

**Piotr Janusz\*, Krystian Liszka\*, Mariusz Łaciak\*, Andrii Oliinyk\*\*,  
Aleksandr Susak\*\*\***

## **AN ANALYSIS OF THE CHANGES OF THE COMPOSITION OF NATURAL GAS TRANSPORTED IN HIGH-PRESSURE GAS PIPELINES**

### **1. INTRODUCTION**

Natural gas consumption in Poland in the last few years equaled to about 15 billion m<sup>3</sup>. About 67–71% of annual gas consumption was covered by import, whereas the remaining 29–33% came from home production.

The basic element providing energy safety of each country is proper diversification of sources and directions of deliveries. In the case of natural gas the most important factor is the properly developed transport infrastructure. With the increased predicted natural gas deliveries to Poland, the national pipeline network started to dynamically develop. It began from the construction of connections between systems, the main tasks of which was the integration of Europe's natural gas markets, through parallel investments in the transport and distribution, and finishing with the construction and development of underground gas storages.

Stabilized, high methane natural gas is delivered to Poland, though with the increasing natural gas import from other directions than east one could expect gas of a different composition. This stems from the fact that the Europe's market is serviced by various gas suppliers, i.e. from deposits localized in different regions of the world. Gas composition depends on its source and has a decisive influence on the thermodynamic and hydraulic properties. The content of heavy hydrocarbon gases increases the calorific value of the gaseous fuel, whereas the high content of inorganic components lowers the amount of energy obtained in the course of natural gas combustion; as a side effect, environmentally hazardous chemical compounds are formed.

As far as gas transport is concerned, too high content of heavy hydrocarbon gases (propane, butane, pentane) is disadvantageous. In high pressure conditions the C3–C5 class gases

---

\* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

\*\* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland – doctoral student

\*\*\* Ivano-Frankivsk National Technical University of Oil and Gas, Faculty Oil and Gas Engineering

change to a liquid phase. This results in the change of the calorific value, lower hydraulic efficiency of the pipeline diameter, potentially faster corrosion processes on the inner surface of the pipeline and faster filtration.

The paper is aimed at presenting the results of changes of natural gas composition in a function of distance to which the fuel is transported.

## 2. ASSUMPTIONS AND INPUT DATA

The analyzed natural gas composition has been presented in Table 1. Gas 1 has the lowest methane content, and highest participation of heavy, i.e. ethane, propane and butane. This gas does not meet the qualitative requirements because it is too high in heavy hydrocarbons and nitrogen. According to the standards such gas cannot be transported by the national transport and distribution network. However, for the sake of comparison, it was included in the analysis. Gas 3 is high in methane and low in heavy hydrocarbons. The composition of Gas 2 is a transient variant, with a high participation of methane and other gases.

**Table 1**  
Analyzed natural gas composition

Components	Molar participation [%]		
	Gas 1	Gas 2	Gas 3
Methane	65.83	83	90
Ethane	12.34	4	1.9
Propane	5.92	3	1.3
<i>i</i> -butane	2.42	1.6	0.9
<i>n</i> -butane	1	1.4	0.9
<i>i</i> -pentane	1.1	1.1	1.1
<i>n</i> -pentane	0.17	0.68	0.68
Nitrogen	10	4	2.02
CO <sub>2</sub>	1.22	1.22	1.2

The changes of gas composition were modeled on a transmission pipeline specified in Table 2. The pressure of transmitted gas and changes of its temperature in a function of distance at which it is transported are presented in Figures 1 and 2.

**Table 2**  
Technical parameters of pipeline

Length [m]	Inner diameter [m]	Initial pressure [MPa]	Initial temperature [K]	Soil temperature [K]	Gas flow rate [m <sup>3</sup> /h]
70,000	0.291	8.5	310	280	60,000

The calculations were performed for a pipeline which was divided into 70 sections 1 000 m each. The pressure and temperature at the end of each section was calculated on the basis of the initial parameters in the pipeline, using the General Flow Equation and nonisothermal radial model of heat exchange between the gas pipeline and the environment. The changes of pressure of the transmitted gas and its changes in a function of distance at which it was transported, are presented in Figures 1 and 2.

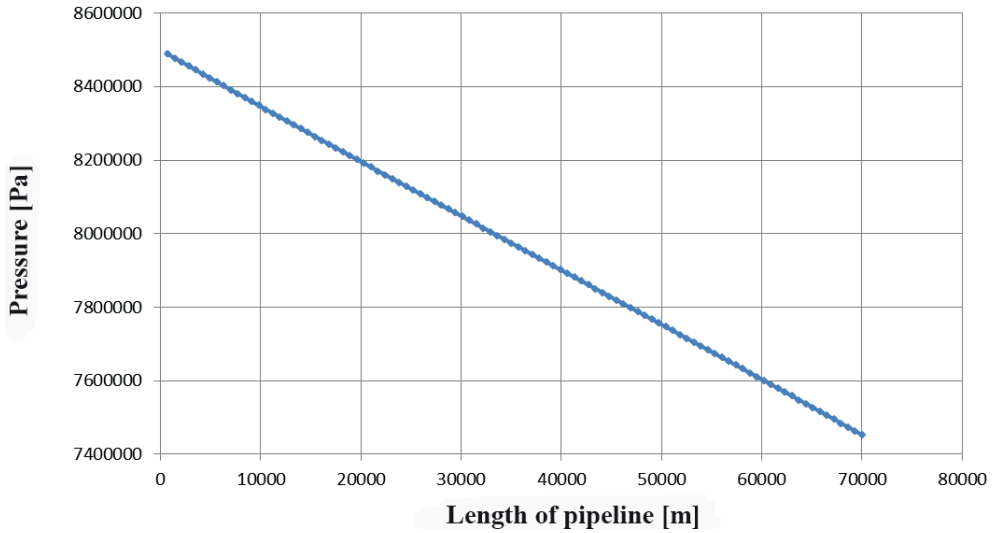


Fig. 1. Change of pressure of transmitted gas in a function of pipeline length

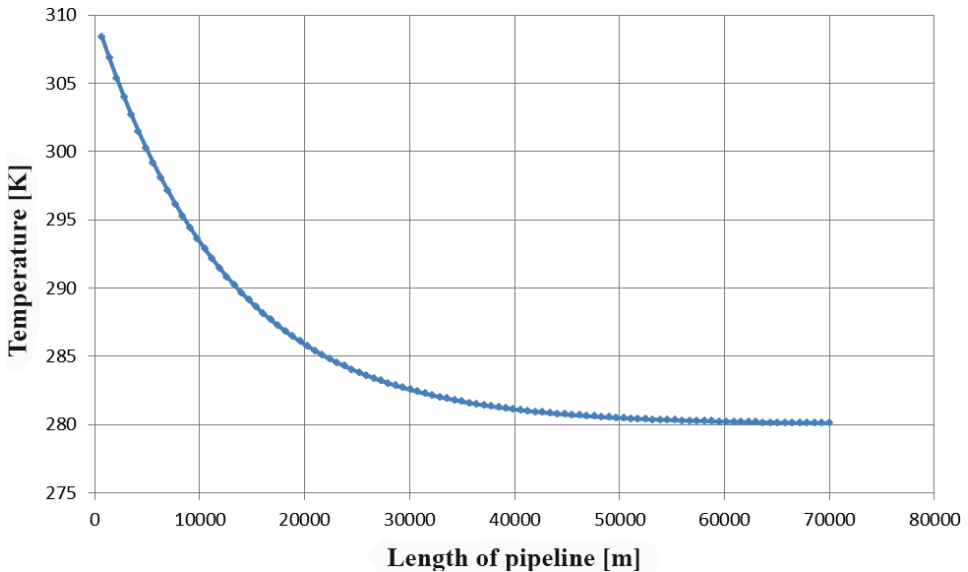


Fig. 2. Change of temperature of transmitted gas in a function of pipeline length

Calculations of changes of the transmitted natural gas in high pressure gas pipelines were performed on the basis of Rachford–Rice equation, where the equilibrium constants were calculated with the Wilson correlation.

### 3. ANALYSIS OF RESULTS

The results of simulations of change of liquid, gaseous phase and participation of liquid phase in a gas mixture for Gas 1, Gas 2 and Gas 3 are presented in Figures 3–11.

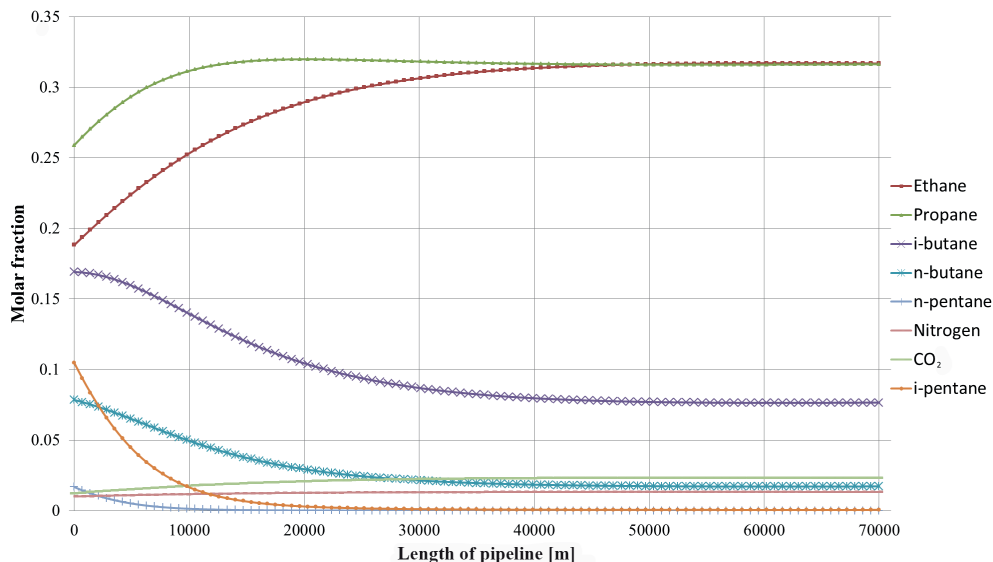


Fig. 3. Change of gas composition (liquid phase) in Gas 1

The analysis of composition changes of Gas 1 along the length reveals that the participation of methane in the mixture increased for the liquid and gaseous phase with the growing distance at which the gas was transmitted. In the case of gaseous phase these heavy hydrocarbons (e.g. propane and butane) precipitated from gas as first. After some time the participation of propane in the mixture had a dropping tendency which contributes to the considerable increase of methane and slight changes in the nitrogen and carbon dioxide content. Attention should be paid to the fact that nitrogen content considerably increased as its initial participation in the mixture was several times higher than that of carbon dioxide.

The *i*-pentane, as well as *iso*- and *n*-butane content decreased most dynamically in the liquid phase. These components were high in the mixture in the first kilometers of the pipeline, then the participation of *i*-pentane and *n*-pentane lowered nearly by zero whereas butane content decreased almost twice. The participation of propane and ethane in the liquid phase for Gas 1 increased along the pipeline, which is an interesting phenomenon because of the very high pressure in the entire pipeline (8.5–8.3 MPa) and the fact that gas temperature considerably lowered from 308 K to 280 K, deciding about the precipitation of propane and ethane.

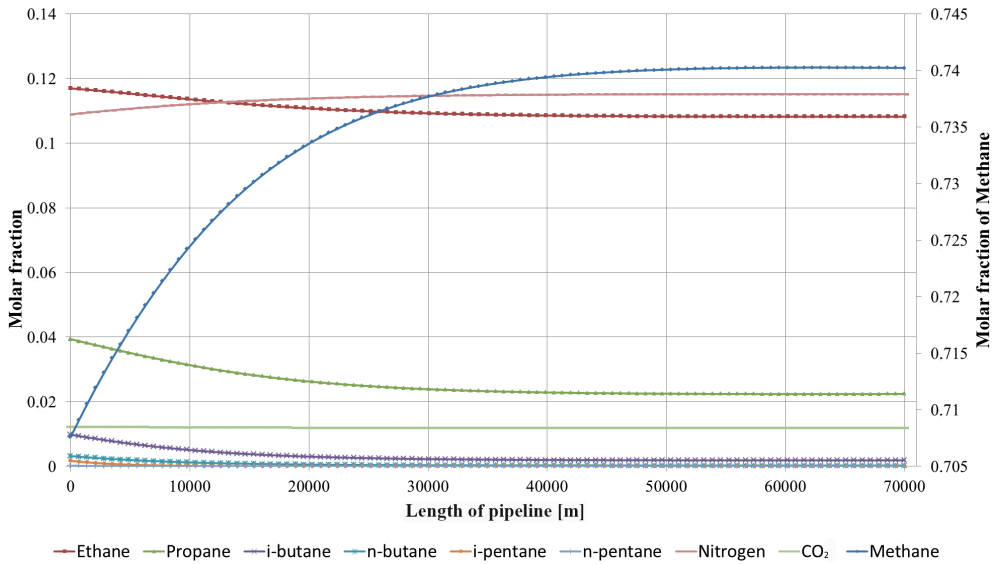


Fig. 4. Change of gas composition (gaseous phase) in Gas 1

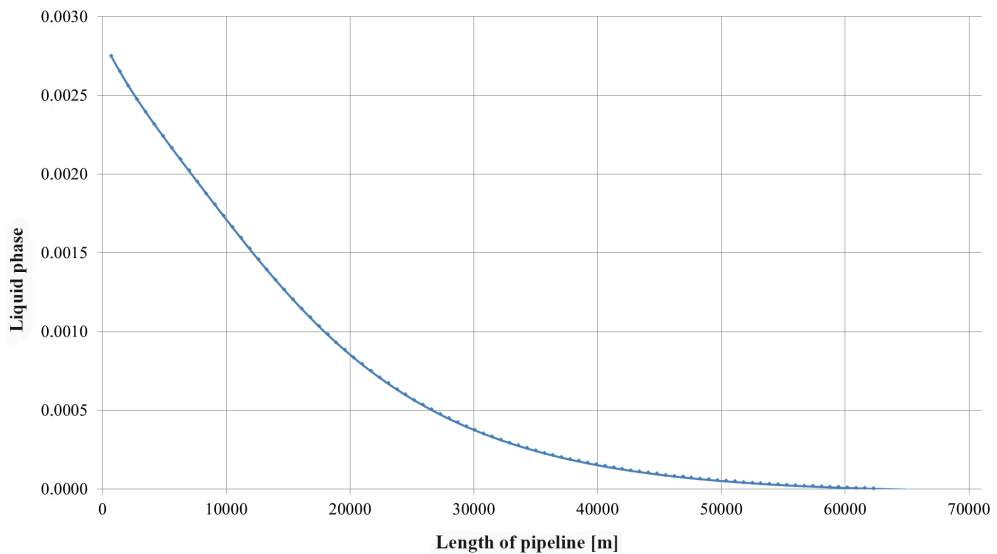
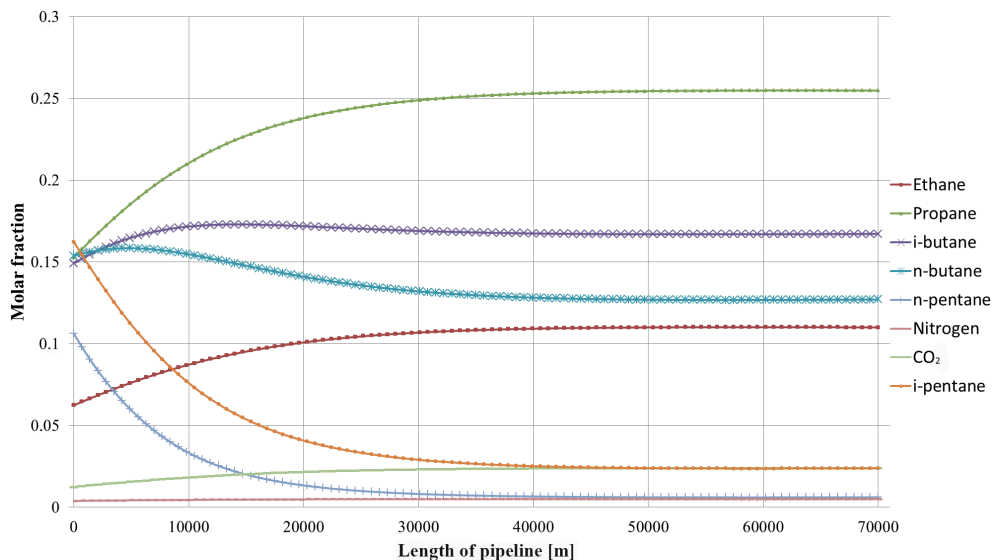
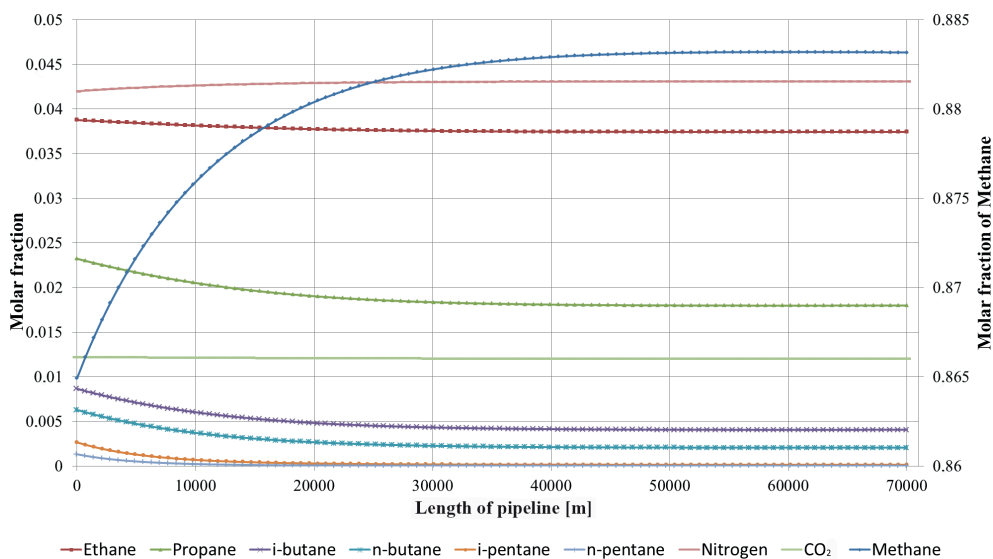


Fig. 5. Change of participation of liquid phase in a mixture of Gas 1

The liquid to gaseous phase ratio along the pipeline asymptotically tended to zero, which was both understandable and predictable because the content of heavy hydrocarbons decreased; the closer to the end of the analyzed pipeline the more liquid phase vanished and the calculation model did not account either for the movement of the liquid phase in the pipeline, or for re-gasification.



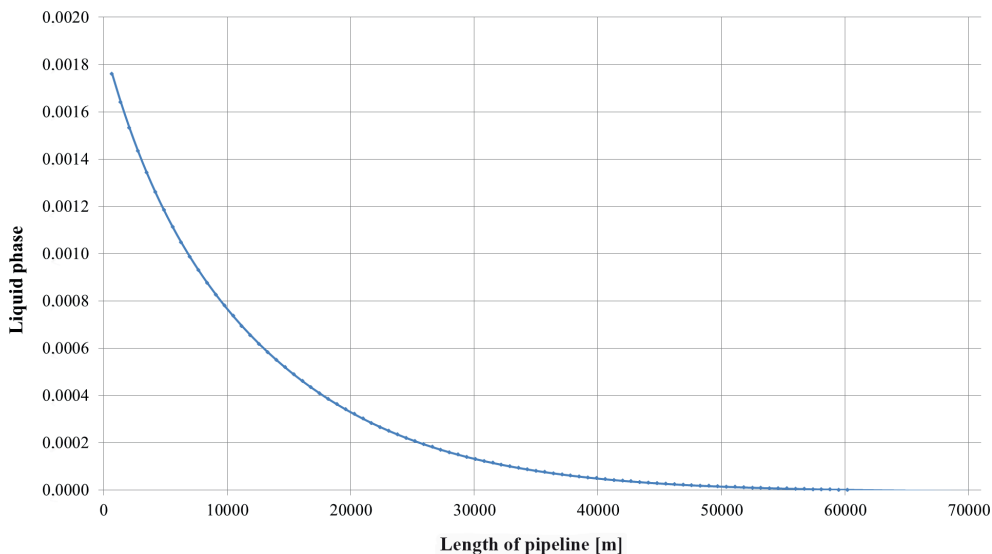
**Fig. 6.** Change of liquid phase in Gas 2



**Fig. 7.** Changes of gaseous phase composition in Gas 2

The changes in participation of particular components in the mixture of Gas 2 were similar as in Gas 1. The analysis of molar composition of liquid phase revealed that the heavier components were first to precipitate from the gaseous mixture. The participation of these components in liquid phase decreased with the growing distance at which the gas was transmitted. As compared to the pentane, butane content increased. The *n*-butane content had a declining

tendency from the 10<sup>th</sup> kilometer of the pipeline and *i*-butane from the 20<sup>th</sup> kilometer, though the process was milder than in the case of the *n*-butane. The lower temperature of the transmitted gas resulted in higher propane content and so liquid ethane, both in Gas 1 and 2. The participation of the methane increased less than in the propane, which is understandable as ethane is a lighter gas, therefore precipitates in higher pressures and lower temperature.



**Fig. 8.** Changes of liquid phase participation in a mixture of Gas 2

The changes of composition of gaseous phase were analogous as in Gas 1. The participation of heavy components, e.g. *i*-pentane, *n*-pentane, *i*-butane and *n*-butane was observed to have a more intense decreasing tendency, whereas the decreasing trend in lighter components in the mixture of propane and ethane was smaller. With the decreasing molar participation of certain components, the share of the other ones increased; the nitrogen content in the gaseous mixture slightly increased whereas the increase of methane was high.

The analysis of the liquid phase and comparison of its quantity in the transported Gas 1 and 2 revealed that the amount of liquid generated in Gas 2 was almost twice as low as in Gas 1, though the character of the change (lowering the quantity of the liquid along the pipeline) was similar in both cases.

Gas 3 had the highest participation of methane in the gaseous mixture and the lowest content of heavy hydrocarbons, which resulted in the lowest (of all analyzed gases) content of the liquid phase generated while transmitting gas through a high pressure pipeline. The course of changes in liquid phase composition was similar to Gases 1 and 2. Initially *i*-pentane and *n*-pentane dominated in the mixture. Being the heaviest components of the mixture these gases precipitated almost immediately under high pressure. Then the participation of these components decreased which was caused by the lowering gas temperature; the remaining gas components changed their state more actively. The *i*-butane and *n*-butane content increased in the liquid phase; the participation of propane changed to a less degree and ethane remained almost unchanged.

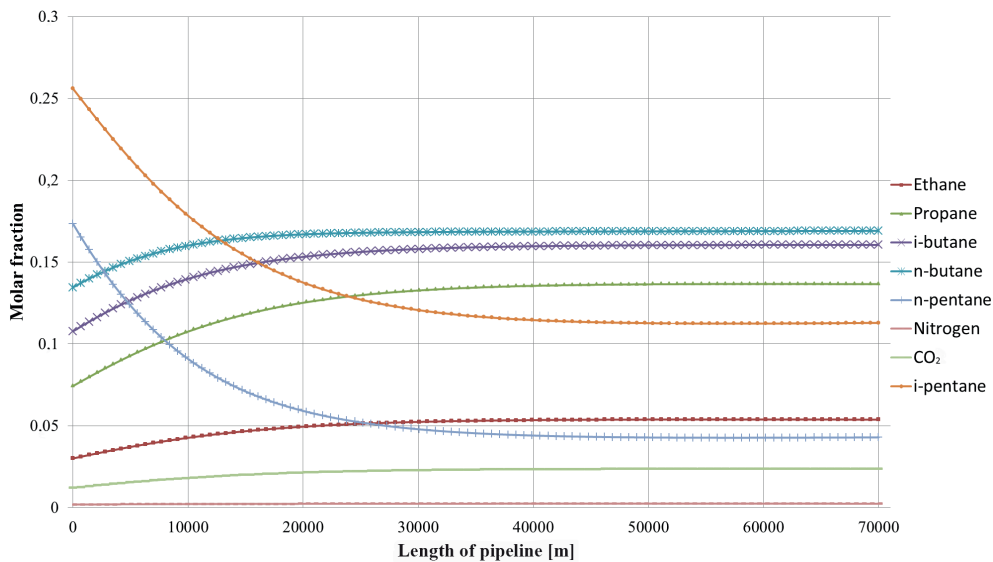


Fig. 9. Changes of liquid phase composition in Gas 3

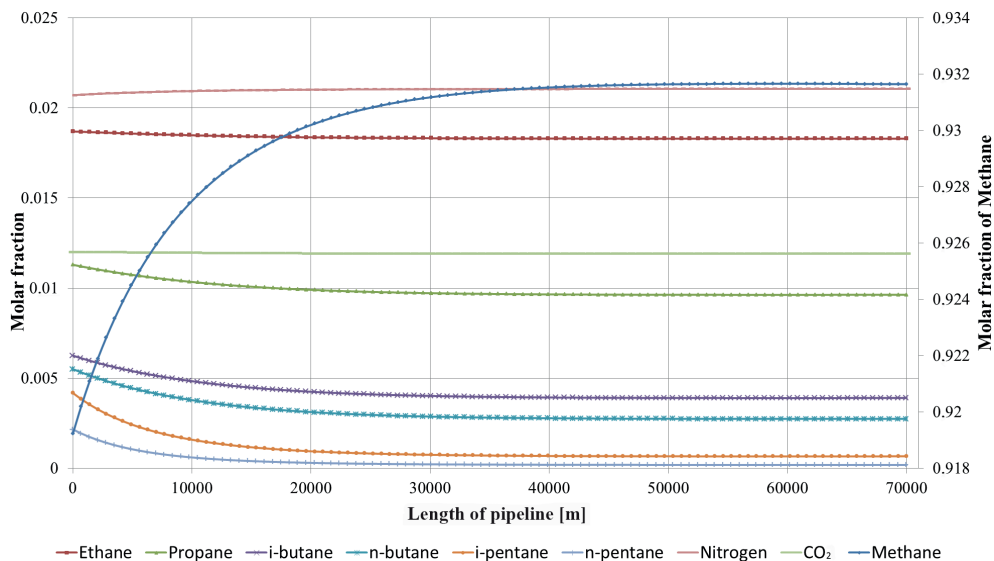
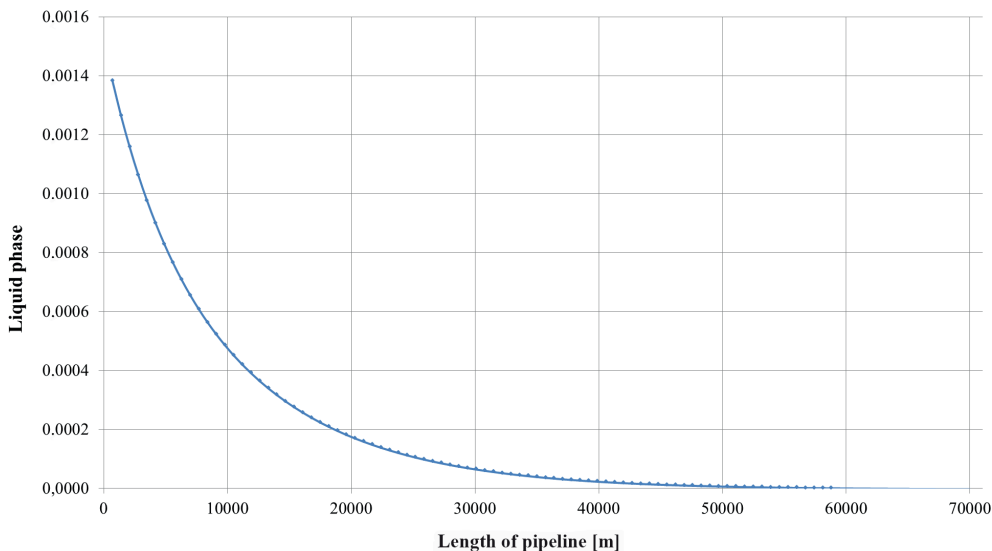


Fig. 10. Changes in gaseous phase composition in Gas 3





**Fig. 11.** Changes in liquid phase participation in a mixture of Gas 3

The changes of gas composition were almost unnoticeable as compared with the small amount of precipitated liquid. The participation of such heavy hydrocarbons as *i*-pentane, *n*-pentane, *i*-butane and *n*-butane decreased to a less extent, whereas the participation of propane and ethane remained almost the same.

#### 4. CONCLUSIONS

The analysis of the simulation revealed that the natural gas composition decides about the amount of energy transported by the transmission pipelines. Moreover the composition and so the thermodynamic processes in it, vary considerably along the pipeline and the distance at which the gas is transmitted. When the transported natural gas is high in heavy hydrocarbons (C3–C5), *i*-pentane and *n*-pentane are first to precipitate, then at a distance of about 30–40 km from the beginning of the pipeline these components change their participation in the mixture. *I*-butane and *n*-butane content increases, and to a lesser degree propane and ethane content increases.

Despite the change in the liquid and gaseous phase composition, the amount of precipitated liquid is very low.

The gaseous composition also changes due to the lowering participation of heavier hydrocarbons the participation of ethane and methane increases in the mixture as well as that of nitrogen and carbon dioxide.

The analysis of the obtained results revealed that if a gas high in heavy hydrocarbons is sent through a high pressure pipeline, after a few tens of kilometers the amount of these components in the gaseous phase considerably decreases, which improves the qualitative characteristic of the delivered gas.

## REFERENCES

- [1] Operator Gazociągów Przesyłowych GAZ-SYSTEM S.A.: *Plan rozwoju na lata 2014–2023*.
- [2] Łoś M.: *Zmiany na krajowym rynku gazu ziemnego w zakresie infrastruktury*. Zeszyty Studenckiego Towarzystwa Naukowego, no. 27, Materiały konferencyjne: VII Ogólnopolska Konferencja Naukowa „Energia – Ekologia – Etyka”, Wyd. STN, Kraków 2013, pp. 69–77.
- [3] Operator Gazociągów Przesyłowych GAZ-SYSTEM SA [own materials].
- [4] International Energy Agency: *Natural Gas Information*. 2000–2013.
- [5] Łaciak M.: *Ocena niepewności wyników statycznej symulacji sieci gazowych*. Wiertnictwo, Nafta, Gaz, vol. 26, no. 4, 2009, pp. 661–669.
- [6] Łaciak M.: *Wpływ zmian wysokości położenia na wyniki obliczeń hydraulicznych gazociągów*. Wiertnictwo, Nafta, Gaz, vol. 26, no. 3, 2009, pp. 547–553.
- [7] Łaciak M., Gniewek-Grzybczyk B., Siuciak M., Grela I.: *Energetyka gazowa*. Wyd. Tarbonus, Kraków – Tarnobrzeg 2011.
- [8] Ikoku Chi U.: *Natural Gas Production Engineering*. John Wiley & Sons, Inc., New York 1984.
- [9] Liszka K., Łaciak M., Oliińsk A.: *Study of the effect of geometrical parameters of the LNG storage tanks on the process of liquefied natural gas evaporation*. XXV Międzynarodowa Konferencja Naukowo-Techniczna: Wiertnictwo, Nafta, Gaz – Dziś i Jutro, Kraków, 11–13.06.2014.