EAGE

21133

Optimization of underground gas storages exploitation as result of time-lapse gravity measurements and 4d interpretation – case study of Dashava UGS

O. Petrovskyy[1], T. Petrovska[2], A. Trachuk[3]*, R. Bojko[4]

[1] STC "DEPROIL", [2] STC "DEPROIL", [3] STC "DEPROIL", [4] Underground gas storage department of Ukrtransgaz

Summary

Ukraine has 30 bcm active capacity in 12 underground gas storages (USG). The safe and effective performance of UGS may be base on the understanding of the changes in the properties of the storage reservoirs. Dynamic 4D models of the density of rocks, volume, and gas pressure in place for multilayer reservoirs on the base of time-lapse gravity measurements and interpretation workflow discussed and summarized. For creating of 4D model of rock density changing proposed to use 4D inversion of time-lapse gravity data. Prediction of the location of dynamic reservoirs that takes the most of the working and cushion gas on the different stages of exploitation (injection - withdraw) proposed. Relations between the changing of the rock density and changing of the volume and pressure of gas were established. Calibration of 4D models of volume and gas pressure to the industrial parameters of USG allowed to estimate the volume of working gas and determine stagnant zones and gas migration pathways. New workflow for the building of 4D models of volume and gas pressure in gas reservoirs on the base of time-lapse gravity measurements and 4D gravity inversion proposed for optimization of exploitation of UGS.

21133

Optimization of underground gas storages exploitation as result of time-lapse gravity measurements and 4d interpretation – case study of Dashava UGS

O. Petrovskyy *(STC "DEPROIL")*, **T. Petrovska** *(STC "DEPROIL")*, ***A. Trachuk** *(STC "DEPROIL")*, **R. Bojko** *(Underground gas storage department of Ukrtransgaz)*

SUMMARY

Ukraine has 30 bcm active capacity in 12 underground gas storages (USG). The safe and effective performance of UGS may be base on the understanding of the changes in the properties of the storage reservoirs. Dynamic 4D models of the density of rocks, volume, and gas pressure in place for multilayer reservoirs on the base of time-lapse gravity measurements and interpretation workflow discussed and summarized. For creating of 4D model of rock density changing proposed to use 4D inversion of time-lapse gravity data. Prediction of the location of dynamic reservoirs that takes the most of the working and cushion gas on the different stages of exploitation (injection - withdraw) proposed. Relations between the changing of the rock density and changing of the volume and pressure of gas were established. Calibration of 4D models of volume and gas pressure to the industrial parameters of USG allowed to estimate the volume of working gas and determine stagnant zones and gas migration pathways. New workflow for the building of 4D models of volume and gas pressure in gas reservoirs on the base of time-lapse gravity measurements and 4D gravity inversion proposed for optimization of exploitation of UGS.

Introduction

Time-lapse geophysics is becoming an increasingly important and powerful method to measure, monitor, verify, and predict complex time-varying processes in the earth. An application includes resource management (hydrocarbons, groundwater, geothermal…), geohazard risk assessment (natural and induced seismicity, overpressure zones…), environmental issues (CO2 sequestration, groundwater contamination, and remediation…), and fundamental science questions (subsurface flow of fluids, stress and heat, time-variant rock properties, fault dynamics and fracturing, geophysical source mechanisms, near-surface variations in vadose and permafrost zones…) (Lumely et al., 2015).

Time-lapse UGS monitoring is usually performed in inspection wells and rare via 4D seismic survey and incorporates 3D models of porosity and permeability, pressure, and volume of gas by dynamic modeling. However, take into account the high cost of 4D seismic survey often these data unavailable and well data are too sparse to build an adequate 3D reservoir model. That was the case for the Dashava UGS, located in the Carpathian region of Ukraine. Time-lapse gravity was executed. 4D model of formation pressure was built. Working and cushion gas volume were estimated. Working gas migration pathways were mapped. A relative misfit of gas pressure prediction in the 4D model was 3.7 % for empty UGS and 3.5 % for full UGS. A relative misfit of working gas volume prediction was 1.0 %.

Physical precondition and method of time-lapse gravity for underground gas storage study.

The exploitation of underground gas storage related to cyclic gas volume changing in the reservoir – Injection and withdrawing of the gas. It is why pressure and volume of the gas in place changed depending on the exploitation regime. Gravity is the geophysical method that is sensitive to mass changing. Gas drive exploitation regime characterized by pressure increasing with gas injection to UGS. Pressure increasing causes increasing in gas density in place. Gas density increasing causes increasing in rock density. Rock density increasing caused increasing in gravity on the earth`s surface (Figure 1), which can be measured by modern high precise gravimeters. For UGS that exploited in the water drive regime mass changing will also take place, but gravity change will have an inverse character because replacement of gas by formation water will induce opposite density anomaly.

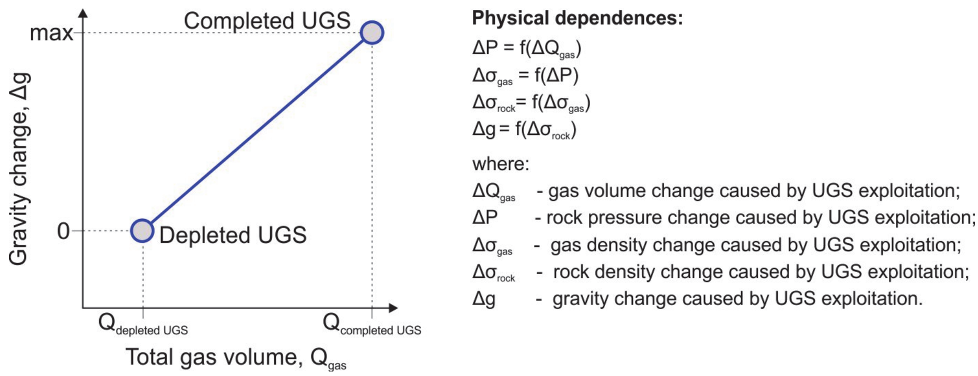


Figure 1 *Dependence between volume of gas in UGS and gravity anomaly associated with this changing*

Practical usage of time lapse gravity in UGS exploitation.

Time-lapse UGS monitoring is usually performed in inspection wells and via 4D seismic survey and incorporates 3D models of porosity and permeability, formation pressure, and volume of gas by dynamic modeling. Unfortunately, 4D seismic is rarely available and well data are too sparse to build an adequate reservoir model. The aim of exploration is UGS exploitation efficiency to increase with using of time-lapse gravity measurements and creation of 4D properties models of UGS. Based on obtained 4D model formation pressure within inner-well space need to be predicted as well as working gas migration pathways need to be determined. That was the case for the Dashava UGS, located in the Carpathian region of Ukraine. UGS was created in 1972 and comprises of 6 depleted gas pools within 8 and 9 lower Dashavian horizons of the Neogene in Dashava gas field. All gas pools are the parts of one hydrodynamic unit. Dashava UGS is the third-largest in Ukraine. UGS has the next industrial parameters: total gas volume – 5 339 Mcm, working gas volume – 2 150 Mcm. maximal formation pressure – 5.75 MPa, minimal formation pressure – 1.93 MPa, the gas-drive regime and operated by the 100 storage wells. 27 injection/withdrawal cycles resulted here one-third increase of cushion gas volume in the reservoir.

An annual cyclic process of UGS exploitation includes four periods: -gas injection, -gas withdrawing, and two neutral periods between them. Each period is characterized by special conditions of reservoirs.

Four seasons of time-lapse high precision gravity measurements were taken for two years. Two series were taken at empty UGS and two series were taken at full UGS (Figure 2). Twofold gravity measures were provided on stations. The average standard deviation of gravity measurements was 4,3 μGal. A gravity change map that was related to gas injection was built. For map building, all gravity measurements were divided into three classes (Figure 3). Class I - gravity field was changed proportionally with storage pressure change; Class II - gravity field was changed inversely proportionally with storage pressure change; Class III - gravity field wasn`t changed after gas withdrawal/injection.

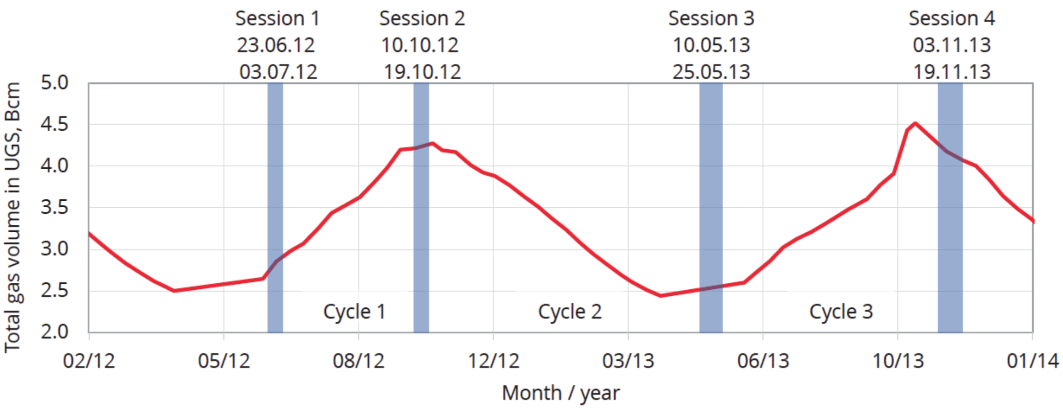
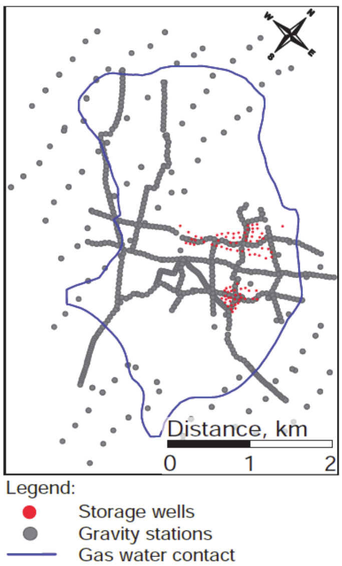
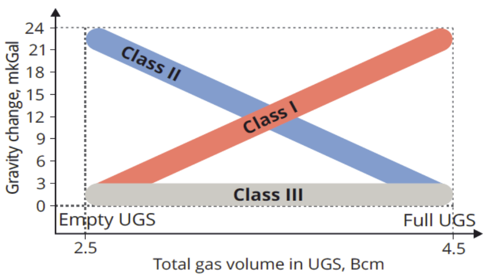


Figure 2 *Gas volume changing at the period of time-lapse gravity session*





Cycle	Activity	Year	Different classes gravity station ratio		
			I	II	III
1	Injection	2012	32.3%	37.7%	30.0%
2	Withdrawing	2012-2013	52.8%	22.3%	24.9%
3	Injection	2013	55.2%	20.9%	23.9%
Quantity of I and II class gravity station			60.2%	39.8%	

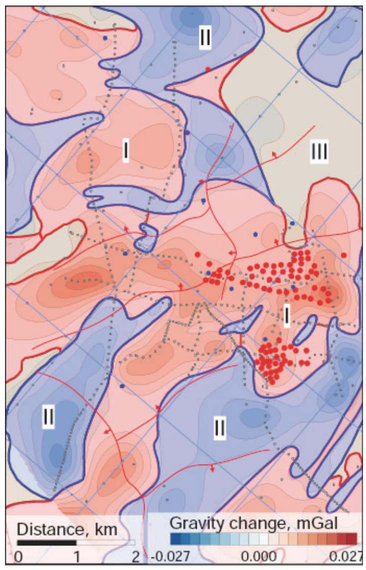


Figure 3 *Location (left), classification (centre) of stations with time-lapse gravity measurements and gravity anomaly map for injection of gas (right). Classification of gravity stations based on the dependence between UGS gas volume and gravity change*

The 3D model of Dashava UGS was created at the next stages. A structural framework of the 3D model was built using the results of 2D and 3D seismic data. Well logging and gas pressure measured in wells were used to define an initial 3D density model in withdrawal condition of Dashava UGS as of 2012.

The 3D density model consists of 29.8 million cells (cell dimensions 100 x 100 x 1 m). Planar 3D model dimensions are 8 x 12 km. The depth interval of the 3D model is from 0 to 790 meters. The standard deviation between observed and calculated gravity fields for the initial 3D density model was 5.5 μGal. The 3D density model was refined by a joint full-depth inversion of gravity and well data on a period when UGS was injected of gas in 2013. The standard deviation for the final UGS 3D density model was 3.6 μGal (Figure 4). The final 3D model of density difference was transferred to a 3D gas pressure difference model using dependencies between gas pressure change which was measured in wells and reservoir density change in the final 3D model of density difference. A 4D model of cushion and working gas distribution was calculated based on the final 4D gas pressure model. The relative misfit between gas pressure in wells and predicted in the 4D model was 3.7 % for withdrawn UGS and 3.5 % for the injected UGS. The relative misfit between the real volume of injected working gas and predicted in the 4D model was 1.0 %.

Results of time-lapse gravity measurements confirmed the presence of gravity anomalies with amplitude ±12-24 μGal which are related to gas volume change in UGS. Direct dependency between gas volume of injected gas and gravity anomaly observed on 60 % of measured stations (Figure 3, Class I – red colour). Inverse dependency observed on 40 % of stations (Figure 3, Class II – blue colour). Created 4D rock density, gas pressure, and gas volume models allowed to map the location of dynamic reservoirs that take the most of the injected gas on the different stages of exploitation (injection - withdraw) and where cushion gas is accumulated. Also, these 4D models allowed to calculate gas volume within dynamic reservoirs, to map working gas migration pathways from storage wells to dynamic reservoirs (Figure 4). Blocking pathways of gas migration to distant dynamic reservoirs was recommended to cushion gas accumulation congestion.

Optimization management of UGS exploitation on the base of the time-lapse gravity measurements

Following the theoretical justification and practical experience for Dashava UGS for optimization of management of UGS exploitation proposed the next time-lapse gravity measurement and interpretation workflow:

- Acquisitions: not less than four sessions of high precision time-lapse gravity survey on the injection and withdraw stages of UGS exploitation; using modern high precision equipment and survey parameters to ensure required accuracy and acquisition time less than a neutral period in UGS.
- Processing: application of all necessary gravity correction to each time-lapse session; classification of all gravity stations regarding the relation between gravity anomalies and the volume of gas in UGS (physical model); dividing of the area of UGS on the closed regions according to the classification of gravity stations; a building of the gravity anomaly difference map.
- Initial 3D density model: build using all available and approved geological, geophysical, and industrial data about the UGS area; calculation of gravity field from an initial 3D model with further adding of measured gravity difference; the resulted gravity field should be used for further inversion.
- Inversion: 3D+1D gravity inversion with active well data usage; constraints on the density of rocks in 3D model calculated on the base of UGS gas reservoirs properties.
- Rock density and formation pressure relation: determination of the relation between rock density difference and formation pressure difference using the final 3D rock density difference model and formation pressure measurement in wells; conversation of final 3D rock density difference model to 3D formation pressure difference model.
- 4D formation pressure model: creating of an initial approximation of 3D formation pressure models on different stages of UGS exploitation using measurements in wells and 3D model of formation pressure change (the result of time-lapse gravity inversion); total gas volume calculation based on initial approximation of 3D models of formation pressure.
- Calibration: determination of gas saturated space within 3D model which is equal to UGS project value; comparison of total and cushion gas volume with UGS balance volumes; determination of working gas space in 3D model where working gas cyclic movement occurred; calibration of initial approximation of 3D formation pressure models by using of regression for uniform distribution of

cushion gas following UGS balance.

- Interpretation: determination of the spatial location of dynamic reservoirs; calculation of working and cushion gas volume within dynamic reservoirs; prediction of working gas pathways from dynamic reservoirs to storage wells.

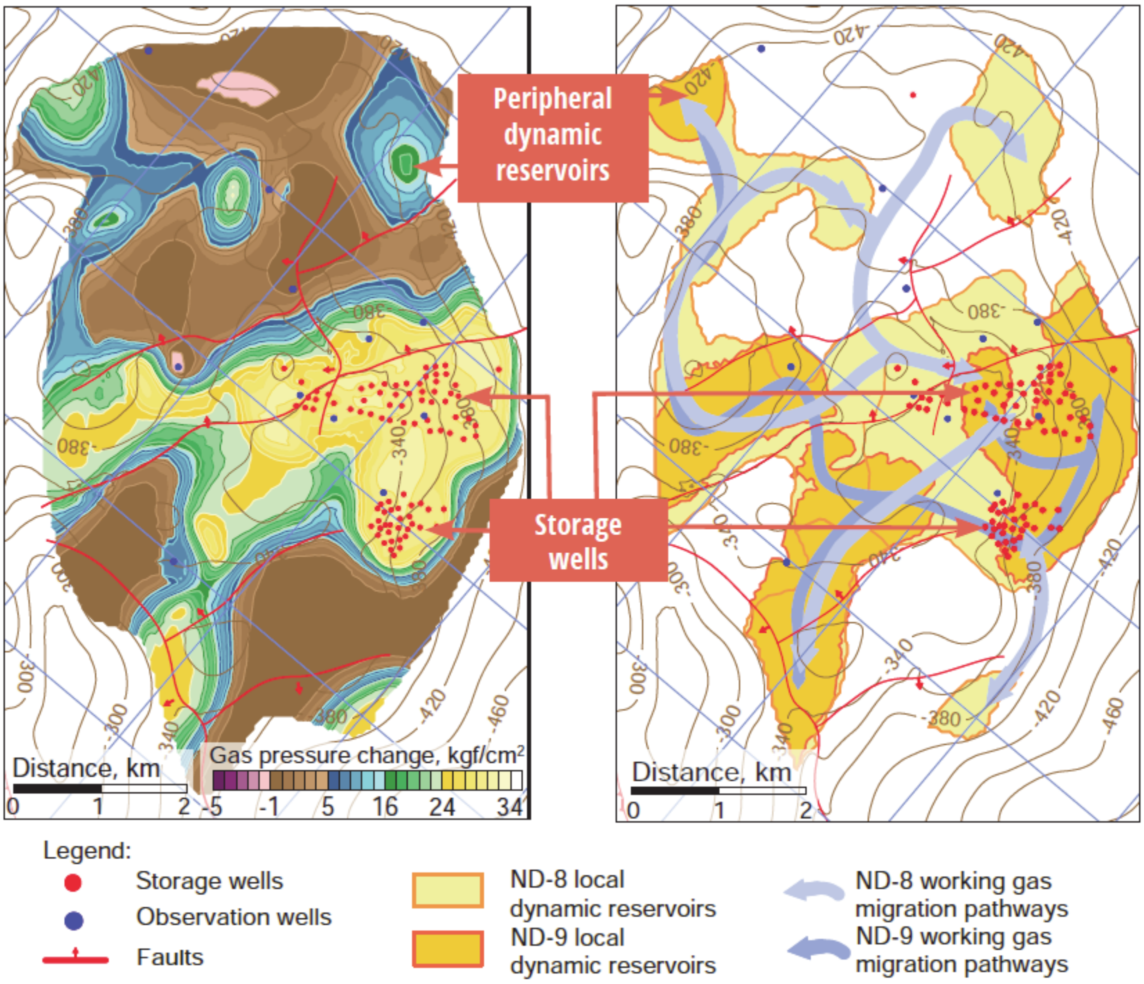


Figure 4 *Map of formation pressure difference in LD-8 horizon (left). Location of dynamic reservoirs and working gas pathways for LD-8 and LD-9 horizons (right)*

Conclusions

Physical preconditions and practical application results of time-lapse gravity measurements and interpretation allowed increasing the efficiency of UGS exploitation.

Creation of the realistic 4D model of pressure and volume of gas of Dashava UGS allowed to:

- map of dynamic reservoirs location where cushion gas is accumulated;
- calculate of the working and cushion gas volumes within dynamic reservoirs;
- map of working gas pathways from storage wells to dynamic reservoirs.

The developed workflow of time-lapse gravity measurements and interpretation for Dashava UGS exploitation optimization is proposed to be applied for other UGS including Ukrainian UGS.

References

Lumely, D., Landro, M., Vasconcelos, I., Eisner, L., Hatchel, P., Li, Y., Saul, M. and Thomson, M. [2015] Advances in time-lapse geophysics – Introduction. *Geophysics,* **80 (2)**, WAi-WAii.