ENHANCING THE EFFICIENCY OF GAS DISTRIBUTION STATIONS OPERATION BY SELECTING THE OPTIMAL GAS PRESSURE AND TEMPERATURE PARAMETERS AT THE STATION OUTLET

Ukraine ranks first in the world in terms of energy intensity per unit of GDP, which means that Ukrainian enterprises spend the most energy in comparison with other countries in the production of the unit of production. The Gas Transportation System (GTS) is no exception. Gas transit is expected to reduce from 2020 due to the construction of gas pipelines bypassing the territory of Ukraine, which will lead to a decrease in the profitability of the GTS and, if not sufficiently loaded, to its loss. That is why ensuring efficient operation of the GTS equipment in terms of energy efficiency is becoming more relevant today than ever.

Purpose. To develop methods for enhancing the energy efficiency of the gas transmission system of Ukraine (based on the analysis of the gas distribution stations (GDS) operation) without significant investment, considering the possible decrease in gas transmission.

Methodology. In the work, the analysis of scientific and technical literature and regulatory documents is performed; mathematical modelling and analysis of operational performance of GDS is performed to determine the economic and environmental effect of the proposed measures.

Findings. It was confirmed that adjusting gas pressure at the outlet to the design pressure is a promising direction for energy efficiency increasing. According to the analysis of scientific and technical literature and regulatory documents, the optimal gas temperature at the outlet of the gas distribution system was determined. It was outlined that the implementation of the developed set of measures will allow obtaining a significant economic and environmental effect.

Originality. The necessity of implementation of a set of cost-free measures was developed and justified, mainly, reduction of the present natural gas indicators of temperature and pressure at the outlet of the gas distribution stations to the optimal ones, which will increase energy efficiency and ecological efficiency of its operation.

Practical value. The results will be used for production activity purposes, during the operation of gas distribution stations.

Keywords: energy efficiency, pipeline transportation, gas transmission system, gas distribution station

Introduction. Until recently, one of the main routes for gas transit to Europe ran through the territory of Ukraine. The Ukrainian gas transmission system (GTS) transported about 120 billion cubic meters of gas to Europe (compared to the designed output transit capacity up to 146 billion cubic meters). However, gas infrastructure loading may decrease due to the possible redirection of the entire gas volume to alternative routes. Historically, gas transmission volumes are decreasing, for example, through a partial change of transit routes to alternative (new) ones, bypassing the territory of Ukraine (Yamal, Nord Stream).

Since January 1, 2020, as a result of the unbundling process [1], the natural gas transmission by gas pipelines in Ukraine has been controlled by a new independent operator LLC “GTS of Ukrainian Operator” (GTS operator). After the end of the 10-year transmission contract with Gazprom, as a result of tripartite negotiations, a 5-year contract for the transmission of Russian gas was signed. According to the contract, the total transmission volume for 2020–2024 is equal to 225 billion m³, which is approximately 50 % less than the transit for the last 5 years [2].

Above all, since 2005, there has been a decrease in domestic gas consumption, Fig. 1, from 76 billion m³ in 2005 to 30 billion m³ in 2019 [3], which lead to a decrease in the use of GTS for domestic transportation. A clear trend towards a significant reduction in gas consumption in Ukraine is due to both an increase in gas prices and a decrease in gas consumption in the industrial segment.

Taking all abovementioned facts into consideration, the GTS operator should focus its efforts on optimizing the system by reducing the energy intensity of production to optimize energy costs, which in turn will increase the profitability of the company.

Enforcement of the proposed measures.

The GTS of Ukraine is a significant consumer of energy resources. According to the Annual Report on Energy resources usage in 2019, the total gas consumption for the needs of the GTS, including all branches and divisions totalled 2 321.432 million m³, of which gas consumption for their own engineering and manufacturing demands (EMD) can be roughly divided into three components (Fig. 1): the main component of the costs is fuel gas and electricity for the GCU, the second is the “unbalance” of gas, the third – technical and technological costs, which amounted to 56.7 million m³ or 0.063 % of the volume of gas supplied to the GTS (in 2018, 69.4 million m³, respectively).

The analysis results of annual reports on the use of fuel and energy resources and the transportation operation of the GTS since 2001 are shown on the chart (Fig. 2). The chart shows that the consumption of gas for technical and technological needs, despite the volume of transmission operation, has been steadily declining since 2014. The reduction of the volume of gas used for technical and technological needs coincides with the period of implementation of the energy management system (EMS) in JSC “UKRTRANSGAZ” in accordance with the requirements of ISO 50001 certificate No. 1234047135 TMS; accredited by DAkkS (Germany) [4]. This suggests that technological costs are mostly subjected to energy management and are not dependent on the amount of gas transported (transmission operation of the GTS). Technological costs consist of the costs for boiler stations’ operating in the heating season, the technological costs of verifying the performability of equipment (safety valves, vessels, installations, and others) and fire heaters of natural gas during the operation of gas distribution stations (GDS).

The ways for improving the efficiency of energy resources during the operation of boiler stations for heating the premises were considered in [5], where the specific recommendations...
for improving energy efficiency and the economic effect of such actions were presented.

The costs of verifying the performability of equipment are carried out with a given frequency and on equipment specified in the technological regulations and equipment passports. This type of technological costs is strictly regulated and is directly related to the safety of gas supply. The areas of energy efficiency will be associated with the rejection of the use of part of the equipment that will not be involved in the operation with a decrease in transmission volumes.

According to the above mentioned information, the authors focused on optimizing the use of energy resources by gas heaters at gas distribution stations.

Gas distribution stations are to reduce the gas pressure from the main gas pipeline to a certain level, which will ensure the safe consumption of natural gas. The following main processes are carried out at the GDS: gas purification from solid and liquid impurities; gas heating; gas pressure decreasing (reduction); gas odorization; gas metering (consumption) before supplying it to the consumers.

Natural gas at a certain temperature and pressure being saturated with water vapours is capable of forming dense formations of gas hydrates on the operating surface of pipelines [6]. To prevent the formation of gas hydrates, the following methods are used: gas heating, heating the pressure regulator body; introduction of methanol into the gas pipeline.

The method of general or partial gas heating has found the widest application. The cost of heaters is high and depends on thermal power, capacity and equipment. This method is financially costly, but it allows maintaining constantly the required gas temperature regardless of the electricity supply and is safe for personnel ensuring the autonomy of the GDS and the safety of gas supply to the population.

**Unsolved aspects of the problem.** When the gas pressure at the GDS decreases, its temperature drops sharply and gas hydrates can form on the surface of the valves and pressure regulators’ seats, which will lead to their failure and cause a complete stop of the GDS. To prevent the formation of gas hydrates, natural gas is heated to the appropriate temperature.

The normative documents regulating the operation of the GTS of Ukraine do not regulate the gas temperature at the outlet of the GDS. This situation dates back to Soviet times, when the focus was on the reliability of the system, and no one paid attention to the cost of energy resources, due to their low cost. It is clear that today the reliability of gas supply is and should remain a priority of the GTS operation, but a significant increase in the cost of energy resources forces to look for energy-efficient approaches to such systems’ operation.

**Purpose.** According to the given purpose, the following goals are formulated:

- to analyse the value of the gas dew point temperature in the main transmission gas pipelines and the requirements of regulatory documents governing the operation of gas distribution stations to determine the optimal gas temperature;
- to analyse the average temperature, pressure and gas flow rate at the selected gas distribution stations to determine its savings at the optimal outlet gas temperature;
- to determine the economic and environmental effect of increasing the gas pressure at the outlet of the gas distribution system to the designed one.

**Literature review.** The problem of optimizing the operation of gas heaters is studied quite deeply by many scientists; in particular, in [7] it was proposed to use turbo-expanders on gas distribution stations to reduce pressure, to compensate the part of the energy consumed at compressor stations. In [8], the processes of heat transfer and pressure drop on a GDS heater...
The overconsumption of natural gas at GDS per day is obtained by the formula

\[
Q_{\text{oc}} = \frac{Q_{\text{het}}}{T_{\text{coal}} - T_{2r}} (T_{2r} - T_{2g}),
\]

where \(Q_{\text{het}}\) is gas quantity used for natural gas heating per day, \(m^3\); \(T_{\text{coal}}\) is gas temperature at the outlet of GDS according to the formula (1), 0 K; \(T_{2g}\) is the actual temperature of heated gas at the outlet of GDS; \(T_{2r}\) is the minimum permissible temperature at the outlet of the GDS, K.

The authors analysed the operation of all GDSs (Table 1), which are part of the Gas Main Pipeline Division “Cherkasytransgaz” (GMPD “CTG”) and found that out of 199 GDSs, gas heaters are only operated 161 GDSs.

According to the data from Table 1, the design pressure output pressure is set at only 11 GDS. By agreement with gas supply organizations, the outlet pressure was reduced by 150 GDS to optimize the pressure drop zone at the measuring units. The pressure was decreased from 0.01 to 0.09 MPa. The average pressure drop was 0.43 MPa.

After calculating (1) for each GDS, it is established that the average Joule-Thomson coefficient is 5.42 K/MPa.

To verify the calculation, the Joule-Thomson coefficient was applied to GDSs without gas heaters and compared to the actual gas temperature at the outlet of GDSs. The average temperature difference was less than 0.5 °C, which confirms the correctness of the calculations. Summary of the actual gas temperature at the outlet of GDSs. The average pressure drop was 0.43 MPa.

The obtained data are put into the formula (3) and the result is the amount of gas, which is additionally consumed by the heater to heat the gas to a temperature \(T_{\text{incr}}\) per day.

\[
Q_{\text{oc}} = \frac{Q_{\text{het}}}{T_{\text{coal}} - T_{2r}} T_{2r}
\]

Using the ASK software, the average gas temperature at the outlet and the average gas consumption of each of the 150 GDSs, belonging to GMPD “Cherkasytransgaz”. The given GDS are equipped with gas heaters and perform the entire array of data, which is about 70,000 calculations, was calculated using Mathcad. Qos is 170,423 m³.

The cost of gas consumed is calculated by the formula, thousand UAH

\[
C = Q_{\text{het}} \cdot P = 1891,
\]

where \(P\) is gas average price for industry in 2018 according to [10]. The obtained cost value of the gas is estimated, but its value confirms the prospects of this area of GDS management, in order to improve its energy efficiency. To obtain the accurate values of the costs of gas overconsumption for all GDSs, it is necessary to perform calculations for each of them individually, taking into account the actual values of pressure and temperature of the gas.

After analysis of the requirements of the current normative documents governing the activity of the GDS, the authors found that, the state building codes of Ukraine in force up to 2018 set the temperature of gas at the outlet of GDS of the main gas pipelines, when fed into underground gas pipelines, not being less than minus 10 °C [11]. This norm was determined in order to prevent the formation of icing of underground gas pipelines and, as a consequence, the occurrence of emergencies. In the current building codes of Ukraine from 2012 [12] this rule is absent, but all studied GDS were constructed before 2018 and underground gas pipelines are designed for gas temperatures up to minus 10 °C.

To prevent the formation of hydrates in the pipeline, the gas temperature should be higher than the dew point [13]. The dew point of the gas in the GTS pipelines is minus 8 °C at an absolute gas pressure of 3.92 MPa [14].

The authors also analysed the dew point temperature in the main transmission gas pipelines of the GMPD “Cherkasytrans-
Using the ASK software complex, the average gas temperature at the outlet and the average gas consumption of each of the 161 GDSs at GMPD “Cherkasytransgaz” that have gas heaters for 2018 were analysed.

As mentioned above, the optimum gas temperature at the GDS outlet should be at minus 5 °C. To determine the economic effect of bringing the gas temperature at the GDS outlet to the minimum allowable requirements in formula (3) instead of the value of \( T_{2g} \), the value of minus 5 °C is set. The entire data set, which is more than 73 thousand calculations, were grouped by reporting periods (months) and posted in Table 3.

The volume of gas consumed by the GDS fire heaters at \(-5^\circ C\) gas temperature is calculated by the formula

\[
Q_{opt} = Q_{cons} - Q_{OC}, \tag{7}
\]

where \( Q_{cons} \) is the volume of gas consumed by the GDS heaters.

According to the calculations provided the following charts of the actual consumption of natural gas for fire heaters to the simulated consumption with the temperature minus 5 °C at the outlet of the GDS (Fig. 3).

The area of the blue shape is for the gas saving at a given gas outlet temperature of 5 °C compared to the actual.

As can be seen from Table 3 \( Q_2 \) for 2018 is 274 717 m³. According to [12], the average gas price for industry for 2018 amounted to 11096 UAH.

Thus, according to (6) the cost of gas overconsumption is equal to 3048.07 thousand UAH in 2018.

Therefore, the total savings from the proposed measures, in particular bringing the pressure on the GDS to the designed one and setting the gas temperature minus 5 °C at the outlet of the GDS could be

\[
Q_s = Q_{s(1)} + Q_{s(2)} = 445 140, \tag{8}
\]
where $Q_{s}$ is savings of natural gas on gas heaters from bringing the gas pressure at the GDS outlet to the designed one, m$^3$; $Q_{di}$ is savings of natural gas on gas heaters from setting the gas temperature minus 5 °C at the outlet of the GDS.

Along with the economic effect of implementing these measures, it is also to take into account environmental effect. Natural gas combustion produces compounds such as carbon monoxide, nitric oxide, and other lightweight non-methane compounds, which are some of the most common greenhouse gases in nature [17]. Mass consumption of natural gas per year is calculated by the formula

$$C = Q_s \cdot p = 309.8,$$  \hspace{1cm} (9)

where $C$ is mass consumption of natural gas per year, t; $Q_s$ is the total volume of saved gas (m$^3$); $p$ is natural gas density under normal conditions, kg/m$^3$; $p = 0.696$ kg/m$^3$ [4].

According to [18], emissions of pollutants E(t) entering the atmosphere with flue gases for the reporting period are found by the formula

$$E = 10^{-6} \cdot R \cdot B \cdot Q_{comb},$$  \hspace{1cm} (10)

where $E$ is gross emission of pollutants during natural gas combustion for the reporting year, tonnes; $R$ is the emission index of the $i^{th}$ pollutant for natural gas, g/GJ; $B$ is consumption of natural gas for the reported year, tonnes; $Q_{comb}$ is lower operating calorific value of natural gas, MJ/kg.

Calculation results are given in Table 4.

**Table 4** Calculation of pollutant emissions from natural gas combustion

| Designation indicator | Value of indicator, g/GJ | Gross output of emission indicator, ton | Pollutant rate, UAH/ton | Tax liabilities, UAH |
|-----------------------|-------------------------|---------------------------------------|------------------------|-------------------|
| NO$_x$                | 64.3111                 | 0.977                                 | 2454.81                | 2399.10           |
| CO                    | 248.75                  | 3.780                                 | 92.37                  | 349.17            |
| CO$_2$                | 58 748.13               | 892.769                               | 10                     | 8927.69           |
| CH$_4$                | 1                      | 0.015                                 | 138.57                 | 2.11              |
| **Total:**            | **897.541**             | **11 678.06**                         | **-**                  | **-**             |

89.72 tons, CO by 3.8 tons, NO$_x$ by 0.977 tons, CH$_4$ by 0.015 tons, when considering the given calculation of gas consumption volumes.

Possibility, safety, necessity and energy efficiency of gas transmission to consumers with temperatures below zero and normative value of pressure were proved.

### References

1. Legislation of Ukraine (n.d.). Resolution of the Cabinet of Ministers of Ukraine No. 840 “On the separation of natural gas transportation activities and ensuring the activities of the gas transmission system operator” of 18.09.2019. Retrieved from https://zakon.rada.gov.ua/laws/show/840-2019-%D0%BF.
2. Ukrinform (2020). Gas start 2020: a new contract, European rules and ... higher prices. Retrieved from https://www.ukrinform.ua/rubric-economic/2849463-gazovij-start-2020-novij-kontrakt-evropeiski-pravila-i-vizit-citi.html.
3. Naftogaz group (n.d.). Volumes of gas use in 2019. Retrieved from http://www.naftogaz.com/www/3/nakweb.nsf/0/8B3289F9F4B2CF50C2237F700843EA33?OpenDocument&ExpandId=7&.
4. Naftogaz. Ukrtransgaz (2019). The quality of gas. Retrieved from http://utg.ua/utg/business-info/yakst-gazu.html.
5. Trofimchuk, V. I. (2018). Experience of the system from target energy monitoring and internal benchmarking at the branch of UMG “Cherkasytransgaz”. Naftohazova haluz Ukrainy, (51), 3-8.
6. Rybitskyi, I. V., Olijnyk, A. P., Yavorskyi, A. V., Karpash, O. M., Karpash, M. O., Tsyk, V. S., & Slobodyan, M. B. (2019). Impact Assess-ment of Non-Technological Fluid Accumulations in the Cavity of an Existing Gas Pipeline on the Energy Efficiency of Its Operation. Physics and chemistry of solid state, 20(4), 457-466. https://doi.org/10.15330/pess.20.4.457-466.
7. Krushnevych, S. P., Piatnychko, A. Y., Zhuk, H. V., & Soldanybereshne, M. A. (2016). The use of differential pressure at gas distribution stations to produce electrical energy during periods of peak loads. Energetychnosti i resursosberezhennye, (4), 14-17.
8. Saham Salari, & Koorosh Goudarzi (2017). Heat transfer enhancement and fuel consumption reduction in heaters of CGS gas stations. Case Studies in Thermal Engineering, 10, 641-649. https://doi.org/10.1016/j.csete.2017.11.007.
9. Redko, A., & Babenko, E. (2014). Hydrate formation in a gas ejector. Commission of motorization and energetics in agriculture, 16(6), 19-26.
10. Naftogaz group (n.d.). The price of gas for industry. Retrieved from http://www.naftogaz.com/www/3/nakweb.nsf/0/468E117B34CF13EEC2257BCE0041B995/OpenDocument.
11. Derzhbud Ukrainy (2001). DBN V.2.5-20-2001. Gas supply. State construction standards. Engineering equipment of buildings and structures. Art.1.6 Retrieved from http://www.rasko.ua/assets/files/B.2.5-20-2001/gaz.pdf.
12. DBN V.2.5-20:2018. Gas supply. Engineering equipment of buildings and structures. State construction standards. Art. 4.1-4.8. Retrieved from https://dnb.co.ua/load/normativy/dbn/1-1-0-360.
13. Consortium Kodeks (n.d.). GOST 5542-87 “Combustible natural gases for industrial and municipal purposes. Technical conditions ” Art.1.2. Retrieved from http://docs.cntd.ru/document/gost-5542-87.
14. Code of the gas transportation system of Ukraine. Approved by the Resolution of the NCRECP of 30.09.2015 No.2493, III.1.p.13.
15. DSTU ISO 6327:2004. Gas analysis. Determination of the dew point of water of natural gas. Hygrometers with a cooled surface (ISO 6327:1981. IDT), p. 6.
16. Rozgoniuk, V. V., Rudnik, A. A., Kolomeiev, V. M., Hryhil, M. A., Bolokan, O. O., Khachikian, L. A., & Herasymenko, Yu. M. (2001). Handbook of the employee of the gas transportation enterprise. Kyiv: Rostok.
Підвищення ефективності роботи газорозподільних станцій шляхом вибору оптимального тиску та температури газу на виході

І. В. Рибицький, В. І. Трофимчук, Г. М. Когут

Івано-Франківський національний технічний університет нефти і газу, м. Івано-Франківськ, Україна, e-mail: rybitsky@gmail.com

Україна займає перше місце у світі за інтенсивністю використання енергії на единицю ВВП. Це означає, що підприємствами України на виготовлення одиниці продукції витрачається найбільше енергоносіїв у порівнянні з іншими країнами світу. Не є виключенням і газотранспортна система України (ГТС). Із 2020 року очікується зменшення транзиту газу у зв’язку з будівництвом газопроводів в обхід території України, що приведе до зменшення рентабельності ГГС, а при недостатньому завантаженні – до її збитковості. Тому сьогодні завдання рациональної експлуатації обладнання ГГС із точки зору енергоефективності набуває все більшої актуальності.

Мета. Розроблення комплексу заходів підвищення енергоефективності роботи газотранспортної системи України на основі аналізу результатів роботи газорозподільних станцій (ГГС) без залучення суттєвих капіталовкладень з урахуванням умов можливого зменшення транспортування газу.

Методика. У роботі проведен аналіз науково-технічної літератури, нормативних документів, виконано математичне моделювання та аналіз експлуатаційних показників роботи ГГС для визначення економічного та екологічного ефекту запропонованих заходів.

Результати. Підтверджено, що доведення тиску газу на вхід до проектного є перспективним напрямом підвищення енергоефективності. На основі аналізу науково-технічної літератури та нормативних документів визначено оптимальна температура газу на виході з ГГС. Показано, що впровадження запропонованого комплексу заходів дозволить отримати значний економічний та екологічний ефект.

Наукова новизна. Розроблена та обґрунтована необхідність упровадження комплексу безвитратних заходів, зокрема приведення фактичних показників температури та тиску природного газу на вхід до ГГС до оптимальних, що підвищує енергоефективність та екологічність її експлуатації.

Практична значимість. Отримані результати будуть використані у виробничій діяльності для підвищення енергоефективності експлуатації ГГС.