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Diagnostics of the technological condition of gas pipelines based on the composition of the transported gas mixtures

Diagnostyka stanu technologicznego gazociągów na podstawie składu transportowanych mieszanin gazowych

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ABSTRACT: The efficiency of natural gas transportation hinges largely on the quality of technological processes involved. Imperfect separation process can lead to the liquid particles remaining in the gas and entering the transport systems, causing various technological issues with gas pipelines (clogging, hydrate formation, corrosion wear, etc.). The presence of mechanical particles in gas mixtures accelerates the degradation of metallic components of the transport system due to erosion. Additionally, the multiphase nature of gases contributes to complications during transportation, altering the quality indicators when different gas qualities are mixed. Consequently, the composition of gas mixtures, their mechanical particles, moisture, and other indicators, deviate non-linearly from their initial values. The technological condition of the main gas pipelines significantly impacts their discharge capacity and hydraulic characteristics. Failure to clean natural gas to current standards and requirements at production stations can result in condensation of water and hydrocarbon vapours in pipelines, leading to the accumulation of the liquid phase in the cavities of the pipeline and the formation of blockages due to hydrate compounds formation, the reduction of the cross-section of the gas pipeline or its complete blockage. Sediment accumulation on the inner surfaces of gas pipelines installed in complex geographical conditions adversely affects transportation system, increasing maintenance, energy, and transportation costs. Utilizing gas composition as an auxiliary tool (indicator) for diagnosing various technological processes and predicting transport parameters has been investigated in numerous research works in the oil and gas production industry.

Key words: natural gas, gas mixture, gas pipeline, structural change, composition of gas components, technological condition, rank classification.

STRESZCZENIE: Efektywność transportu gazu ziemnego zależy w dużej mierze od jakości procesów technologicznych. Niewłaściwy proces separacji może skutkować pozostawaniem cząstek cieczy w gazie i przedostawaniem się ich do systemów transportowych, co z kolei może powodować różne problemy technologiczne związane z gazociągami (zatykanie, powstawanie hydratów, korozja itp.). Obecność cząstek mechanicznych w mieszaninach gazowych przyspiesza degradację metalowych elementów systemu transportowego w wyniku erozji. Ponadto wielofazowy charakter gazów przyczynia się do powstania problemów podczas transportu, ponieważ mieszanie gazów o różnych właściwościach powoduje zmianę wskaźników jakościowych. W rezultacie skład mieszanin gazowych, ich cząstki mechaniczne, wilgotność i inne wskaźniki odbiegają nieliniowo od wartości początkowych. Na przepustowość i charakterystykę hydrauliczną głównych gazociągów znacząco wpływa ich stan technologiczny. Jeśli gaz ziemny nie zostanie oczyszczony zgodnie z obowiązującymi normami i wymaganiami na stacjach produkcyjnych, może to skutkować kondensacją wody i oparów węglowodorów w rurociągach, prowadząc do gromadzenia się fazy ciekłej w pustych przestrzeniach rurociągu i powstawania zatorów z powodu tworzenia się związków hydratowych, zmniejszenia przekroju gazociągu lub jego całkowitego zablokowania. Gromadzenie się osadów na wewnętrznych powierzchniach gazociągów zainstalowanych w złożonych warunkach geograficznych niekorzystnie wpływa na system transportowy, zwiększając koszty konserwacji, energii i transportu. Wykorzystanie składu gazu jako narzędzia pomocniczego (wskaźnika) do diagnozowania różnych procesów technologicznych i przewidywania parametrów transportu było przedmiotem licznych prac badawczych w przemyśle wydobywczym ropy naftowej i gazu ziemnego.

Słowa kluczowe: gaz ziemny, mieszanina gazów, gazociąg, zmiana strukturalna, składniki gazu, stan technologiczny, klasyfikacja rang.

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Introduction

The article investigates the effect of structural changes in the mixture of two natural gases with different compositions on the technological condition of gas pipelines. The classification function was evaluated and ranked based on mining data obtained from the component composition of natural gas and quality indicators using diagnostic signs such as gas components, density, and other parameters. This can aid in predicting technological complications that may arise based on changes in the rank function (Mirzajanzade et al., 1985; Sattarov, 1987; Kamal et al., 2023).

Research has shown that the component composition and quality indicators of transported gases can serve as diagnostic criteria for assessing the technological condition of pipelines transporting gas mixtures (Ismayilov et al., 2016; Iskenderov et al., 2017b; Leporini et al., 2019). This finding was further supported by studying the dynamics of changes in the composition of components of mixtures of natural and neutral gases and some important parameters characterising their quality (Gritsenko et al., 1994; Iskenderov et al., 2017b; Bissor et al., 2020).

Methods and discussion

During the study, the dynamics of changes in the parameters characterising the mixtures of two different natural gases were investigated. The mixing of natural gases transported from two points through the gas pipeline, whose technical parameters are given in Table 1, was considered (Figure 1).

The natural gas transported from point 1 is mixed with other natural gas coming from point 2 at point A and transported to points 3, 4 and 5 through a gas pipeline with a diameter of 1020 mm (Figure 1). Gas samples were taken at stations 1 and 2, as well as at stations 3, 4 and 5 along the route. Their composition and some physico-chemical parameters were studied, and the effect of structural changes in gas mixtures due to the geometry of pipelines (syphons, bends etc) of gas pipelines was considered (Katza, 2002; Ismayilov et al., 2017).

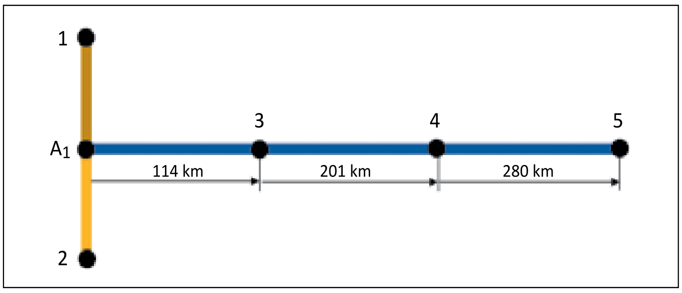

Figure 1. Stations where gas samples were taken in the gas pipelines

Rysunek 1. Stacje, w których pobrano próbki gazu z gazociągów

It is well-established that the quality indicators of natural gases supplied to the gas pipeline undergo significant changes as a result of mixing gases from different sources (Iskenderov et al., 2017a; Ismayilov et al., 2018; Wu et al., 2022).

It should be noted that the "Cromotech-Crystal 5000/9000" equipment was used to conduct the experiments. A total of 15 experimental studies were conducted. Gas samples were analysed simultaneously each day for 15 days, and the dynamics of changes in gas components and some gas quality indicators were monitored based on data collected at individual stations. The analysis showed that the parameters C_1, C_3, C_{5+}, CO_2, N_2, ρ_g undergo significant changes along the pipelines. The dependencies, which reflect the dynamics of the changes in the values of the mentioned indicators by points, are shown in Figures 2–4.

Natural gas with two different quality indicators is transported from stations 1 and 2, mixed at station A_1 and transported through a pipeline with a diameter of 1020 mm. Experiments have shown that their quality indicators change due to the mixing of natural gases from different sources. The structural changes that occurred led the deterioration of the technological condition of the gas pipeline. To investigate these complications, gas samples were taken and analysed for 15 days at points 1, 2, 3, 4 and 5 of the gas pipeline, as shown in Figure 1. It was found that the parameters C_1, C_3, C_{5+}, CO_2, N_2, ρ_g undergo significant changes along the pipeline. Figures 2, 3, and 4 show the dependencies reflecting the dynamics of changes in the values of the mentioned indicators by points.

Table 1. Some technical indicators of gas pipelines

Tabela 1. Wybrane wskaźniki techniczne gazociągów

Gas pipelines [km]	The year the gas pipeline was put into operation	Gas pipe diameter 1020 mm and length [m]	Gas pipeline pressure [MPa]	
			maximum allowable pressure	project pressure
71–114.0	1970	43 000	3.2	5.5
114–260.0	1970	146 000	2.8	5.5
260–378.3	1970	118 300	2.6	5.5
	Total	307 300		

As can be seen from Figures 2–4, the values of the C_1 component at stations 3, 4 and 5, where gas samples were taken, were lower than the initial values at stations 1 and 2, while the values of the N_2 and ρ_g indicators were higher than their initial values. The dynamics of change of other parameters also varied by station. In this case, characteristic changes in the composition of the gas mixture components were observed at the 3rd and 5th stations.

Classification was performed for parameters C_1, C_3, C_{5+}, CO_2, N_2 and ρ_g, which underwent more characteristic changes during the research. The 5-point scoring system shown in Table 2 was applied to the intervals of change of the monitored parameters and the corresponding ranks (R_i) were noted. The ranks of the C_1, C_3, C_{5+}, CO_2, N_2 and ρ_g indicators at the stations were summed, and the aggregate values of the ranks for each day of the study ($R = \sum R_i$) were found. The values of the total ranks by stations are given in Table 3.

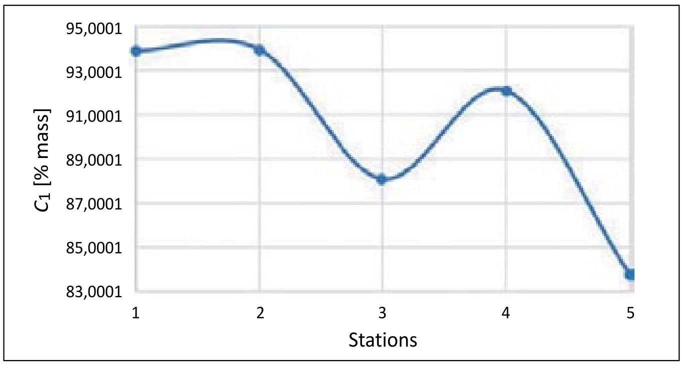

Figure 2. Dynamics of the change in the C_1 component by stations

Rysunek 2. Dynamika zmian składnika C_1 według stacji

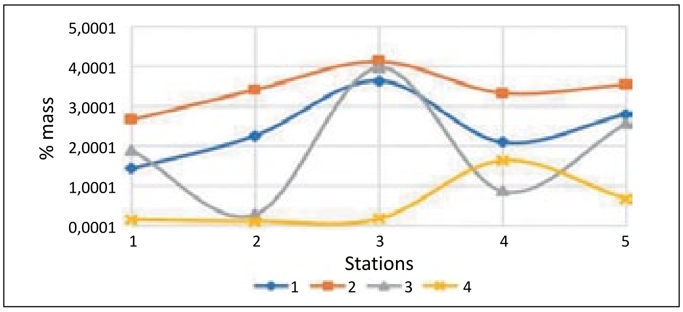

Figure 3. Dynamics of changes in the C_2, C_{3+}, CO_2, N_2 components by stations; 1 – C_{3+}, 2 – C_2, 3 – CO_2, 4 – N_2

Rysunek 3. Dynamika zmian składników C_2, C_{3+}, CO_2, N_2 według stacji; 1 – C_{3+}, 2 – C_2, 3 – CO_2, 4 – N_2

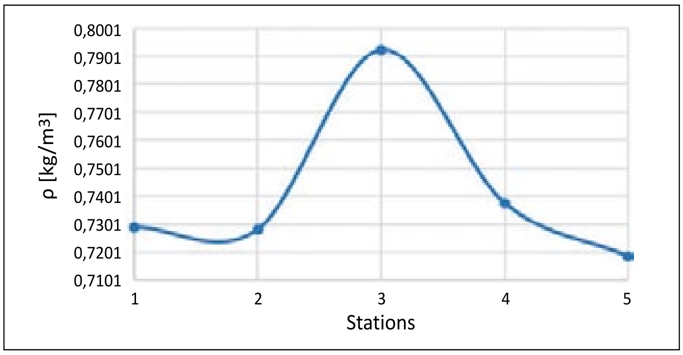

Figure 4. Dynamics of density by station

Rysunek 4. Dynamika gęstości według stacji

The dynamics of the changes in these ranks were then analysed, and the dependencies showing the dynamics of the changes in the calculated values of the ranks by stations and days were established (Figures 5 and 6).

Table 2. Grades and degrees of the classification marks

Tabela 2. Klasy i poziomy ocen klasyfikacyjnych

Ranks	C_1	C_2	C_{3+}	N_2	CO_2	ρ_g
1	<88	<1.0	<0.1	<0.5	–	–
2	88–90	1.0–1.5	0.10–0.15	0.5–1.0	1–2	0.74–0.76
3	90–92	1.5–2.0	0.15–0.20	1.0–1.5	2–3	0.76–0.78
4	92–94	2.0–2.5	0.20–0.25	1.5–2.0	3–4	0.78–0.80
5	>94	>2.5	>0.25	>2.0	–	–

Table 3. Aggregate rank (R) values for the gas pipeline

Tabela 3. Sumaryczne wartości rangi (R) dla gazociągu

Days		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stations	1	11	11	11	11	11	10	10	10	10	10	10	11	11	11	11
	2	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	3	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	4	13	13	13	14	15	14	13	12	12	12	12	13	13	13	13
	5	12	13	14	16	16	17	15	16	16	16	16	14	14	14	14

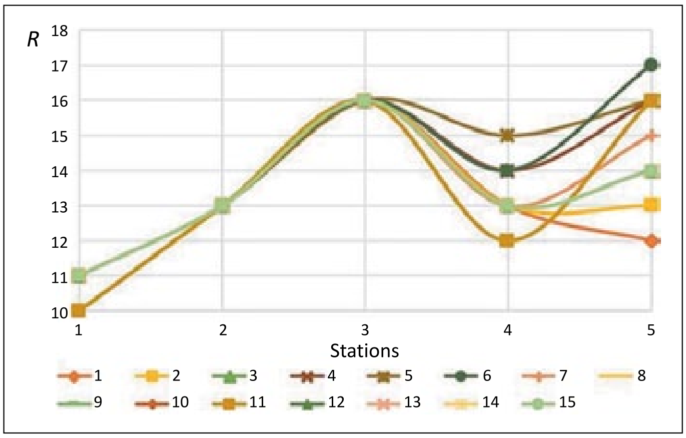

Figure 5. Change of R values by station 1–15 days
Rysunek 5. Zmiana wartości *R* według stacji w przedziale 1–15 dni

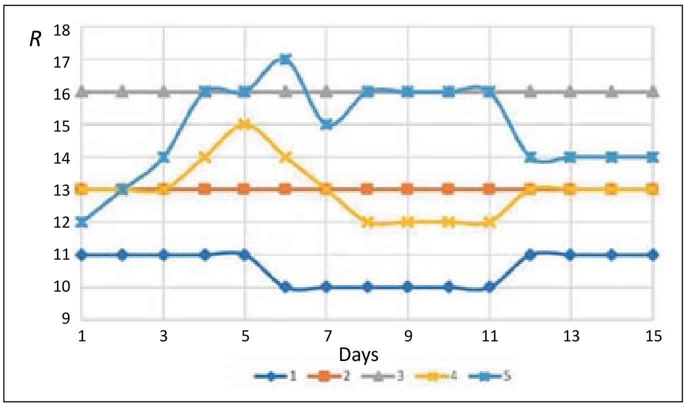

Figure 6. Daily change of R values at stations 1–5
Rysunek 6. Dzienne zmiany wartości *R* na stacjach 1–5

As can be seen from Figures 5 and 6, the calculated values of the ranks (R_i) at all points for the mixture of natural gases in the gas pipeline are greater than the initial values of the gases at points 1 and 2. Analysis of the results shows that the gas mixture transported by the gas pipeline is does not adhere the additivity rules.

Additivity is a property of mathematical or physical quantities wherein the value of the quantity corresponding to the whole object equals the sum of the values of the quantities corresponding to its parts.

The high and stable rank of station 3 is attributed to the fact that although mixing of natural gases has occurred, the processes of gas modification have not yet taken place at this station. Up to point 3, the *R* value has not changed. Between points 4 and 5, the operation of the gas pipeline has largely remained stable, with only occasional changes observed on a few days. Therefore, there were no notable exceptions for gas station 2, except for the segment of the pipeline up to station 3, where serious complications occurred between stations 3 and 4, as well as 4 and 5. More characteristic changes were observed in the segment of the pipeline between stations 4 and 5. Here, the rank values increased significantly, stabilised, and then decreased. The processes occurring at stations 4 and 5 led to fluctuations in the rank values. A decrease in the value of the rank function can be considered as an indirect confirmation of reverse condensation (i.e. separation of liquid hydrocarbons) in the pipeline and an increase in reverse evaporation. This trend is clearly reflected in the dynamics of the rank change for point 3.

Complications arising in pipelines during the mixing of different gases stem from the non-additive nature of the processes occurring within them. Structural changes resulting from mixing of gases contribute to the occurrence of liquid phase drops in the gas pipeline, retrograde phenomena, and other technological complications.

Based on the research conducted on the transportation of individual natural gases or mixtures of natural gas and cyanide gas, it can be concluded that it is possible to diagnose the internal condition of pipelines transporting gas mixtures based on the change of the component composition and quality indicators of the mixed gases.

Utilizing the proposed rank classification method enables the diagnosis of complications occurring in the transport lines of various mixed and facilitates timely preventive measures.

All of the above can be considered as advantages of the proposed method. It should also be noted that no disadvantages were identified during the experiment.

Conclusions

1. Changes in certain gas components and density of the gas can be considered as confirmation of changes in the dynamics of the ranks. This confirms once again that the complications that occur in pipelines during the mixing of different gases are attributed to the non-additive nature of the processes within them. The structural changes occurring during this process, including the occurrence of liquid phase drops in the gas pipeline and retrograde events form the basis for a series of technological complications.
2. On the basis of the analysis of the research carried out on the transportation of mixtures of individual gases, it can be concluded that it is possible to diagnose the internal condition of pipelines transporting gas mixtures on the basis of changes in the composition of the components and quality indicators of the mixed gases. If the sum of the ranks calculated for gas mixtures remains constant along the length of the pipeline, this indicates that no structural changes have occurred in the pipeline. If the *R* final value calculated for gas mixtures changes non-additively from its initial value along the pipeline, it should be evaluated

as a case of structural changes and phase transformations in the gas pipeline. In the first case, if the additivity rule is satisfied, the change in the final rank value indicates the formation of a liquid phase (hydrocarbon and water) in the pipeline. If the additivity rule is violated, the change in the final rank value indicates the occurrence of 'reverse evaporation' or 'reverse condensation' events.

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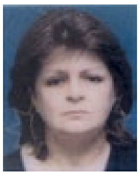

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