor for option IV

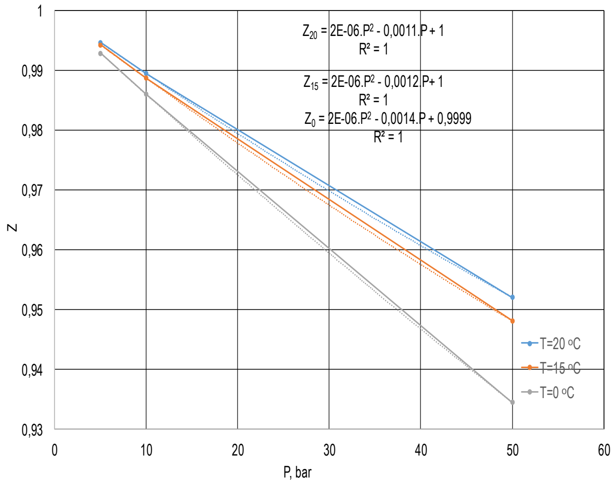

Fig. 6. Variation of the coefficient of compressibility factor for option V

Conclusions

From the calculations made according to the presented methodology, it was established that the coefficient of the compressibility factor for a gas-hydrogen mixture in the analysed thermobaric range and with a hydrogen content of 5 to 15% hydrogen in the gas-hydrogen mixture changes significantly.

In the developed methodology, the use of the GERG-2008 equation for calculating the coefficient of compressibility for a gas-hydrogen mixture, has deviations smaller than ± 0.1%; and are usually less than ± 0.05 %.

The derived correlation dependences to express step-by-step determination of the coefficient of the compressibility factor in the analysed thermobaric range at a hydrogen content of 5 to 15% in a gas-hydrogen mixture are applicable when considering the consumption of gas-hydrogen mixtures by consumers, as well as for the hydraulic dimensioning of gas distribution networks.

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