TECHNICAL AND ECONOMICAL PERFORMANCE OF THE UNDERGROUND GAS STORAGE IN LOW QUALITY GAS RESERVOIR

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Abstract

The case study of the Wierzchowice UGS in Poland is presented. The aim of this paper is to show that UGS in depleted low quality gas reservoir can be very efficient from both technical and economical points of view. In the paper, the application of the simulation model to control and manage of the UGS created in the low quality gas reservoir is presented. It is shown, that the pipeline quality gas standards may be fulfilled and the gas composition may be effectively controlled.

The results of the original economical calculations are also presented in the paper to compare the economic characteristics of the UGS-s in Poland and in Western Europe.

On the other side, the UGS in low quality gas field causes technical problem related to the possible mixing of the injected gas (usually high methane) and original, low quality gas. It was shown, that this phenomenon can be effectively controlled and minimized.

Introduction

Poland is a gas transition country located between the Russia and Western Europe (Fig.1). For this reason it plays important role in the European gas supply system. At present, the gas transition system in Poland consists of more than 18000 km of pipelines and 6 UGS facilities with the total working capacity of more than 1,6 mld cu.m. (Fig.2). In 2008 total gas consumption in Poland reached 13.8 bcm, including more than 30% from national sources. This places Poland on the 4-th place in Europe in terms of independence from gas imports.

The comparison of share of working capacity in annual consumption of natural gas to share of domestic production in total gas consumption for selected European countries (Fig. 3) shows that four groups of countries can be distinguished: the first without own gas sources and significant working volumes (Spain, Belgium, Greece); the second with enough storage capacities and without own gas (Austria, France, Germany, Italy), the third group with domestic sources of gas and low share of storage capacities in annual consumption (The Netherlands, The United Kingdom and Denmark) and Poland which is between these groups.

Underground gas storages play important role in the gas supply safety and optimization of the cost of delivery of gas to the consumers. But the gas market in Europe is changing and UGS objectives are changing and broadening too. The emphasis exerted by the EU on liberating gas market and promoting competition causes treating underground gas storage as a commercial undertaking. In a free market the economic effectiveness of underground gas storage is a key factor which allows to achieve both technical and economic success.

The aim of this paper is to show that UGS in depleted low quality gas reservoir can be efficient from both technical and economical points of view.

Review of the Polish gas reservoirs in the context of underground storing of natural gas

Most of the UGS in Poland are created in depleted gas fields. Natural gas fields in Poland can be found mainly in the Polish Lowland (nord-western part) and Carpathian Foredeep (south-eastern part); moreover, small natural gas fields occur in the Carpathian area and in the Polish economic zone of the Baltic Sea (Fig.1). About three quarters of natural gas resources are present in the Miocene and Rotliegendes beds, whereas the remaining ones in the Cambrian, Devonian, Carboniferous, Zechstein, Jurassic and Cretaceous strata.
The natural gas fields in the Carpathian Foredeep occur in the Jurassic, Cretaceous and Miocene beds. Most frequently this is high methane, low nitrogen gas. Only in 4 fields nitrided gas occurs. These fields belong to structurally-lithologically multilayered, less frequently massive fields, producing with gas expansion drive mechanism (Stopa et al., 2009).

The natural gas in the Carpathians occurs in the Cretaceous and Tertiary strata, both in autonomous deposits, and accompanying oil or condensate deposits. Gas exploitation from the Carpathian deposits is performed with gas expansion drive mechanism. The gas is high methane (most frequently over 85% of methane), nitrided (a few percent, on average).

Natural gas fields in the Polish Lowland occur in the Fore-Sudetes and Wielkopolska Permian beds; in the West Pomerania they can be found in the Carboniferous and Permian strata. Gas occurs in the massive and block-type reservoirs with water drive mechanism and gas expansion drive mechanism. In 2005 about 66% of documented natural gas fields were found in the Lowland area; the resources in the Carpathian Foredeep constituted 29.5% of Poland’s resources, Polish economic zone of the Baltic Sea - 3.2%, and the Carpathian resources - only 0.9%.

As may be deduced from Fig.1, the north-western part of Poland is convenient for UGS in relation to the gas transmission system and the European gas market. Natural gas in this region contains nitrogen, typically from 15% to 70%. The methane content is variable, in the most cases it varies from 30% to over 85% of methane. Hence, this is a methane-nitrogen or nitrogen-methane combination. The nitrogen-methane combination (below 30% of methane) was found in 15 reservoirs, unmanaged so far and preliminarily recognized in most cases (Zawisza et al., 2005). In the case of storages build in this region, the low quality original gas (cheaper than high methane gas) may be used as a gas cushion, that improves economical performance. On the other hand, some technical problems can arise during operation of such underground gas stores. Most important is mixing of injected high quality gas and original low-quality gas which affect the quality of gas produced from storage. In such a case, the gas withdrawal should be precisely controlled to meet the pipeline quality gas standards. One example of the successful operation of the UGS created in the low quality gas field is Wierzchowice UGS.

**Technical performance of the Wierzchowice UGS**

Wierzchowice UGS was developed in a depleted natural gas field. The reservoir represents a brachi-anticline whose areal sizes within the gas-water contact are 7 km by 3.5 km. The reservoir has a surface area of 24 km² and average thickness of 44 m. Permeability ranges between 0.1 and 250 mD, average porosity is 13.4%. The shallowest closure is located to the north-east. The structure wings go deeper in the other directions. The gas production from the Wierzchowice field started in November 1972 and continued till the end of March 1995. The total production was 7809.7 million m³ of gas (about 65% of the original gas reserves of 12 bln sm³) and 11142 m³ of water. The reservoir pressure declined from the original 16.50 MPa to 5.65 MPa. The field primary recovery mechanism was volumetric expansion. The Wierzchowice reservoir has been converted into an underground gas storage of a high quality gas, from partially depleted natural gas reservoir of low quality gas (Table 1). The main parameters of the Wierzchowice UGS are presented in Table 2 and Figure 4.

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole fraction Original gas</th>
<th>Mole fraction Injected gas</th>
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<tbody>
<tr>
<td>N₂</td>
<td>0.2957</td>
<td>0.01-0.03</td>
</tr>
<tr>
<td>C₁</td>
<td>0.6938</td>
<td>0.96-0.985</td>
</tr>
<tr>
<td>C₂+</td>
<td>0.0105</td>
<td>0.005-0.006</td>
</tr>
</tbody>
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Table 2. Main parameters of the Wierzchowice UGS

<table>
<thead>
<tr>
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<th>Present state</th>
<th>Expected in 2011, I stage</th>
<th>Expected II stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working capacity [mln ( \text{sm}^3 )]</td>
<td>575</td>
<td>1200</td>
<td>3500</td>
</tr>
<tr>
<td>Max. withdrawal rate, [mln ( \text{sm}^3 / \text{d} )]</td>
<td>4.8</td>
<td>14.40</td>
<td>50</td>
</tr>
<tr>
<td>Max. Injection rate [mln ( \text{sm}^3 / \text{d} )]</td>
<td>3.6</td>
<td>9.60</td>
<td>30</td>
</tr>
<tr>
<td>No. of operational wells</td>
<td>21</td>
<td>10 vertical + 12 horizontal</td>
<td>28 horizontal</td>
</tr>
</tbody>
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The problem of optimal control during both injection and production cycles to achieve the necessary gas composition, has been especially difficult due to the large amount of the nitrogen-rich gas left in the reservoir. The problem of the withdrawn gas to meet the pipeline quality gas standards has been solved by use of the advanced well control based on the computer simulation of reservoir. The simulation model, developed by the authors, was able to simulate the gas composition in place and to forecast the methane content in the produced gas depending on the wells controls.

The commercial compositional simulator ECLIPSE300 was used. The following components were employed to simulate the gas phase: \( \text{N}_2 \), \( \text{C}_1 \), \( \text{C}_2+ \). The physical dispersion responsible for the gas mixing in reservoir was simulated by numerical dispersion on the simulation grid. In order to control the numerical dispersion, the local grid refinements near the wellbores have been used. The dimensions of the local grid blocks were selected by "history matching" procedure using the measurements (pressures, rates and compositions) beginning from 1995. The simulation model, presented in this paper, is perfectly verified because the gas composition during withdrawal as well as injection periods is precisely monitored by chromatography for all individual wells and during every cycle.

The results of the history matching for the selected wells are presented in Figures 5 and 6. In Fig.5, representing the well operating since 1995, gradual reducing of the \( \text{N}_2 \) concentration can be observed. The simulation model has been used for evaluations of the various scenarios of managing the UGS. This allowed us to optimize the strategy of development the UGS. The simulations were also used for optimization of the gas injection strategy at the early stage of the storage operation. The objective of this strategy was to create the stable zone of the high quality gas. The visualization of the gas composition in the reservoir is presented in Figure 7. The predicted content of the nitrogen in gas produced from storage for one possible scenario is presented in Fig.8.

**Economical performance of the Wierzchowice UGS**

The construction of underground gas storage is very expensive. The size and structure of capital cost depends on a number of factors, e.g.:

- type of storage,
- geological conditions,
- working capacity of UGS.

An exemplary structure of capital cost of a UGS in a depleted natural gas field is presented in Fig. 9. The main elements of capital cost are cushion gas, wells and such surface installations as, e.g. pumping station.

Additionally, the analysis of economic efficiency of UGS and influence of specific factors reveals that the capital cost is of key importance to the financial success of UGS investment.

The analysis of sensitivity of UGS Net Present Value (NPV), being one of the measures of profitability, to the change of selected factors, e.g.:

- price for storing,
- capital cost,
- level of fixed costs,
- level of variable costs.

is presented in Fig. 10.

The presented plot reveals that the change of NPV, i.e. improvement or deterioration of economic efficiency of UGS, is mostly influenced by two factors, i.e. storing price and capital costs. The influence of fixed and floating costs is relatively small. This is typical of investments requiring high capital costs, where the future operating costs are incomparably lower.
From the investor's point of view, the economic efficiency is of top importance, therefore efforts should be undertaken to increase it to the maximum. In the conditions of free market, it may be hard to influence the UGS financial effects by means of storing prices. Another solution is to considerably lower the capital costs.

As already mentioned, the cost of cushion gas is one of the biggest elements of capital cost. In this situation, UGS localized in depleted high-nitrogen natural gas fields, offering a cheaper cushion gas, are more advantageous. One should not forget that apart from natural gas, which during UGS construction is injected, increasing the buffer capacity, there still remains native natural gas. In the case of future exploitation of the field, this gas would be exploited and sold, generating income to the owner. This fact should be accounted for when assessing the economic efficiency of an UGS in a partly depleted field. The value of the leftover natural gas should be calculated and added to the capital costs of UGS construction.

In a case of Wierzchowice UGS the gas buffer consists of 4.59*10^9 sm^3 (4.1*10^9 sm^3 exploitable) of native high-nitrogen gas and 1.4*10^8 sm^3 of injected high-methane gas. After finishing the final, second stage of UGS construction (3.5*10^9 sm^3 of working capacity) the exploitable buffer/working capacity ratio will be equal to 1.57 (1.57 sm^3 of exploitable buffer capacity per 1 sm^3 of working capacity). But, when we take into account that high-nitrogen gas is cheaper than high-methane (in the case of Wierzchowice UGS its price is ca. 60% of high methane gas price) the buffer value/working capacity value ratio is equal to 1.10. Such decrease in capital cost has a significant influence on UGS economical efficiency (Fig. 10). Another important factor which has impact on Wierzchowice UGS economics is a scale effect arising from its huge potential capacity.

All these factors demonstrate the high economic and technical potential of Wierzchowice UGS and its competitiveness against other UGS.

Additionally, Figure 11 presents the price for storage for selected operators of underground gas storage facilities in Europe. They differ considerably depending on the type of storage and its size. These prices were compared to hypothetical prices for UGS located in Poland. Prices for these facilities were calculated using the discounted cash flow method, assuming the achievement of the internal rate of return on investment at 10% or 15%. Their values are close to the minimum values for operators in other European countries. It shows that in the event of free market of gas storage services and high demand, an operator of underground gas storage facilities in Poland could reap the considerable benefits.

Conclusions

In this paper the case study of the Wierzchowice UGS build in the depleted low quality gas is presented to show that such type of UGS, if properly managed, may be efficient from both technical and economical point of view. UGS require high capital costs and definitely lower level of operation cost in the future. To maximize economic effects, the UGS operator should concentrate on optimization of capital costs related to UGS construction. As indicated in this paper, the economic situation of the UGS operator in the competitive market conditions can be significantly improved if the UGS is localized in a partly depleted high-nitrogen gas field. There also exists a technical risk related with using this type of fields, e.g. threat that the quality of the received gas may deteriorate. However, the experience related with operation of such facilities, e.g.: the largest Polish UGS in Wierzchowice localized in a partly depleted high-nitrogen gas field, does not confirm these threats. The selection of high-nitrogen gas field results in lowered capital costs and improved economic-financial indices of UGS. In the face of commercialization of storing services, the lower capital costs may be a competitive factor in the free market conditions. It should be also emphasized that all fields analyzed as potential UGS, should be analyzed separately as their economic efficiency may be influenced by a number of geological, technical and economic factors typical of every field.

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References

2. J. Stopa, P. Kosowski, Factors influencing the costs of underground gas storage, Polityka Energetyczna, Wydawnictwo IGSMiE PAN, 2006
Figures

Fig.1. Location of the Poland relating to the European gas map. Small circles represent major gas fields. (Extracted from World Gas Map, 2006 edition. www.petroleum-economist.com/maps)

Fig.2. Location of the UGS in Poland relating to the scheme of the gas transmission system. (Extracted from reference[3])
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Fig. 6. Comparison of the simulation results (solid line) and measurements for a selected new well, nitrogen content vs. time
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Fig. 8. Simulated nitrogen concentration (mole fraction) in gas produced from storage for 3 withdrawal cycles.
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Source: Stopa J. Kosowski P. 2006.

Fig. 10. The analysis of sensitivity of UGS NPV to the change of key financial factors
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- facility I – capacity of 250 million m$^3$, no compressors,
- facility II - capacity of 500 million m$^3$, compressors,
- facility III - capacity 30 million m$^3$, compressors,
- facility IV – capacity of 500 million m$^3$, facility placed in salt caverns.