KUALA LUMPUR 2012 WORLD GAS CONFERENCE

25th world gas conference

"Gas: Sustaining Future Global Growth"

SIMULATION AND PRACTICE OF THE GAS STORAGE IN LOW QUALITY GAS RESERVOIR

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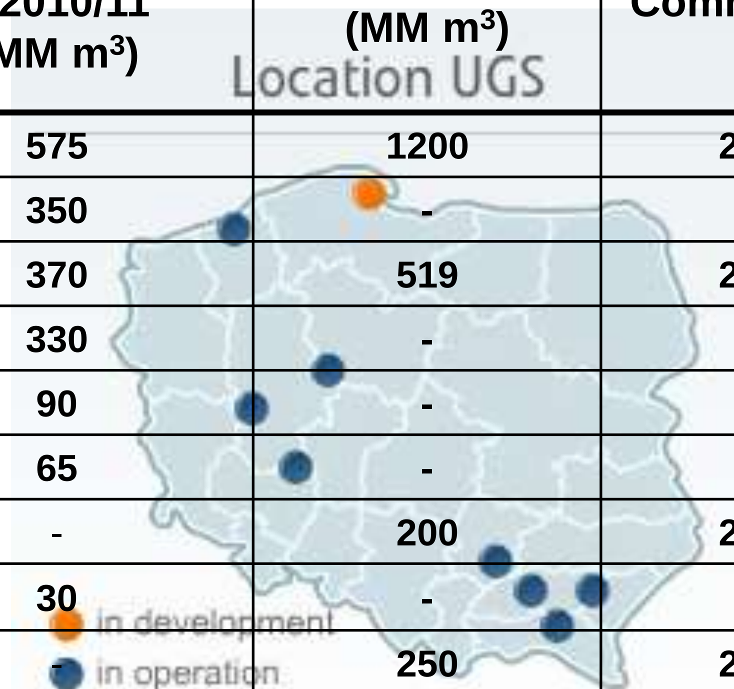
Introduction

- Poland as gas transition country
  - more than 9800 km of pipelines
- Poland as gas producer
  - Conventional gas: 164.3 Bcm
  - Tight gas
  - CBM
- Shale gas revolution in Poland
  - Possible reserves: 5.3 Tcm
  - Still at preliminary stage
- Gas storage system
  - 8 UGS
  - Total capacity: 2.5 Bcm

Bcm=10^9 m^3, Tcm=10^{12} m^3

Gas storage system in Poland

UGS	Working volume 2010/11 (MM m^3)	Under development (MM m^3)	Commitment	Potential working volume (MM m^3)
Wierzchowice	575	1200	2012	3500
Husów	350	-	-	500
Mogilno	370	519	2015	800
Strachocina	330	-	-	1200
Swarzów	90	-	-	90
Brzeźnica	65	-	-	100
Bonikowo	-	200	2010	200
Daszewo	30	-	-	60
Kosakowo	-	250	2020	250
TOTAL	1630	2499		6710



Technical performance of the Wierzchowice UGS

- One of the most important gas storage facilities in Poland
- Developed in a depleted reservoir of natural gas containing 70% of methane and 29% of nitrogen
- 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.

	Present state	Expected in 2012, I stage	Expected II stage
Working capacity [bln sm^3]	**0.575**	**1.2**	**3.5**
Max. withdrawal rate, [mln sm^3/d]	**4.8**	**14,40**	**50**
Max. Injection rate [mln sm^3/d]	**3.6**	**9,60**	**30**
No. of operational wells	**21**	**10 vertical + 12 horizontal**	**28 horizontal**

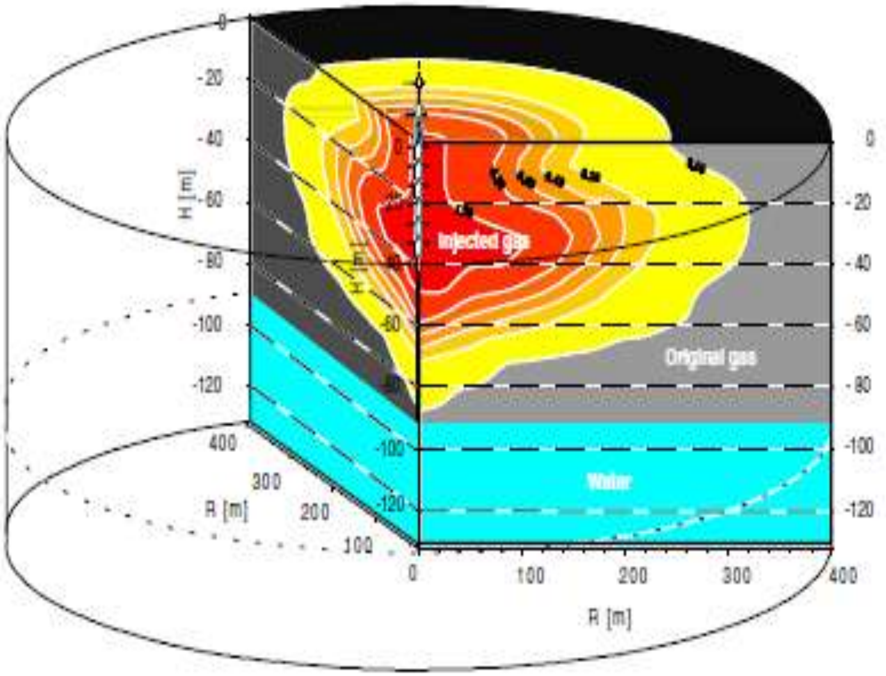
Gas composition problem

After 1995 the low quality gas reservoir Wierzchowice has been converted into an underground gas storage of a high quality 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. The reservoir simulation technique has been used to optimize the UGS performance and to control the composition of the produced gas.

Component	**Mole fraction Original gas**	**Mole fraction Injected gas**
N2	**0.29**	**0.01-0.03**
C1	0.70	0.96-0.985
C2+	0.01	0.005-0.006

Gas mixing

- The produced gas will be a mixture of injected and original gas.
- Reproduced gas may not meet the pipeline gas standards.
- Care must be taken for compromising the storage performance and quality of the produced gas.
- In order to optimize the use of cushion gas, the mixing process needs to be understood.



Mathematical modelling 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

Mathematical modelling of the gas mixing

Dispersion is cumulative effect of: molecular diffusion, heterogeneity of the porous media, turbulence of flow, viscous fingering, adsorption/desorption, stagnant fraction of pore space, presence of immobile fluid etc

$$J_i = \vec{u} \cdot C_i + K \cdot \nabla C_i \qquad i = 1,2,3 \ldots n$$

$$K = D_M + \beta \cdot u$$

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

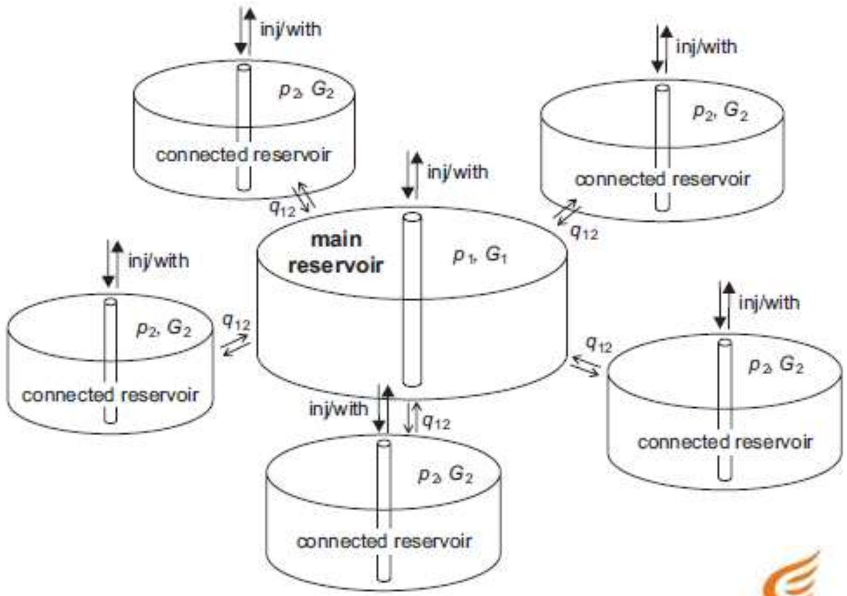
Initial condition: *C(r,0) = C(,inf, t) = 0*

For injection periods: *C(rw , t) = 1*

Approximate solution for composition of the reproduced gas

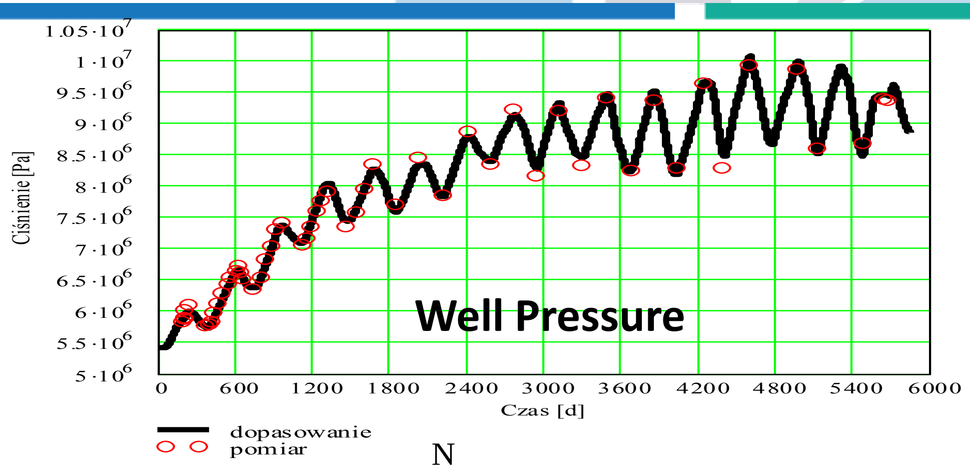
$$C = C_{N2} \cdot \left(1 - \frac{1}{2} \operatorname{erfc} \left(\frac{r^2 - r_f(t)^2}{2 \cdot \sqrt{\frac{4}{\phi} \cdot \left(\int_0^t D_M \cdot r_f^{\,2}(t) \cdot dz + \int_0^t \beta \cdot u(z) \cdot r_f^{\,2}(t) \cdot dz \right)}} \right) \right)$$

$$r_f(t) = \sqrt{\frac{\frac{p_n \cdot z \cdot T}{p \cdot T_n} \cdot \int_0^t q_t(\tau) \cdot d\tau}{\pi \cdot h \cdot \phi \cdot (1 - Sw)}}$$

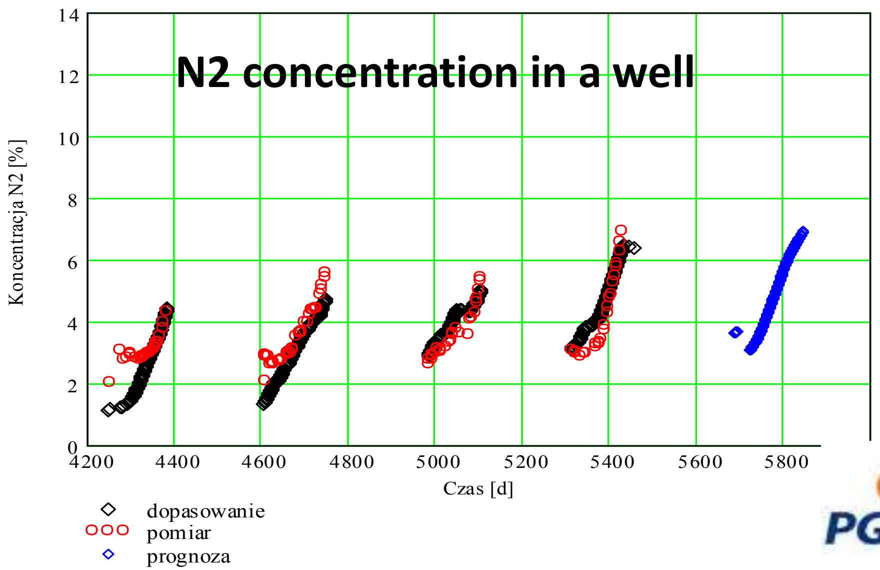


Model calibration – 16 years

Well	Diffusivity, [m²/s]	Dispersivity, [m]
W2	$2.61\ 10^{-6}$	**9.58**
W3	$8.84\ 10^{-6}$	**5.42**
W4	$8.53\ 10^{-7}$	**1.88**
W6	$1.88\ 10^{-6}$	**2.23**
W27	$7.11\ 10^{-7}$	**4.28**
W28	$1.34\ 10^{-6}$	**7.13**
W30	$2.29\ 10^{-6}$	**19.46**
W31	$8.48\ 10^{-7}$	**4.47**
W32	$1.72\ 10^{-7}$	**8.99**
W38	$5.63\ 10^{-7}$	**3.45**
W41	$3.17\ 10^{-7}$	**4.37**
W44	$4.29\ 10^{-7}$	**0.99**
W45	$3.40\ 10^{-6}$	**6.30**

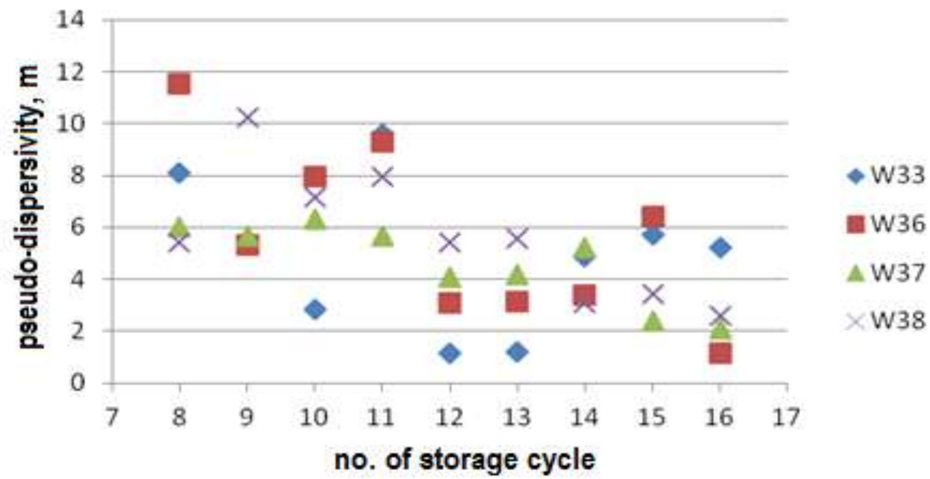


$$F(D_M,\beta)=\sum_{i=1}^{N}\left(C(t_i,D_M,\beta)-C_{oi}\right)^2$$

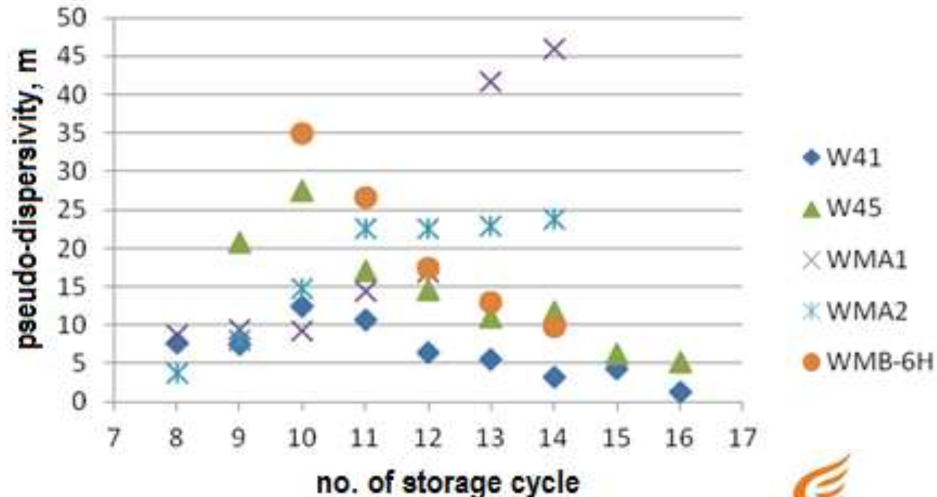


Changes of the pseudo-dispersivities of selected wells for the consecutive storage cycles

- Limited mixing
- Stable near-wellbore zones saturated with the injected gas

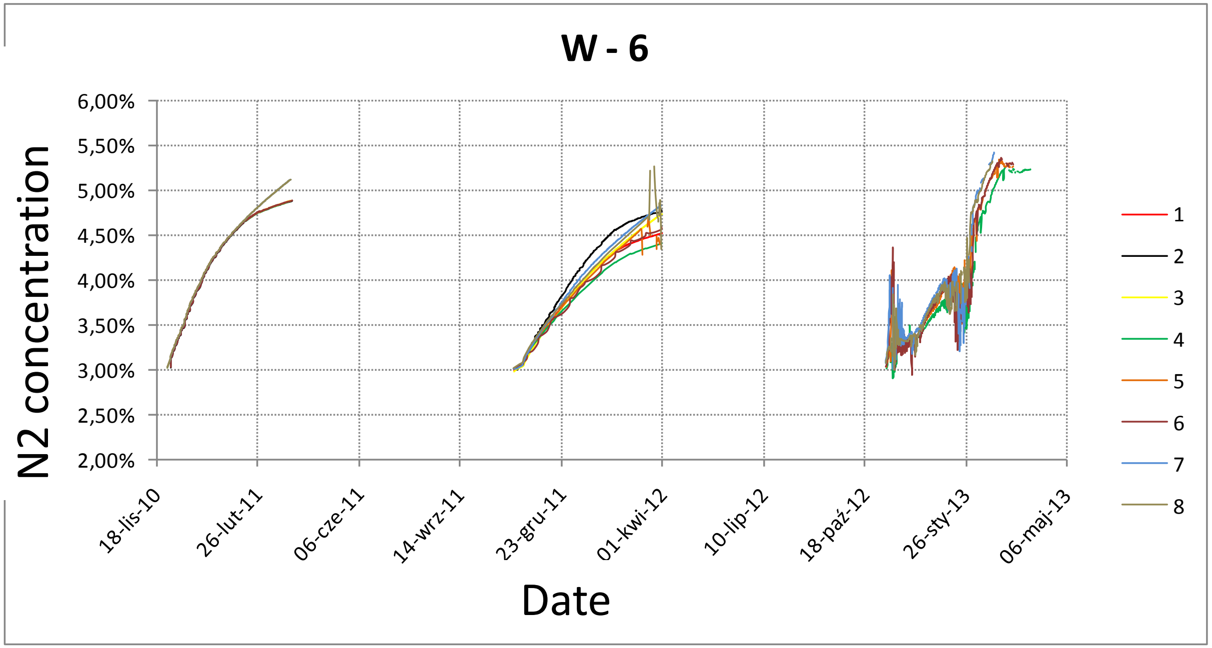


- Intensive mixing behaviour arising from
    - location in zones with greater reservoir heterogeneity
    - more intensive operation
- Horizontal wells are more effective for the formation of working volume than vertical wells



Applications of the model:

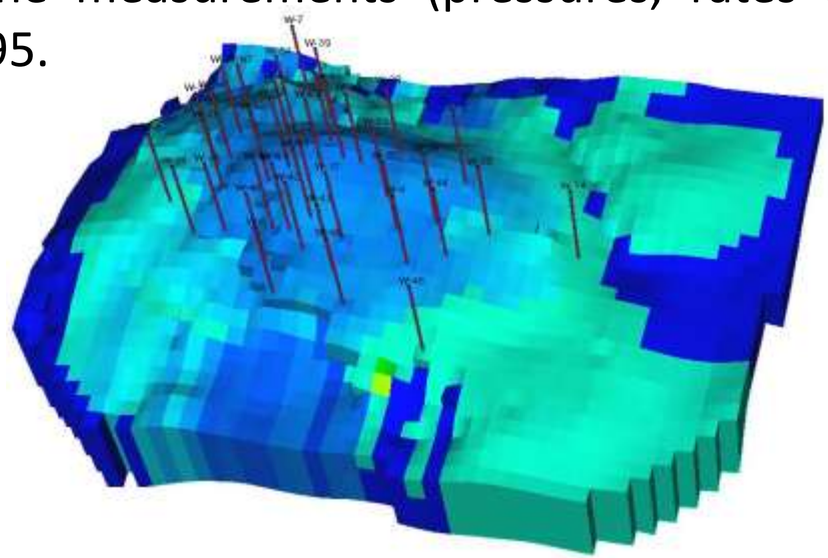
- Fast forecasts and screening for optimal strategy of well controls
- Rough calibration of the numerical model – designing of the LGR-s



Simulated N2 concentration in produced gas for different scenarios

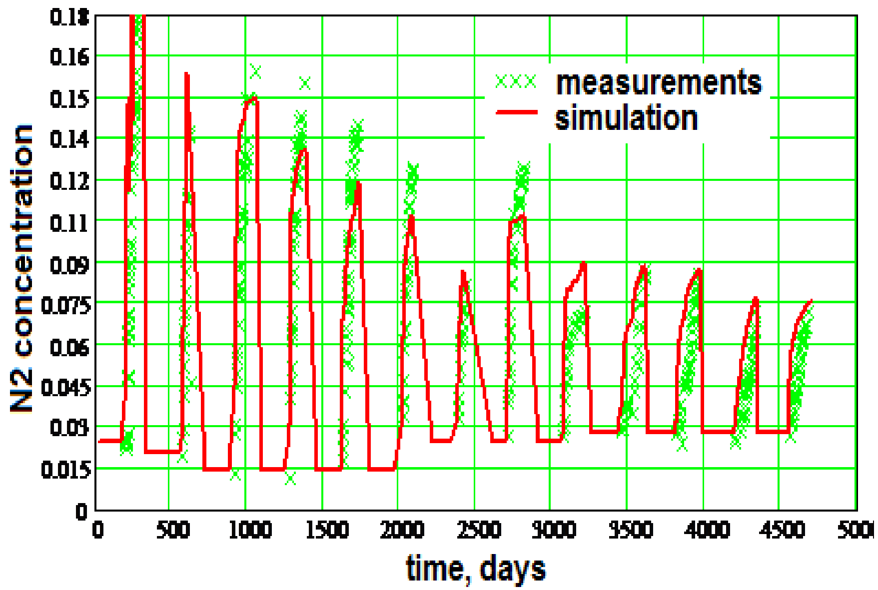
Numerical simulation using ECLIPSE

- Full-scale 3D compositional simulation model was developed by use of Eclipse300 commercial simulator.
- Components used to simulate the gas phase: N_2, C_1, C_{2+}.
- 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.

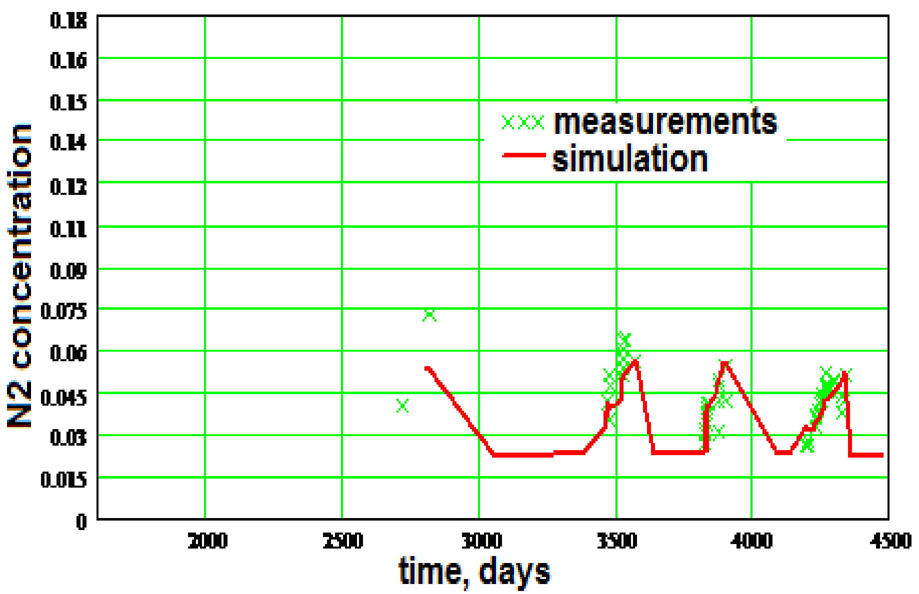


Model calibration

The simulation model 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.



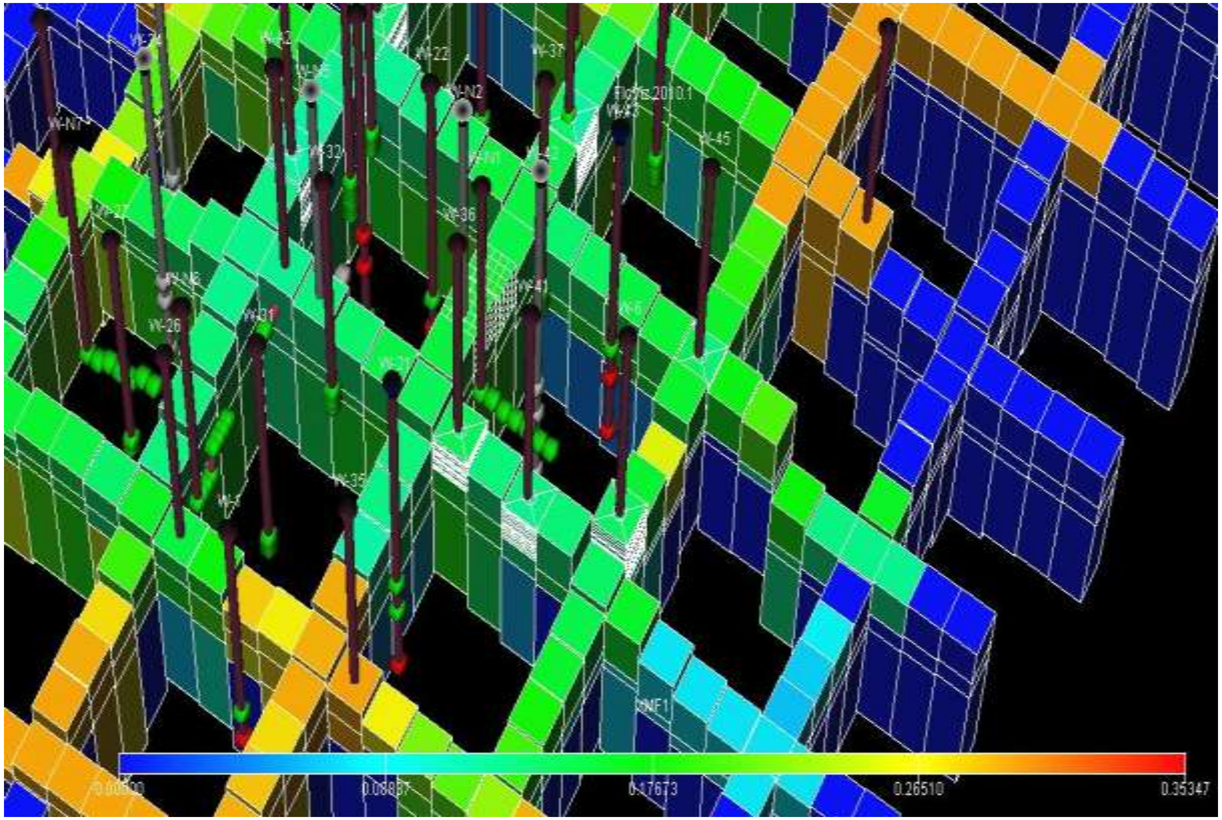
„Old” well



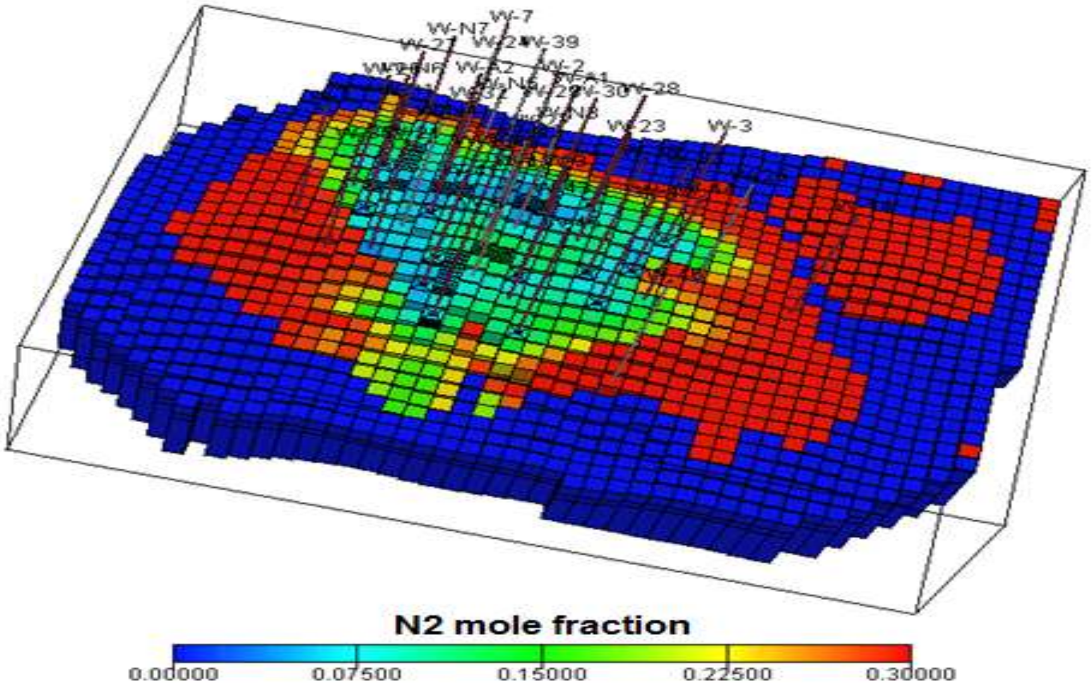
„New” well

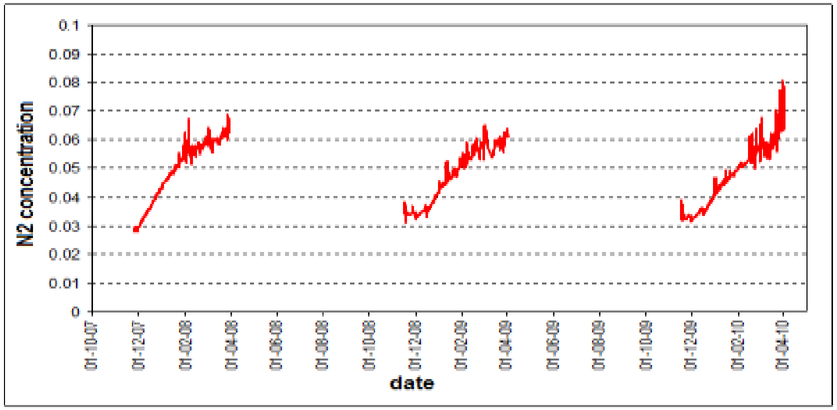
Intelligent control of gas composition

```
UDQ
DEFINE FN2W MAX(WZMF_1 'W*') /
--
/

ACTIONX

ACT1  1000 0 /
FZMF_1 '>=' 0.05 AND /
WZMF_1 '*' = FN2W /
/

WELOPEN
'?' 'SHUT' /
/

ENDACTIO
```



Visualization of the nitrogen content in the reservoir gas

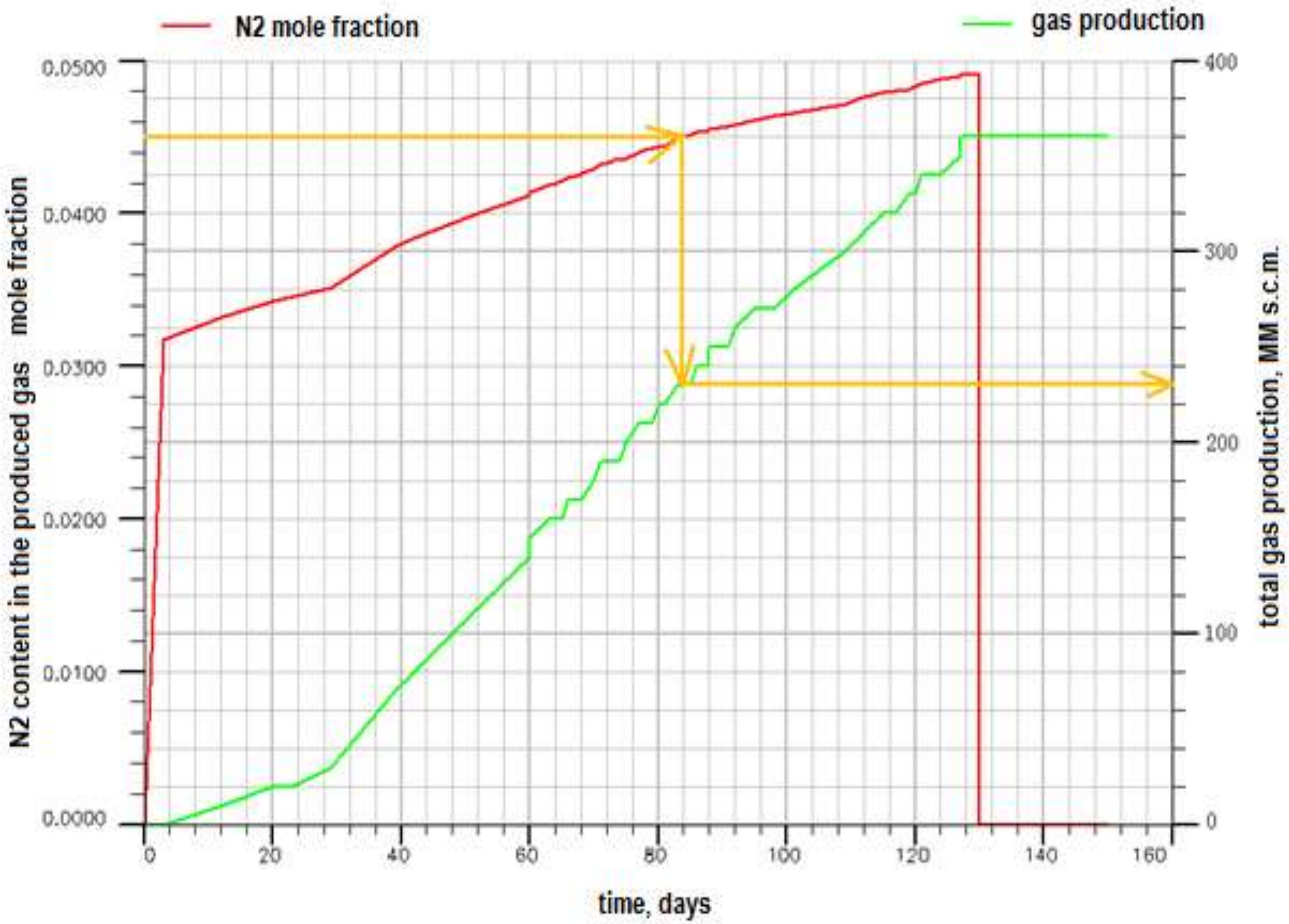




Application of the simulation model

- First model (1995) used for designing the strategy of gas injection to create the working gas zone
- Each year, the model is actualized and used:
  - To create and maintain the stable zone of the high methane working gas
  - To design increasing the working capacity
  - To evaluate various scenarios of managing the UGS and their impact on allowable working volume and composition of the gas produced from UGS
  - To find the UGS working rules including optimal strategies for gas injection and withdrawal

Application of the model – determining the working gas volume depending on withdrawal scheme



Conclusions

- 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.
- 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
- Technical risk related with quality of the produced gas can be minimized by use of the computer simulation to manage the UGS.
- The case study of the Wierzchowice UGS, (developed in the depleted low quality gas reservoir), shows that such type of UGS, if properly managed, may be efficient from both technical and economical point of view.