Simulation And Practice Of The Gas Storage In Low Quality Gas Reservoir

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Background

Critical to the operation of gas storage reservoirs is the management of a cushion gas, i.e., a gas that compresses and expands as the working gas is injected or withdrawn but which is itself not produced. In the case of gas storages in depleted gas reservoirs, the cushion gas is most commonly the native gas left over after the reservoir was depleted. Usually, this gas has high methane content, but there are also reservoirs where the native gas has lower quality than the injected pipeline gas. The advantage of using a lower quality gas cushion is that it is much cheaper, and the operator will not have to buy expensive methane to use as a cushion. The cost of cushion gas is one of the biggest elements of capital cost in underground gas storage (UGS) projects. On the other hand, as the working gas is injected against the cushion gas, the mixing of the cushion gas and the storage gas occurs. Due to mixing, the reproduced gas may not meet the pipeline gas standards. Care must be taken for compromising the storage performance and quality of the produced gas. A cross-section schematic of an idealized gas storage reservoir developed in a depleted gas reservoir is shown in Fig. 1, where the working gas is methane from the pipeline and the cushion gas is lower quality native gas. In reality, there is no interface between the injected gas and native gas (Fig.2). In the operation of a gas storage project, the produced gas will be a mixture of injected and original gas. In order to optimize the use of cushion gas, the mixing process needs to be understood. Various mechanisms contribute to the mixing of the gases. The most important processes are molecular diffusion and hydrodynamic dispersion. As dispersion represents different mixing mechanisms including mixing due to geological heterogeneities of larger scale, the dispersion coefficients may be used as a measure of the mixing intensity. It is known that dispersion in porous media results from an interaction between convective spreading and diffusion. However, the nature and implications of these interactions are not well understood.

Aims

There is a number of papers reporting the investigations in the laboratory scale (Jha et.all, 2011) but limited number of works have been published for the full scale cases.
This paper deals primarily with the mathematical modelling and simulation of the mixing effects on example of Wierzchowice UGS in Poland.
The aim of the paper is to present the impact of gas mixing on UGS performance and to demonstrate how this phenomenon can be controlled by use of computer simulation. Another object of the work is to show that such type of UGS, if properly managed, may be efficient from both technical and economical point of view.

Methods

In order to characterise the various mixing processes in near-wellbore zone, miscible displacement model has been adopted. A miscible displacement process in porous medium can be described by the convection-dispersion equation. Assuming axial symmetry, in radial geometry the convection-dispersion equation reads:

$$\varphi\frac{\partial C}{\partial t}-\frac{1}{r}\frac{\partial}{\partial r}\left(r\cdot K\cdot\frac{\partial C}{\partial r}\right)-\frac{1}{r}\frac{\partial}{\partial r(r\cdot u\cdot C)} \qquad (1)$$

Longitual dispersion in porous medium may be modelled as:

$$K = D_M + \beta \cdot u \tag{2}$$

where β is a fundamental property of the medium called dispersivity, D_M is diffusion coefficient in porous medium, u is Darcy velocity (Jha et.al., 2011). If C is concentration of injected gas, the boundary conditions for equation (1) are:

$$C(r,0) = C(\infty,t) = C_0 \tag{3}$$

For the injection periods: $C(r_w,t) = C_1$ (4)

For the withdrawal periods $C(r_w, t)$ is unknown.

The approximate solution of the problem (1),(2),(3) was found by (Stopa, 1985, 1986). This solution has been adopted for determination of the individual dispersivities in near-wellbore zones by minimizing the squered difference between the measured and calculated concentration of native gas (represented by nitrogen) in produced gas.

Dispersivities were calculated for each consecutive storage cycle on the base of observed concentrations of native gas. For this reason, dispersivities optimised by using this approach, may not be considered as fundamental properties of the medium. For example, if gas is withdrawn from the zone saturated with the gas injected for the previous cycles, mixing effects may not be observed and consequently the calculated dispersivities will be smaller than these calculated in previous cycles. Later in this work, the calculated coefficients will be called “pseudo-dispersivities”. They may be used as a measure of quality of the working gas in individual near-wellbore zones. The method presented above was used for characterization and control of the mixing in near-wellbore zones associated with the wells, especially for the first cycles of storing. Simultaneously, the full-scale 3D compositional simulation model has been developed for optimising the reservoir performance.

Results

The results of modelling will be shown on example of Wierzchowice UGS in Poland (Stopa et.al. 2009). The main parameters of the Wierzchowice UGS are presented in Tables 1 and 2. This storage facility was developed in a depleted reservoir of natural gas containing 70% of methane and 29% of nitrogen. The reservoir has a surface area of 24 km^2 and average thickness of 44 m. Permeability ranges between 0.1 md and 250 md, average porosity is 13.4%. 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 m^3 of gas (about 65% of the original gas reserves of 12 bln sm^3) and 11142 m^3 of water. The reservoir pressure declined from the original 16.50 MPa to 5.65 MPa. The field primary recovery mechanism was volumetric expansion. After 1995 the low quality gas reservoir Wierzchowice has been converted into an underground gas storage of a high quality pipeline gas containing less than 3% of nitrogen. This operation caused the mixing of gases and therefore the variable composition of gas extracted from the storage. This caused a necessity of controlling the injection and withdrawal operations to meet the pipeline standards of the withdrawn gas. Both mathematical modelling and reservoir simulation technique have been using to optimize the UGS performance and to control the composition of the produced gas.

For over 16 years, the operating wells have been analysing at the end of each of 16 storage cycles for the pseudo-dispersivities. The wells present different behaviours depending on local properties of reservoir, construction of the wells and usage rate. In majority of wells, pseudo-dispersivities decreased in time as presented in Fig.3. This resulted from forming of the stable near-wellbore zones saturated with the injected gas. Other wells showed a different behavior arising from the location in zones with greater reservoir heterogeneity or from a more intensive operation as may be observed in Fig.4 for the well WMA1. It can be also deduced that horizontal wells (well WMB-6H in Fig.4) are more effective for the formation of working volume than vertical wells. The calibrated models of the near-wellbore zones were used for fast forecasts and screening for optimal strategy of well controls and for rough calibration of the numerical model, specifically for designing of the locally refined grids. The results of modelling for two selected wells are presented in Fig. 5 to Fig.8.

Parallel with analytical modelling, the full-scale 3D compositional simulation model was developed by use of Eclipse300 commercial simulator. The following components were employed to simulate the gas phase: N2, C1, C2+. 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, was perfectly verified because the gas compositions during withdrawal as well as injection periods were precisely monitored by chromatography for all individual wells and during every cycle. An example of model calibration for the selected wells are shown in Fig.9 and Fig.10.

The simulation model was used for optimization of the gas injection strategy at the early stage of the UGS operation. The objective of this strategy was to create the stable zone of the high quality gas (Fig.11). The simulations were also used for evaluation of the various scenarios of managing the UGS and their impact on allowable working volume (Fig.12) and composition of the gas produced from UGS (Fig.13). 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 first model (1995) was used for designing the strategy of gas injection to create the working gas volume. Each year, the model is actualized and used to create and maintain the stable zone of the high methane working gas and to optimize increasing the storage capacity. Another application of the model is to find the working rules including optimal strategies for gas injection and withdrawal.

Summary/Conclusions

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 low quality gas field. This results in lowered capital costs and improved economic-financial indices of UGS. There also exists a technical risk related with quality of the produced gas. This risk can be minimized by use of the computer simulation to manage the UGS. In the presented case, first simulation model (1995) was used for designing the strategy of gas injection to create the stable working gas zone. In the successive years, the model has been updated and is still using to optimize the working capacity and to find the operational rules including optimal strategies for gas injection and withdrawal.

References

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Tables

Table 1. Average gas composition (source: Stopa et.al.,2009)

Component	**Mole fraction** **Native gas**	**Mole fraction** **Injected gas**
N2	0.2957	0.01-0.03
C1	0.6938	0.96-0.985
C2+	0.0105	0.005-0.006

Table 2. Main parameters of the Wierzchowice UGS (source: Stopa et.al.,2009)

	2010	**Expected in 2012,**	**Expected, II stage**
Working capacity [mln sm^3]	575	1200	3500
Max. withdrawal rate, [mln sm^3/d]	4.8	14,40	do 50
Max. Injection rate [mln sm^3/d]	3.6	9,60	30
No. of operational wells	21	10 vertical + 12 horizontal	28 horizontal

Figures

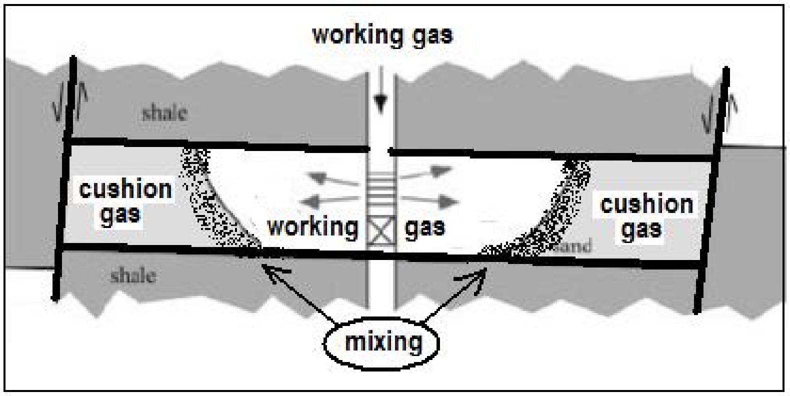

Fig.1. Idealized single-well natural gas storage schematic showing working gas and cushion gas (adopted from Oldenburg, 2003).

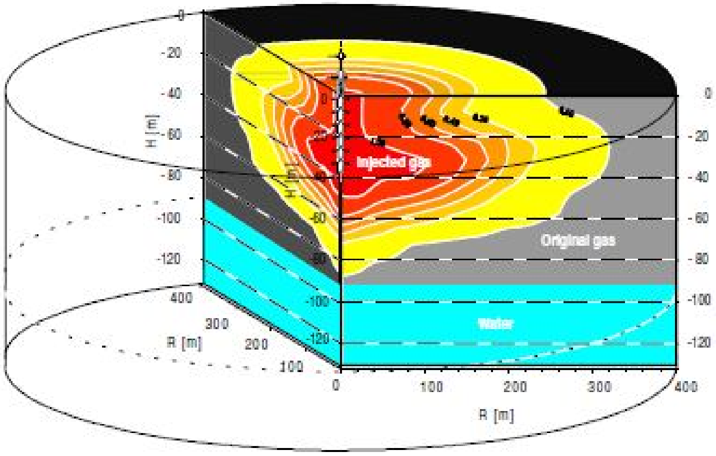

Fig.2. Schematic of the mixing in near-wellbore zone, (Szott, 2000)

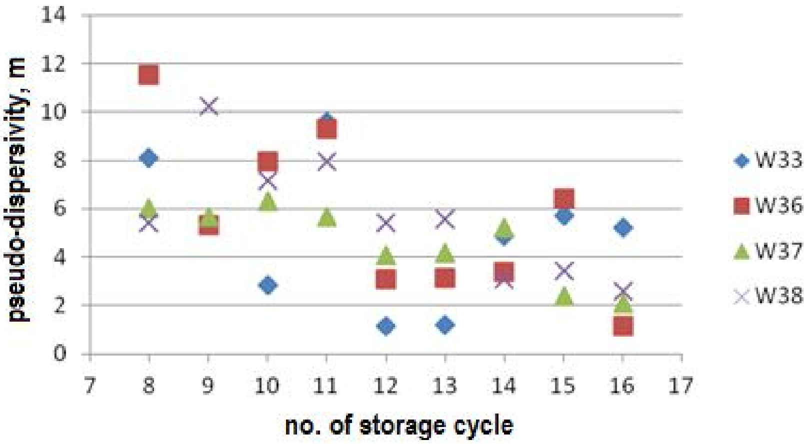

Fig.3. Changes of the pseudo-dispersivities of selected wells for the consecutive storage cycles

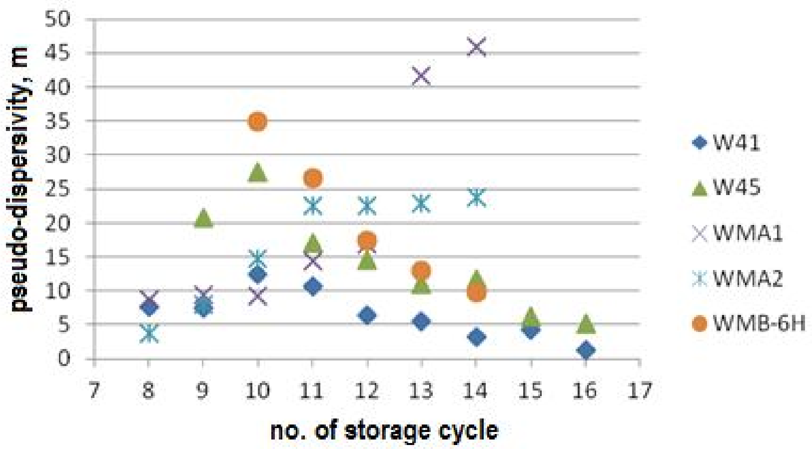

Fig.4. Changes of the pseudo-dispersivities of selected wells for the consecutive storage cycles.

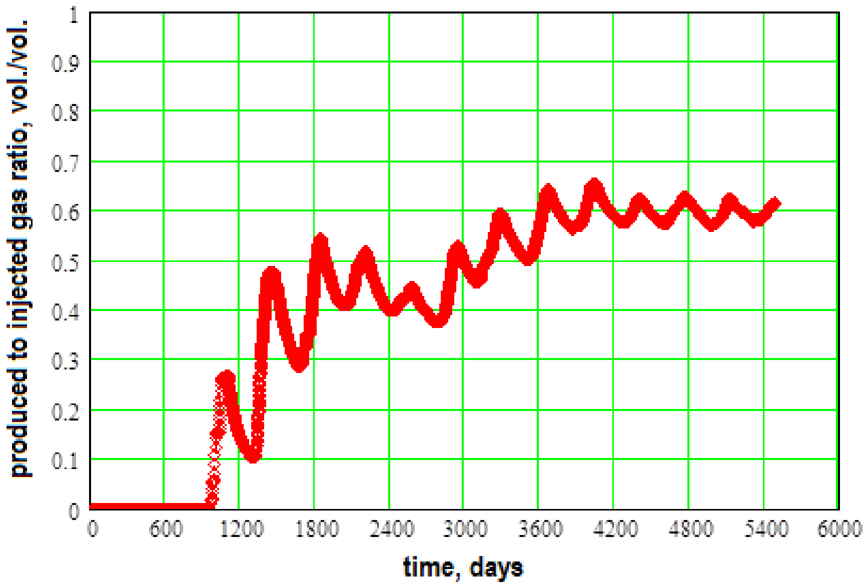

Fig.5. Ratio of the produced to injected gas vs. time for the selected vertical well.

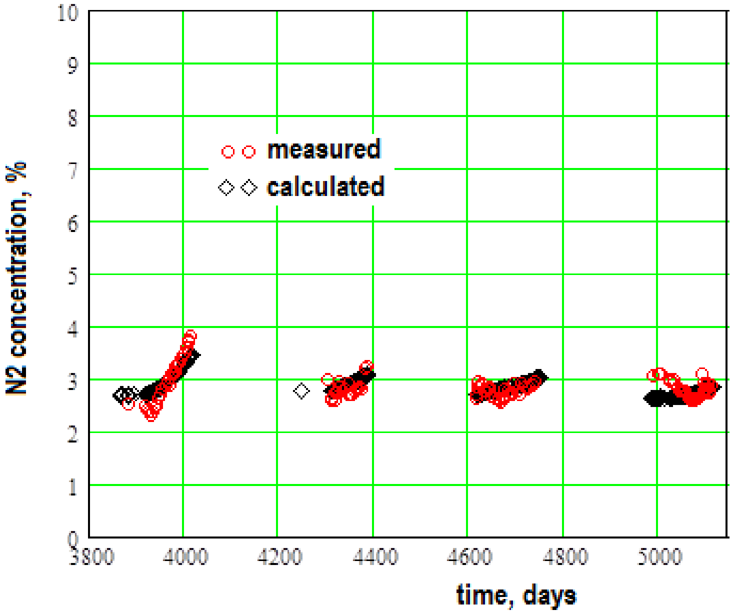

Fig.6. Comparizon of the calculated and measured concentration of N2 in produced gas for the selected vertical well, analytical modelling.

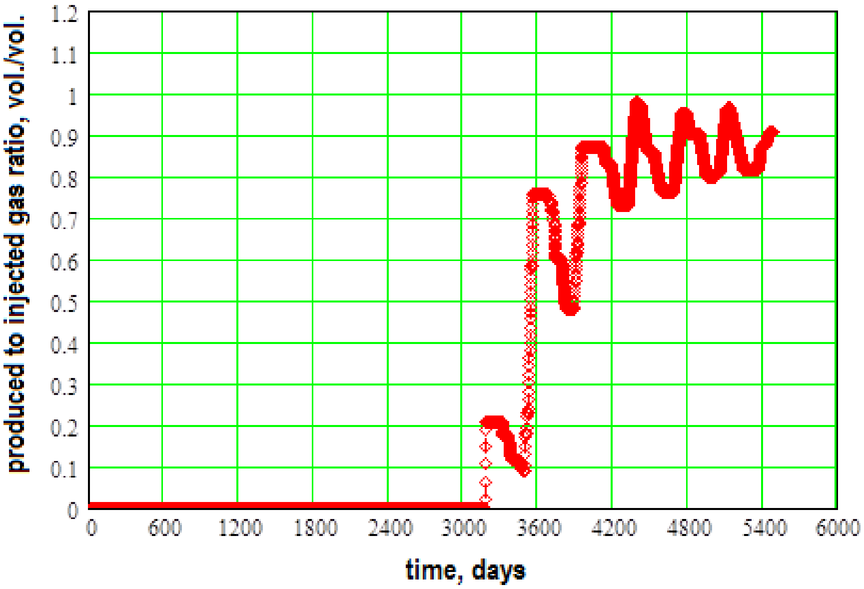

Fig.7. Ratio of the produced to injected gas vs. time for the selected horizontal well.

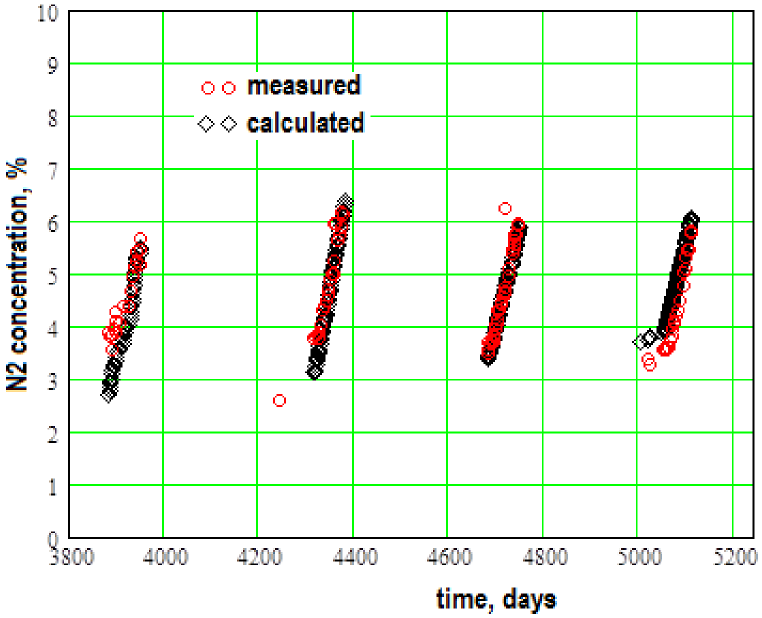

Fig.8. Comparison of the calculated and measured concentration of N2 in produced gas for the selected horizontal well.

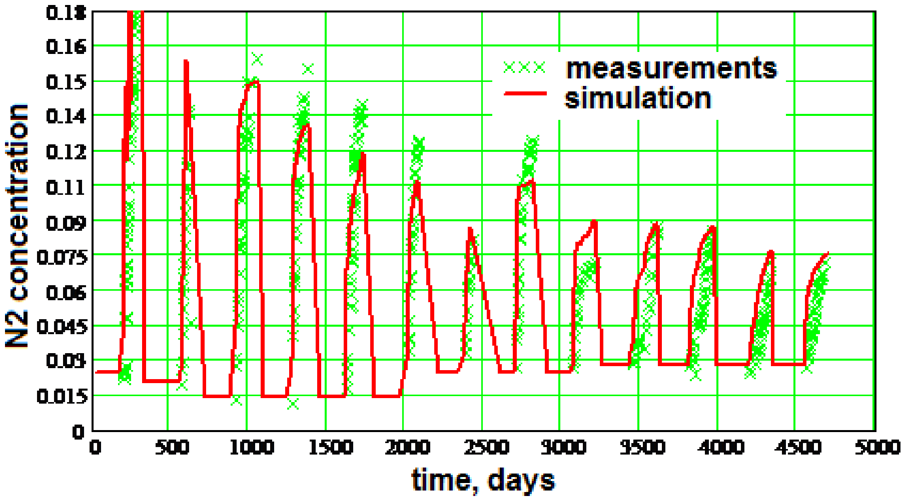

Fig.9. Comparison of the simulation results (solid line) and measurements for a selected old well, nitrogen content vs. time for 13 withdrawal cycles, (Stopa et al. 2009).

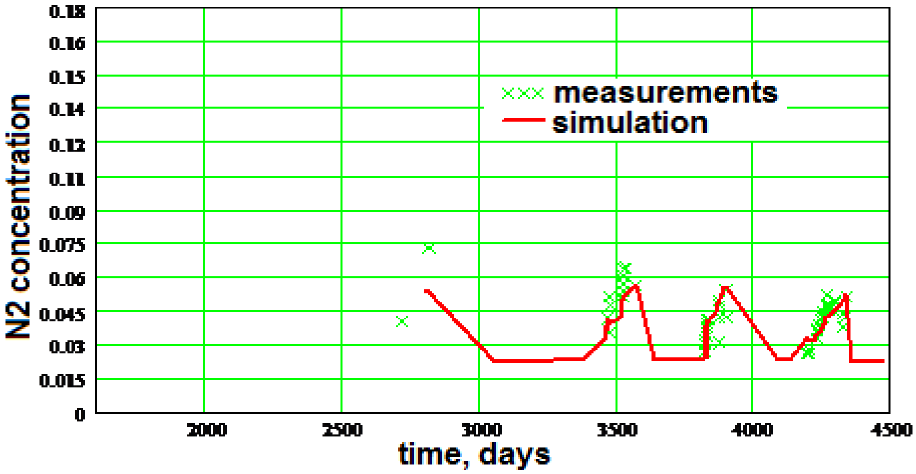

Fig.10. Comparison of the simulation results (solid line) and measurements for a selected new well, nitrogen content vs. time, (Stopa et al. 2009)..

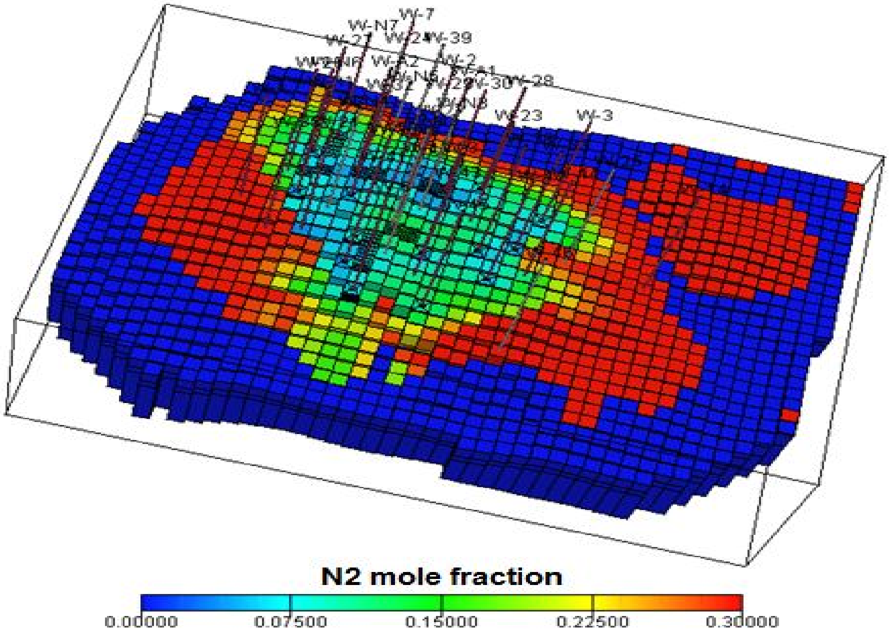

Fig.11. Visualization of the nitrogen content in the reservoir gas.

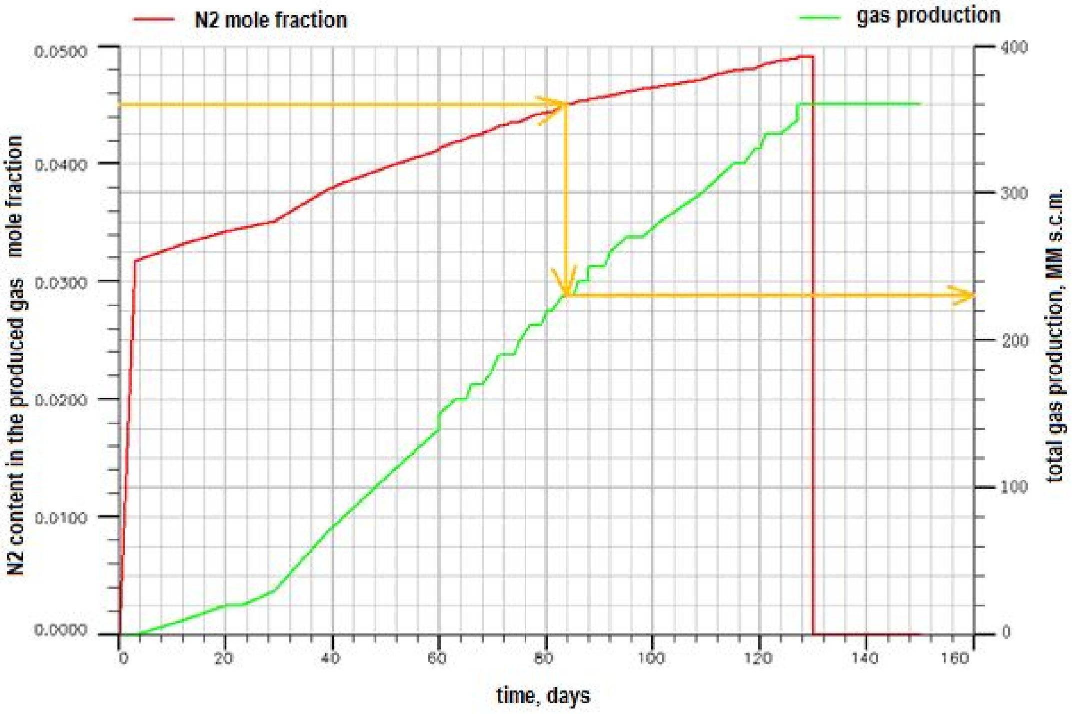

Fig.12. Application of the model for determining the working gas volume for theoretical scenario of the production cycle. The result is depended on withdrawal scheme.

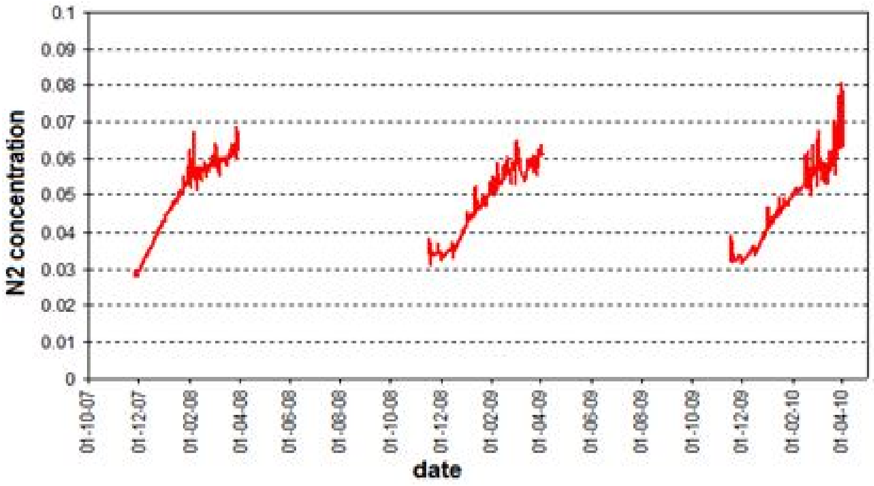

Fig.13. Simulated nitrogen concentration (mole fraction) in gas produced from storage for 3 withdrawal cycles