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Managing the production of natural gas using gas storage in Poland

ABSTRACT. Managing natural gas exploitation which is subject to seasonal changes necessitates gas storage in the periods of lower demand to maintain the stability of gas production. Bearing in mind the natural seasonal character of gas consumption in Poland, it is necessary to use definite working gas volume of underground gas storage facilities (UGS) to maintain a suitable level of gas production from domestic sources in the periods of low gas consumption The main aim of the paper is to investigate the impact of gas storage on gas production strategy from domestic fields based on the example of Poland, and to calculate the amount of gas which should be stored to optimize gas production.

The method of calculation, presented in this paper, has been applied to the historical data of methane-rich and nitrogen-rich gas supply and demand in Poland.

The storage capacity needed for providing stable production, calculated according to formulas presented in this article was about 1.42 billion m^3 of methane-rich natural gas in the last year, which means that 47.7% of yearly domestic production was stored.

Apart from the methane-rich system, two nitrogen-rich gas subsystems are operating in Poland. Those gas systems are regional closed systems, i.e. without the possibility of arbitrarily supplementing with gas deliveries from other transmission systems. The UGS were not used for storing nitrogen-rich gas in the past, therefore production from nitrogen-rich gas fields was increased in the winter and lowered during summer months. At present PGNiG S.A. has at its disposal two nitrogen-rich gas storages: UGS Daszewo and UGS Bonikowo. Working capacity needed for regulating the production of nitrogen-rich gas and calculated according to presented formulas is about 200 million m^3.

The use of UGS enables stable exploitation of methane-rich gas fields and steady production

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levels in gas processing plants. In addition no major fluctuations were observed in the aspect of high seasonality of natural gas consumption (related to climate and the structure of the gas consumers in Poland). In the summer season methane-rich gas imports exceed demand and its flexibility is strongly limited, which results from the realization of contracts, especially the obligation of receive minimum annual and summer amounts of gas, and technical parameters of the transmission network. By using methane-rich UGS in the analyzed period there was neither correlation between the monthly amount of production and consumption of high-methane gas, nor between the size of production and temperature. In the case of the closed nitrogen-rich gas system there have recently been large fluctuations caused by not using UGS. Since then a new UGS Bonikowo has come into use, thanks to which production could be, to a considerable degree, stabilized.

KEY WORDS: underground gas storage, production optimization, working capacity calculation

Introduction

Natural gas consumption in Poland is strongly dominated by seasonal fluctuations on annual, weekly and daily bases. On the other hand, gas flow stability is very important for natural gas exploitation and transmission. The production conditions providing stability of gas field operation result from individual properties of the exploitation wells and frequently depend on a number of factors, e.g. geological and reservoir conditions, properties of formation rocks, design of the borehole and surface infrastructure. Ensuring optimal operation of the reservoir necessitates pressure difference exerted on the reservoir to be possibly constant and lower than the admissible level, which limits the attainable rate of production. This can eliminate or reduce the negative impact of formation waters (elimination of water cones, cutting off parts of the reservoir) and destabilization of the reservoir structure around the wellbore (migration of sand) (Kosowski et al. 2010).

Thus, oil and natural gas reservoirs should be exploited in a stable way, with optimum production rate determined on the basis of measurements and calculations, with no rapid changes involved. Maintaining uniform gas production is also a key factor from the perspective of optimization of costs of natural gas exploitation.

Managing natural gas exploitation which is subject to seasonal changes necessitates gas storage in the periods of lower demand to maintain the stability of gas production. Bearing in mind the natural seasonal character of gas consumption in Poland, it is necessary to use definite working gas volume of underground gas storage facilities (UGS) to maintain a suitable level of gas production from domestic sources in the periods of low gas consumption. Thus, the gas storage installations or their parts used for the realization of this purpose should be treated as elements of the exploitation system; they should be considered differently to other gas storage facilities used for other purposes. The third-party access (TPA) rule should not apply especially to gas storage facilities or their parts, including the virtual ones, playing a regulating role in oil and gas production (Kaliski et al. 2009).

It should be noted, that according to the third energy liberalization package announced in September 2007 by the European Parliament and the Council to facilitate access to gas storage, the storage volumes necessary for gas recovery can be reserved by the gas producing company and can be excluded from the TPA rules (Directive 2009/73/EC, 2009). However, the company must demonstrate what amount of working capacity is necessary to carry out gas production operations (Interpretative note on directive 2009/73/EC, 2010). This task is not minor because gas streams from extraction, import and storage are mixed in the transmission system and direct measurement is not possible.

All import contracts signed by Polish Oil and Gas Company (PGNiG S.A.) have the „take or pay" clause. These contracts usually impose the obligation to buy a minimum annual amount of natural gas, including predefined quantities of gas in the summer period. Such clauses are common practice when assuming long- and average-length contracts and constitute a basic warranty for gas producers. Assuming the priority of gas imported on the basis of long-term contracts over gas from Polish deposits („take or pay" principle), the UGS have to be used for regulating the domestic gas production level in the summer period.

2. Aims

The aim of the paper is to investigate the impact of gas storage on gas production strategy from domestic fields based on the example of Poland, and to calculate the amount of gas which should be stored to optimize gas production.

3. Methods

Natural gas market balance can be illustrated with the following equation:

$$P + I + UGS_P = C + UGS_I + R \tag{1}$$

where: P – deliveries from domestic sources [Nm^3],
I – deliveries from import [Nm^3],
UGS_p – deliveries from UGS [Nm^3],
C – consumption (including export) [Nm^3],
UGS_I – injection to UGS [Nm^3],
R – other (losses, use for technological needs, change of amount of gas in the transmission system) [Nm^3].

The amount of stored natural gas after time t can be described as:

$$S(T) = S_p + \int_0^T [p(t) + i(t) - c(t) - r(t)]dt \tag{2}$$

where: $S(T)$ – stored natural gas [nm^3],
S_p – initial state [Nm^3],
$p(t)$ – deliveries from domestic sources [Nm^3/d],
$i(t)$ – deliveries from import [Nm^3/d],
$c(t)$ – consumption [Nm^3/d],
$r(t)$ – other [Nm^3/d].

The required working capacity is equal to $Z = \max[S(t)]$ for $t \in [0, T]$ (3)

UGS injection rate for natural gas can be described as:

$$q(t) = p(t) + i(t) - c(t) - r(t) \tag{4}$$

But on the assumption that imported gas has to be used first, the UGS injection rate for gas from domestic sources can be calculated from the formula:

If $i(t) \geq c(t) + r(t)$ then UGS injection rate equals to $q(t) = p(t)$ (5)
If $i(t) < c(t) + r(t)$ and simultaneously $i(t) + p(t) > c(t) + r(t)$
then $q(t) = p(t) - [c(t) + r(t) - i(t)]$ (6)
Otherwise, $q(t) = 0$ (7)

4. Results

The above presented method of calculations has been applied to the historical data of methane-rich and nitrogen-rich gas supply and demand in Poland. Methane-rich gas consumption in Poland has been lately characterized by a gradual increase and seasonality, mainly connected with the climatic conditions (fig. 1). The peak of gas consumption is usually observed in January and the minimum during the summer vacation period. At the same time the imported and domestic gas deliveries cannot be arbitrarily adjusted to the consumption level. The variability of import deliveries is significantly limited, which results from the realization of contracts, especially reception of minimum annual and summer quantities („take-or-pay") as well as technical parameters of the gas transfer network.

Hence, the fluctuations can be balanced by using underground gas storage facilities (Figs. 2 and 3). Fig. 2 shows the structure of methane-rich gas delivery sources and Fig. 3 presents the structure of its utilization. The key role of UGS in optimizing the gas system is clearly visible.

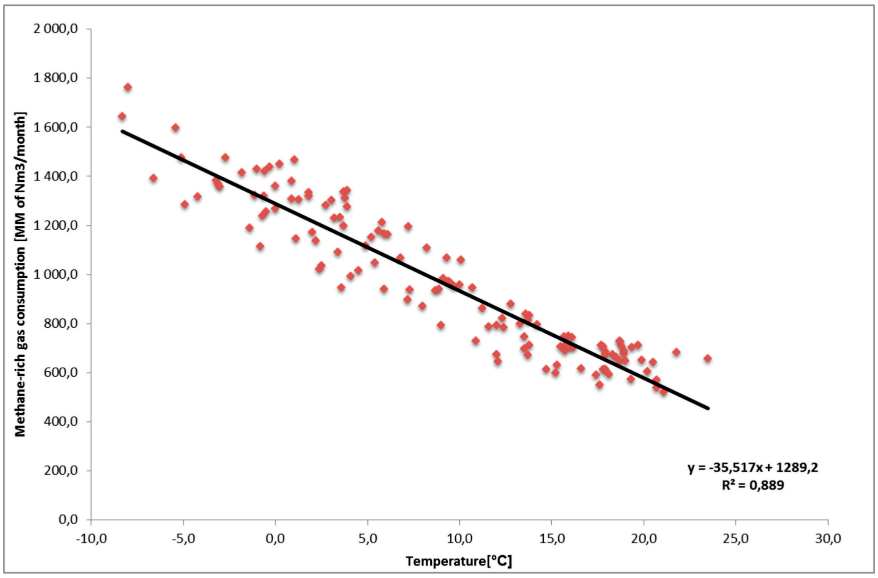

Fig. 1. Monthly consumption of methane-rich natural gas vs. temperature in Poland in 2000–2010 (calculations based on temperature data from http://www.ogimet.com/)

Rys. 1. Zależność miesięcznego zużycia wysokometanowego gazu ziemnego od temperatury w Polsce w latach 2000–2010 (obliczenia oparte o dane serwisu http://www.ogimet.com/)

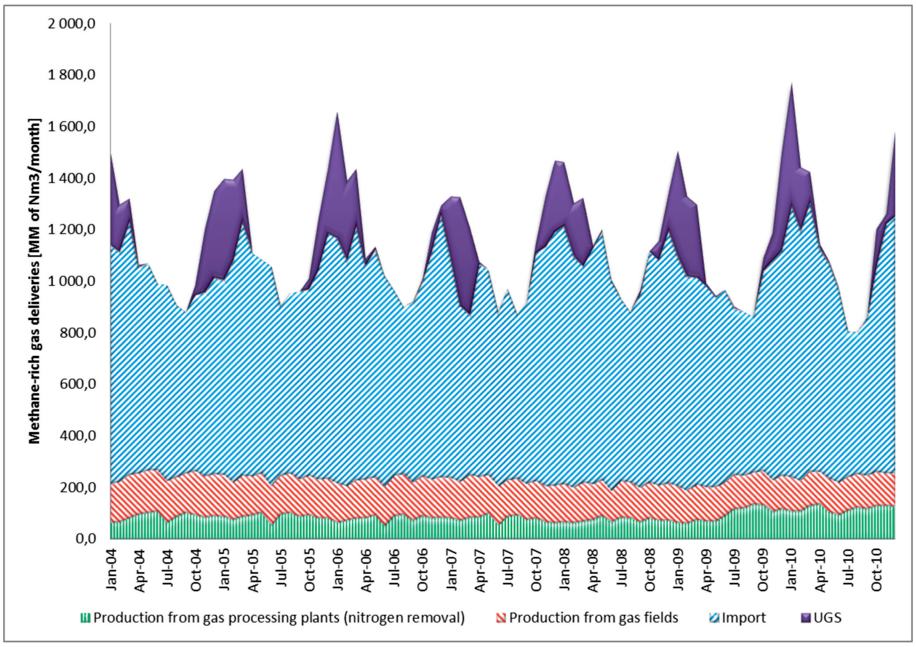

Fig. 2. Structure of delivery sources of methane-rich natural gas in Poland (source: PGNiG S.A.)

Rys. 2. Struktura źródeł dostaw wysokometanowego gazu ziemnego w Polsce (źródło: PGNiG S.A.)

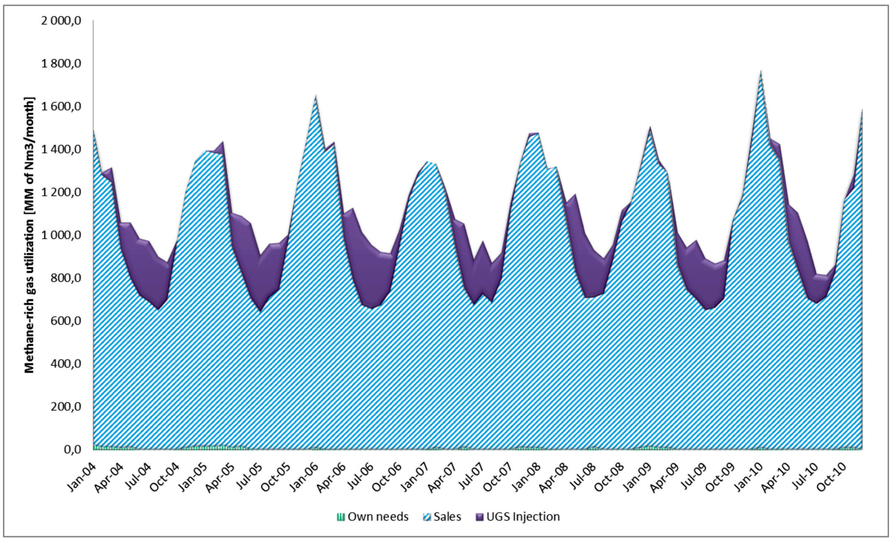

Fig. 3. Structure of methane-rich natural gas utilization in Poland (source: PGNiG S.A.)

Rys. 3. Struktura wykorzystania wysokometanowego gazu ziemnego w Polsce (źródło: PGNiG S.A.)

PGNiG S.A., as a gas producer, is obliged to correctly manage production, i.e. they should try to maintain a uniform level. This task is successfully fulfilled and compared to the strongly seasonal methane-rich gas consumption, the domestic production is stable (Fig. 4). This state was achieved owing to the use of UGS, thanks to which the seasonality of consumption can be balanced and stable domestic production maintained.

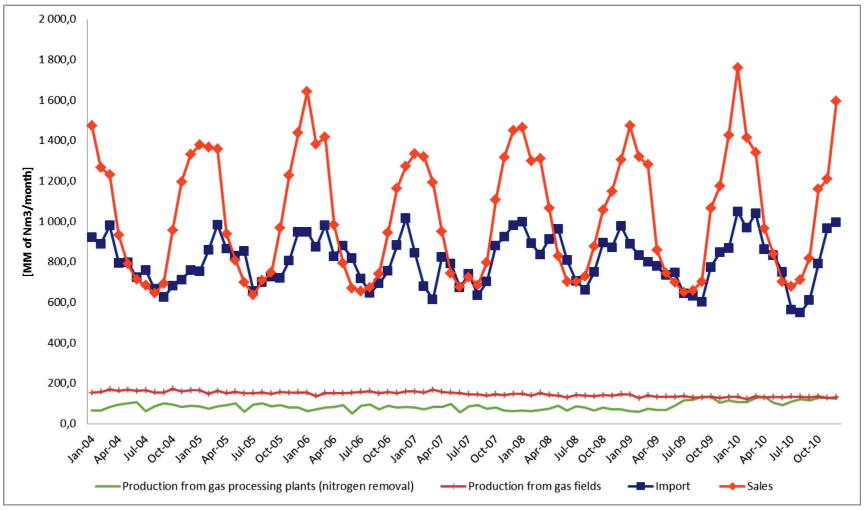

Fig. 4. Consumption, import and domestic production of methane-rich natural gas in Poland (source: PGNiG S.A.)

Rys. 4. Konsumpcja, import i krajowa produkcja wysokometanowego gazu ziemnego w Polsce (źródło: PGNiG S.A.)

If the UGS were not used, the domestic production in summer months would have to be considerably reduced, contracts could not be realized and a gas deficiency in the winter season would be fact. These limitations would be considerable, as imported gas is consumed first. This would lead to unstable and potentially hazardous exploitation of domestic reservoirs. Fulfilling the increased demand for natural gas during the winter months would be hindered as well.

As a consequence of using this consumption model a considerable amount of domestic gas has to be stored during the summer period. It comes from reservoirs in southeastern Poland and gas processing plants, which remove nitrogen from nitrogen-rich gas exploited in the Polish Lowland.

Thanks to use of USG, the production of methane-rich gas in Poland is not very seasonal and relatively stable (Figs. 5, 6).

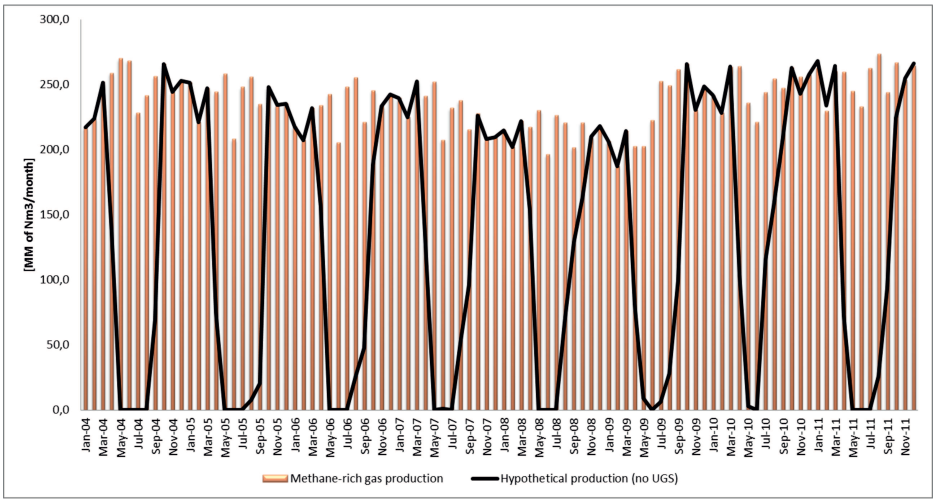

Fig. 5. Monthly production of methane-rich gas and hypothetical production if the UGS had not been used in Poland in 2004–2011

Rys. 5. Miesięczna produkcja gazu wysokometanowego i hipotetyczna produkcja w przypadku braku wykorzystania PMG w Polsce w latach 2004–2011

The storage capacity needed for providing stable production, calculated according to formulas presented in this article was about 1.42 billion m^3 in 2010. Production from methane-rich gas fields in that year was 1,58 billion m^3 and production from gas processing plants was 1,4 billion m^3, which means that about 47,7% of yearly domestic production should have been stored. Total gas production (both methane-rich and nitrogen-rich) in Poland in 2010 was 4,22 billion m^3 (methane-rich equivalent). In 2011 total production increased to 4,33 billion m^3 (methane-rich equivalent).

Apart from the methane-rich system, two nitrogen-rich gas subsystems are operating in Poland. Those gas systems are regional closed systems, i.e. without the possibility of arbitrarily supplementing with gas deliveries from other transmission systems. The UGS were not used for storing nitrogen-rich gas in the past, therefore production from ni-

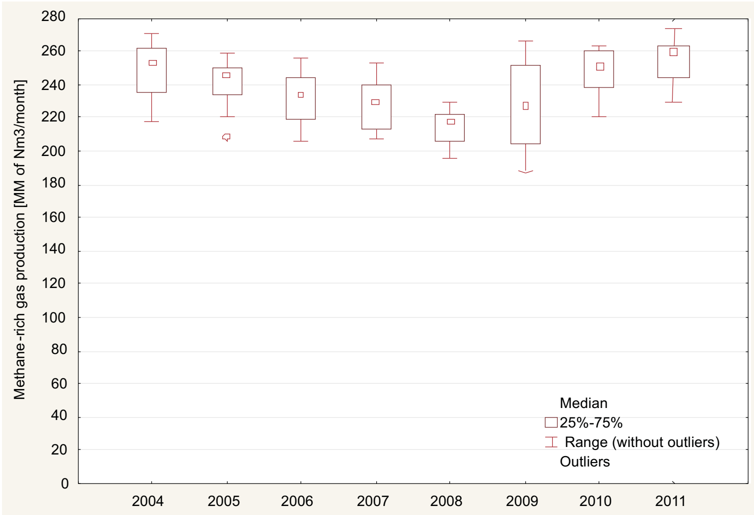

Fig. 6. Variability of the monthly production of methane-rich gas in Poland in 2004–2011

Rys. 6. Zmienność miesięcznej produkcji gazu wysokometanowego w Polsce w latach 2004–2011

trogen-rich gas fields was increased in the winter and lowered during summer months. At present PGNiG S.A. has at its disposal two nitrogen-rich gas storages: UGS Daszewo and UGS Bonikowo.

The example of UGS not being used is clearly visible in the plots (fig. 7 and 8) illustrating production from the nitrogen-rich gas fields. Contrary to the production of methane-rich gas,

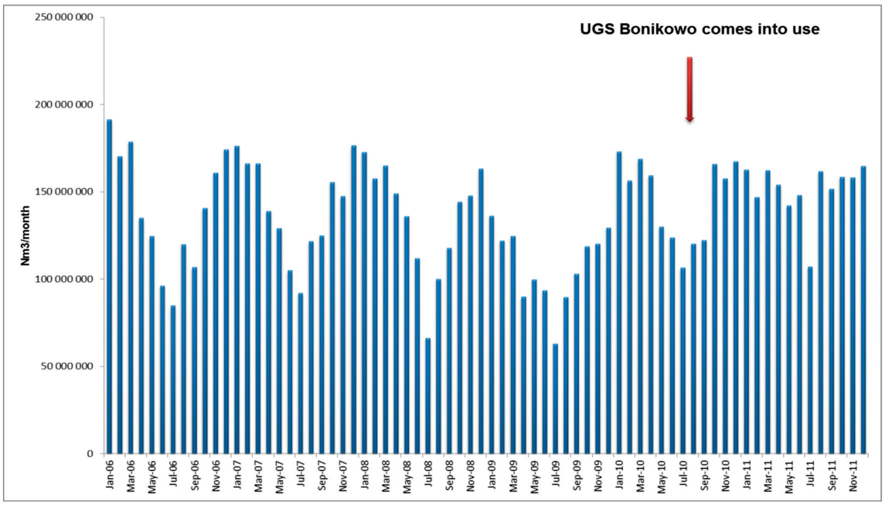

Fig. 7. Monthly production of nitrogen-rich gas from fields linked in to the nitrogen-rich gas subsystem in 2006–2011 (source: PGNiG S.A.)

Rys. 7. Miesięczne wydobycie gazu zaazotowanego ze złóż podłączonych do systemu gazu zaazotowanego w latach 2006–2011 (źródło PGNiG S.A.)

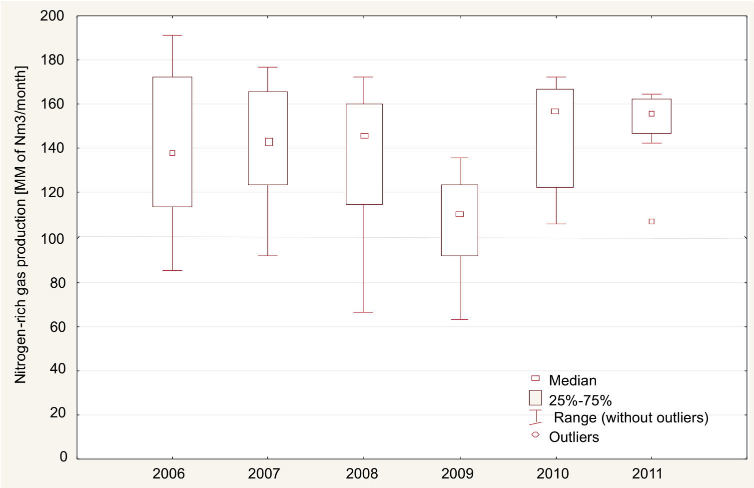

Fig. 8. Variability of the monthly production of nitrogen-rich gas from fields linked in to the nitrogen-rich gas subsystem in 2006–2011

Rys. 8. Zmienność miesięcznej produkcji gazu zaazotowanego ze złóż podłączonych do systemu gazu zaazotowanego w Polsce w latach 2004–2011

here we observe high seasonality, reduced only from mid 2010 owing to the start of UGS Bonikowo operation.

When calculating the storage capacity needed for stabilizing nitrogen-rich gas production, the assumption was made that the calculation will be based on a hypothetical average production level between April and March. To run the production at a constant level over such a period of time, there should exist UGS which could store the production excess and cover the shortages in the period of increased demand. Their minimum working capacity can be calculated by analyzing deviation of the actual production from the assumed average level, and then accumulating them. The minimum storage capacity is the maximum value of accumulated deviations from the average production.

For each April-March season, the calculations were made in the following way:

$$\overline{p} = \frac{1}{T}\int_0^T p(t)dt \tag{8}$$

$$S(t) = S_p + \int_0^t [\overline{p} - c(\tau)]d\tau \tag{9}$$

where: $S(t)$ – accumulated reserves [Nm^3],

S_p – initial state [Nm^3],

$\overline{p}$ – average level of production between April and March [Nm^3],

$p(t)$ – production [Nm^3/d],

$c(t)$ – consumption [Nm^3/d].

Required minimum working capacity $Z = \max[S(t)]$ for $t \in [0, T]$.

Working capacity needed for regulating the production of nitrogen-rich gas and calculated according to above presented formulas is about 200 million m^3.

5. Conclusions

Underground gas storage constitutes an important element of natural gas production, transport and distribution. One of the most important functions of UGS is optimization of the process of natural gas exploitation. The working capacity of UGS needed for the realization of the optimization process depends on a number of factors, e.g. demand and supply of natural gas, strategy of gas utilization, geological and formation conditions, as well as technical standards of exploitation, transport and storage infrastructure.

Managing the production in conditions of strong gas demand fluctuations necessitates calculating required working capacities of UGS, to be used for its regulation. The formulae presented in this paper are a proper tool for doing so.

The use of UGS enabled stable exploitation of methane-rich gas fields and steady production levels in gas processing plants. In addition no major fluctuations were observed in the aspect of high seasonality of natural gas consumption (related to climate and the structure of the gas consumers in Poland). In the summer season methane-rich gas imports exceed demand and its flexibility is strongly limited, which results from the realization of contracts, especially the obligation of receive minimum annual and summer amounts of gas („take-or-pay"), and technical parameters of the transmission network. By using methane-rich UGS in the analyzed period there was neither correlation between the monthly amount of production and consumption of high-methane gas, nor between the size of production and temperature. This state was achieved by storing almost half (47.7%) of yearly domestic production of methane-rich gas,

In the case of the closed nitrogen-rich gas system there have recently been large fluctuations caused by not using UGS. Since then a new UGS Bonikowo has come into use, thanks to which production could be, to a considerable degree, stabilized.

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Weather Information Service, http://www.ogimet.com/

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Wykorzystanie podziemnych magazynów gazu do zarządzania produkcją gazu ziemnego w Polsce

Streszczenie

Wykorzystanie magazynów gazu jest niezbędnym czynnikiem pozwalającym na prawidłową eksploatację złóż gazu ziemnego. W okresach zwiększonego popytu magazyny ułatwiają jego zaspokojenie, a w czasie niskiego zapotrzebowania umożliwiają stabilizację produkcji. Biorąc pod uwagę silną sezonowość konsumpcji gazu ziemnego w Polsce istnieje potrzeba przeznaczenia określonej wielkości pojemność czynnych podziemnych magazynów gazu na regulację krajowego wydobycia. Głównym celem tego artykułu jest pokazanie wpływu magazynowania gazu na przebieg eksploatacji krajowych złóż gazu ziemnego oraz kalkulacja ilości gazu, który powinien być zmagazynowany w celu optymalizacji krajowego wydobycia.

Na podstawie historycznych danych dotyczących wydobycia i konsumpcji gazu ziemnego w Polsce i z wykorzystaniem metody kalkulacji pojemności czynnych, zaprezentowanej w niniejszym artykule, obliczone zostały pojemności czynne podziemnych magazynów gazu, niezbędne do regulacji krajowego wydobycia gazu wysokometanowego. Wyniosły około 1,4 mld m^3, co oznacza, że około 48% rocznego wydobycia wysokometanowego gazu ziemnego powinno być magazynowane. Brak wykorzystania podziemnych magazynów gazu skutkowałby koniecznością znacznego ograniczania wydobycia krajowego i produkcji gazu w odazotowniach w miesiącach letnich, uniemożliwiałby realizację zawartych umów kontraktowych oraz powodował deficyt gazu w miesiącach zimowych.

Oprócz systemu gazu wysokometanowego w Polsce eksploatowane są dwa podsystemy gazu zaazotowanego. Systemy gazu zaazotowanego są regionalnymi systemami zamkniętymi, tzn. nie istnieje możliwość dowolnego uzupełnienia dostaw gazu z krajowego (lub innego) systemu przesyłowego. Ponieważ do niedawna nie eksploatowano PMG na gaz zaazotowany wydobycie ze złóż gazu zaazotowanego było zwiększane w okresie zimowym i zmniejszane w lecie. Obecnie jednak PGNiG S.A. dysponuje dwoma magazynami na gaz zaazotowany: PMG Daszewo (system gazu Ls) i PMG Bonikowo (system gazu Lw). Pojemności, niezbędne do regulacji wydobycia ze złóż podłączonych do podsystemu gazu zaazotowanego Lw skalkulowane przez autorów niniejszej pracy wynoszą około 200 mln nm^3.

Dzięki wykorzystaniu podziemnych magazynów wydobycie ze złóż gazu wysokometanowego i produkcja w odazotowniach w Polsce ma stabilny przebieg i nie wykazuje silnych wahań pomimo bardzo silnej sezonowości zużycia gazu ziemnego, wynikającej m.in. z warunków klimatycznych w Polsce oraz ze struktury odbiorców gazu.

W przypadku zamkniętego systemu gazu zaazotowanego Lw do niedawna występowały silne wahania wydobycia, co było konsekwencją braku wykorzystywania podziemnych magazynów gazu. Od niedawna w tym systemie funkcjonuje PMG Bonikowo, co pozwoliło na znaczną stabilizację wydobycia.

SŁOWA KLUCZOWE: podziemne magazynowanie gazu, optymalizacja wydobycia, kalkulacja pojemności czynnej