Debottlenecking of UGS Lab 3, synergy effects of interconnected storages UGS Lab 3 and reservoir Gajary-baden

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1. Introduction

NAFTA a.s operates a unique gas underground storage (UGS) Lab complex in Slovakia which has been gradually built and expanded since 1973 until today. The first part of UGS Lab complex was put in operation in 1973 as UGS Lab 1. Later some technical improvements were realized in the surface technology and were extended to UGS Lab 2. Subsequently the largest reservoir, the 8th Panonnian, was converted in 1983 into UGS Lab 3 and was then followed by UGS Lab 4, owned and operated by Pozagas a.s.(NAFTA a.s. is one the shareholders). The last reservoir, so far, connected to UGS Lab complex recently is the Gajary-baden reservoir. Nowadays NAFTA a.s. has nearly 40 years of experience in storage development and operation with solid track record of serving its customers.

The complex represents several reservoirs interlinked with surface infrastructure connected with several grids via two Central Stations. The first one is the Central Station Plavecky Stvrtok (CS) with connections to:

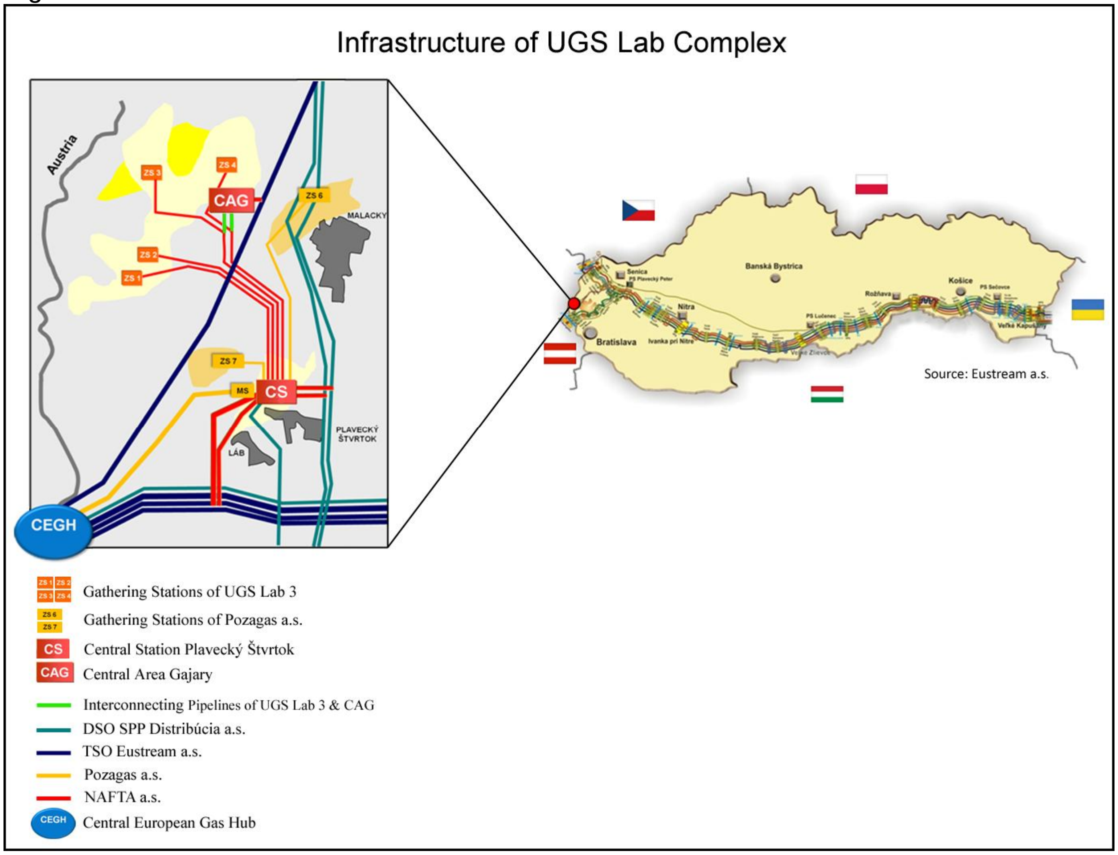
- 4 interstate pipelines,
- 2 transmission pipelines (DN900, DN700),
- CEGH Baumgarten via the storage operated by POZAGAS

The second one is the Central Area Gajary (CAG, station for Gajary-baden reservoir) with connection to a DN 1200 transmission pipeline. The both stations are interconnected, which supports the high flexibility of UGS Lab complex (Figure No.1).

The contribution of UGS Lab 3 to the total storage capacity is approximately 70 % and the similar share applies also for the total withdrawal/injection (W/I) rate. UGS Lab 3 was put into operation in 1983 and consists of nearly one hundred injection/withdrawal wells, four field gathering stations, gathering pipelines and compressor station located at CS. Revamping of UGS Lab 3 between 2001 and 2004 was focused on the upgrade and increase of gas treatment capacity, decrease of pressure losses between reservoir, gathering stations and CS (new pipelines were installed, change of tubing) and an increase of compressor capacities (solved by changing of compressor staging and refurbishment of gas turbines). The investment realized ensured an increase of W/I rate which supported the gas market liberalization and new flexible storage services.

Due to the fact that UGS Lab 3 is our key asset, we have concentrated our efforts on better understanding the limits of subsurface and surface parts. The results of the reservoir model indicated the possibility of a further increase of the working volume and also W/I rate. The surface technology (including well completions) represented a complex of piping restrictions and equipment restrictions (e.g. dehydration capacity, filtration capacity, measurement capacity etc.) for gas transport. The main aim was identification of the bottlenecks for withdrawal part and their efficient reduction via new investment actions. The increased withdrawal rate (WR) would allow us to offer products with higher flexibility to our customers.

Figure No.1



The following methodology was set up and used in the framework of this project:

- Selection of method for bottleneck analysis
- Definition of basic alternatives and variants of basic alternatives (variants) which eliminate the bottlenecks
- Surface model tuning
- Performance calculation for variants
- capital expenditure (CAPEX) evaluation for variants
- Definition of criteria for comparison of the variants
- Field tests
- Recommendation for investment plans

2. Definition of basic alternatives for debottlenecking

The withdrawal part is very complex. We started with a total production system analysis. The „NODAL analysis“ method was used which easily determines the effect of changing any component in the withdrawal chain. The Nodal analysis procedure consists of selecting a division point (node) and dividing the system at this point to optimize performance in the most economical manner. We defined the division point (node), which divides the system into upstream (reservoir, well completion, flowline, dehydration capacity, piping system etc.) and downstream part (compressor, metering station and output pipeline) as the suction header of the compressor station in CS. Performance of the upstream part is represented by an inflow curve and the downstream part by an outflow curve. In our case the outflow curve is represented by compressor curves. At the beginning, the calculations were performed for the point of 50% working gas depletion (reservoir pressure) for individual basic alternatives. Whichever increase of WR is calculated at this point gives a real indication that higher withdrawal rates can be expected in the total withdrawal curve.

The following basic alternatives were considered in the NODAL analysis:

A) Replacement of inlet separator on gathering station ZS4
B) Bypass of dehydration unit on gathering station ZS1
C) Completion of dehydration unit on gathering station
D) Change of pipes on gathering station ZS4
E) Adding of compressor unit – Interconnection with CAG
F) Change of flowlines and tubings for selected wells

Alternative “A”
The reservoir part (wells) which is connected to gathering station ZS4 has more potential than existing gas treatment unit can process. The most limiting part of gas treatment unit is the separator capacity.

Alternative “B”
The vendors of gas dehydration units usually use some margin for design of dehydration capacity. The idea of installation of “By-pass of dehydration unit” is an effective utilization of above mention factor. We checked by separate calculation the hydraulic capacity of inlet nozzle (CFD study), dehydration capacity and the F factor of column. On the basis of these calculation the parameters for by-pass was estimated. Continual field measurements are required for final design of alternative “B”.

Alternative “C”
We have considered the well performance potential connected to gathering station already during preparation of revamping of ZS1 in 2003. We have designed the piping and primary technology for higher withdrawal rates and we included the space for easy installation of parallel TEG dehydration train into the gathering station layout
Alternative “D”
Change of piping (using pipe with larger diameter) makes sense only with replacement of the inlet separator (Alternative “A”), which is the primary bottleneck. By changing the pipe diameter we pursue decreasing of velocity in the pipes, which becomes the limiting factor of the gathering station assuming that the inlet separator is changed. The other approach on how to eliminate this constraint is to verify, by field measurement (e.g. measurement by vibration etc.), whether a higher velocity is acceptable from a safety viewpoint. If the field measurements prove acceptance of a velocity up to 24 m/s, the capacity of gathering station will be the same as with new pipes of increased diameter. Even if we accept the higher velocity in the piping system, we consider operating the gathering station ZS4 on maximal level only in the case of maximal contractual demand.

Alternative “E”
Extension of the UGS Lab complex by adding the Gajary-baden reservoir brought the idea of interconnection of UGS Lab 3 and new infrastructure at CAG. The location of CAG was planned to be near the existing gathering stations. The Gajary-baden reservoir is the one that does not need compression work during withdrawal period due to sufficient reservoir pressure even at the end of withdrawal season. That means that compressors of CAG might be available for UGS Lab 3. Detailed calculations were made by the compressor vendor to optimize the compressor staging (the primary purpose of the compressors remained the injection into the Gajary-baden reservoir). Tandem compressors sets powered by gas turbines were selected for CAG, which might be operated in either of series (injection into the Gajary-baden reservoir) or in parallel for withdrawal/injection to UGS Lab 3.

The basic alternative „E“ (adding a compressor unit) defined for NODAL analysis was updated with as interconnection with CAG.

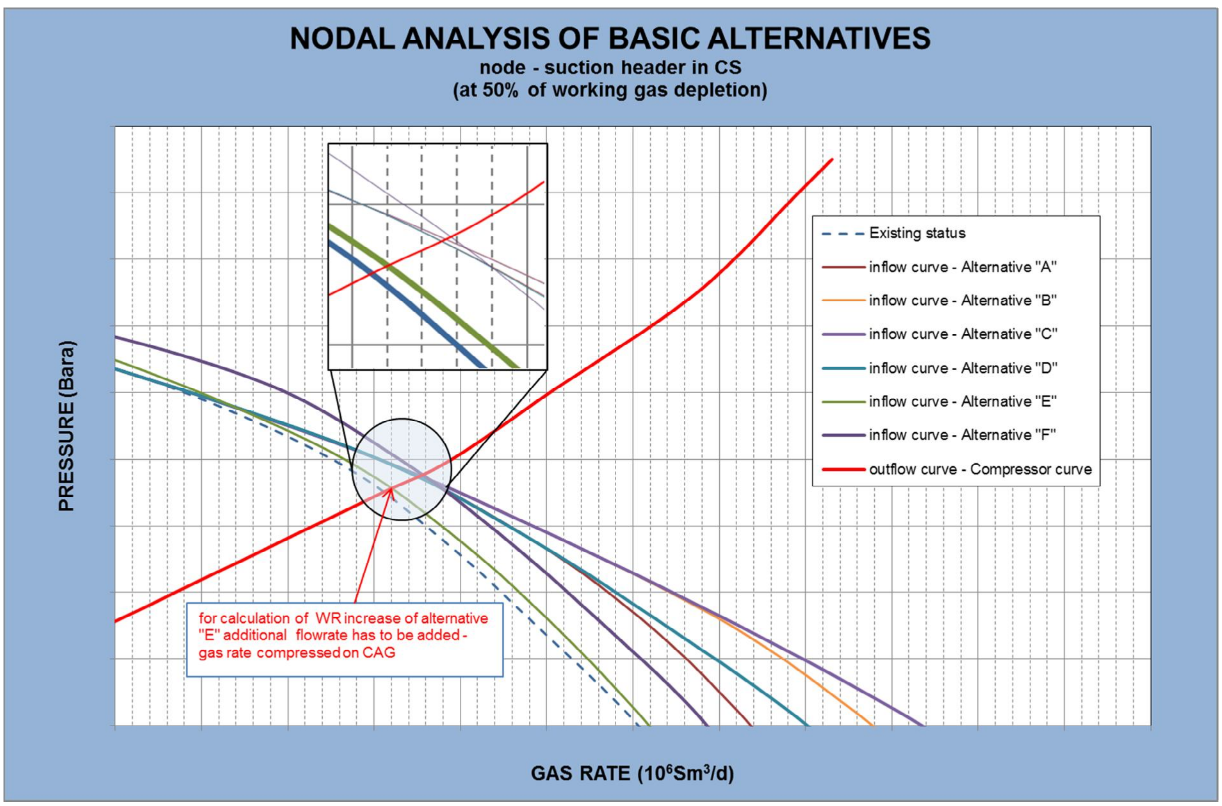
Alternative “F”

The actual reservoir model allows us to increase the flowrate from some wells but the flowrate is limited by pressure losses in the flowlines. The gathering system consists of individual flowlines for each well, which were grouped in clusters where it was possible. In this alternative we proposed to construct new flowlines for one group of wells and looping was proposed for the second one. The old flowlines of the first group were considered to be re-used for looping (short interconnections can be used) where flowlines are in one corridor

3. Comparison and assessment of basic alternatives

The CS has several exit points with different delivery pressures and constraints for maximal gas rate. Therefore Nodal analysis was chosen just for the first rough comparison of alternatives concerning WR. Cross-comparison of alternatives allowed us to find the bottleneck which had to be removed first. The maximal withdrawal rates (for 50 % of WG depletion) for basic alternatives (except alternative “E”) were calculated as an intersection of outflow curve (compressor curve) and inflow curve of individual basic alternatives (Figure No.2). Whereas in alternative “E” we use two compressor stations which are located at different places we had to use different approach for calculation of maximal WR. The maximal WR is the sum of flowrate compressed on CAG (diverted from main flow at the interconnection point) and gas flowrate calculated as an intersection of inflow rate and compressor curve in CS.

Figure No.2



For the economic evaluation of alternatives the following criteria (with different weighting) were used:

- Amount of CAPEX per unit of withdrawal rate increase (weighting 15%)
- Complexity of preparation and realization of construction investment (weighting 10%)
- Absolute amount of CAPEX (weighting 15%)
- Increase of withdrawal rate (weighting 60%)

As the increase in WR was to be the main aim of this investment, we assigned it the highest weighting criteria. The criteria "total CAPEX and "CAPEX per unit increase of WR" were assigned the second highest weighting, in order to maintain the economic feasibility of the investment.

Table No.1 summarizes the result of the nodal analysis included in the economic evaluation. The result showed that alternative "E" was the most effective, but the execution of this alternative is closely associated with the project Gajary-baden i.e. interconnection of UGS Lab 3 and CAG and could not be used before CAG was constructed. At the time when we prepared this analysis, we needed to react to market demand and we could not wait 3 years until commissioning of CAG. The second alternative "By pass of dehydration unit ZS1" seemed to us very interesting but further field tests would be required to verify the theoretical calculations. Therefore the alternative "A" was selected as the first step for debottlenecking of UGS LAB 3. The calculation of withdrawal curve for whole range of working gas depletion confirmed the output from nodal analysis. The alternative "A" was successfully implemented and tested. The results confirmed the calculations and realized investment paid for itself.

Table No.1

BASIC ALTERNATIVES		INCREASE OF WR		CAPEX		CAPEX PER UNIT OF WR INCREASE		COMPLEXITY OF PREPARATION AND REALIZATION OF CONSTRUCTION INVESTMENT			
Lettering	Description of alternatives	Order	Weighting 60%	Order	Weighting 15%	Order	Weighting 15%	Order	Weighting 10%	Total points according to weighting	Total order
A	Repalcement of inlet separator on gathering station ZS 4	4	2.4	2	0.30	3	0.45	2	0.20	3.35	**3**
B	Bypass of dehydration unit on gathering station ZS1	3	1.8	1	0.15	2	0.30	1	0.10	2.35	**2**
C	Completion of dehydration unit on gathering station ZS1	3	1.8	4	0.60	5	0.75	4	0.40	3.55	4
D	Change of pipes on gathering station na ZS4 and replacement of inlet separator on ZS4	4	2.4	3	0.45	4	0.60	3	0.30	3.75	6
E	Interconection with CAG	1	0.6	5	0.75	1	0.15	5	0.50	2.00	**1**
F	Change of flowlines and tubings for selected wells	2	1.2	6	0.90	6	0.90	6	0.60	3.60	5

4. Analysis of different variants for further debottlenecking of UGS Lab 3

It is always challenging for a storage operator to shift the withdrawal performance of their storages. Therefore we have continued with analyses not only with the aim to find synergy effects from interconnection of UGS Lab 3 and CAG, but also with the aim to verify whether any combination of basic alternatives (variants) can improve the withdrawal performance of UGS Lab 3.

For the comparison of the variants the withdrawal curves were calculated. The integrated model (reservoir and surface) was used for calculation of the total withdrawal curves in order to define the increase of WR for the whole range of storage depletion for each variant. We undertook several tests for tuning the model and verifying the calculation. In the surface model we activated all delivery points with exit pipelines including part of piping system of UGS Lab 1 where mixed flow from both storages has to be considered. Basis for calculation of any withdrawal curve is definition conditions of calculation like preferred delivery point, flow limits for delivery points etc.

The alternative "A" was used as a basis for further calculation focused on finding the optimal combination of basic alternatives for further debottlenecking of UGS Lab 3. Table No.2 summarizes the variants considered for evaluation. The variants include different combination of basic alternative. The alternative "A" is included in all variants.

Table No.2

BASIC ALTERNATIVES	DESCRIPTION OF ALTERNATIVES	VARIANT 1	VARIANT 2	VARIANT 3	VARIANT 4	VARIANT 5	VARIANT 6	VARIANT 7
A (reference case)	Repalcement of inlet separator on gathering station ZS 4	x	x	x	x	x	x	x
B	Bypass of dehydration unit on gathering station ZS1					x		
C	Completion of dehydration unit on gathering station ZS1				x		x	
D	Change of pipes on gathering station ZS4		x				x	
E	Interconection with CAG	x	x	x	x	x	x	
F	Change of flowlines and tubings for selected wells			x			x	x

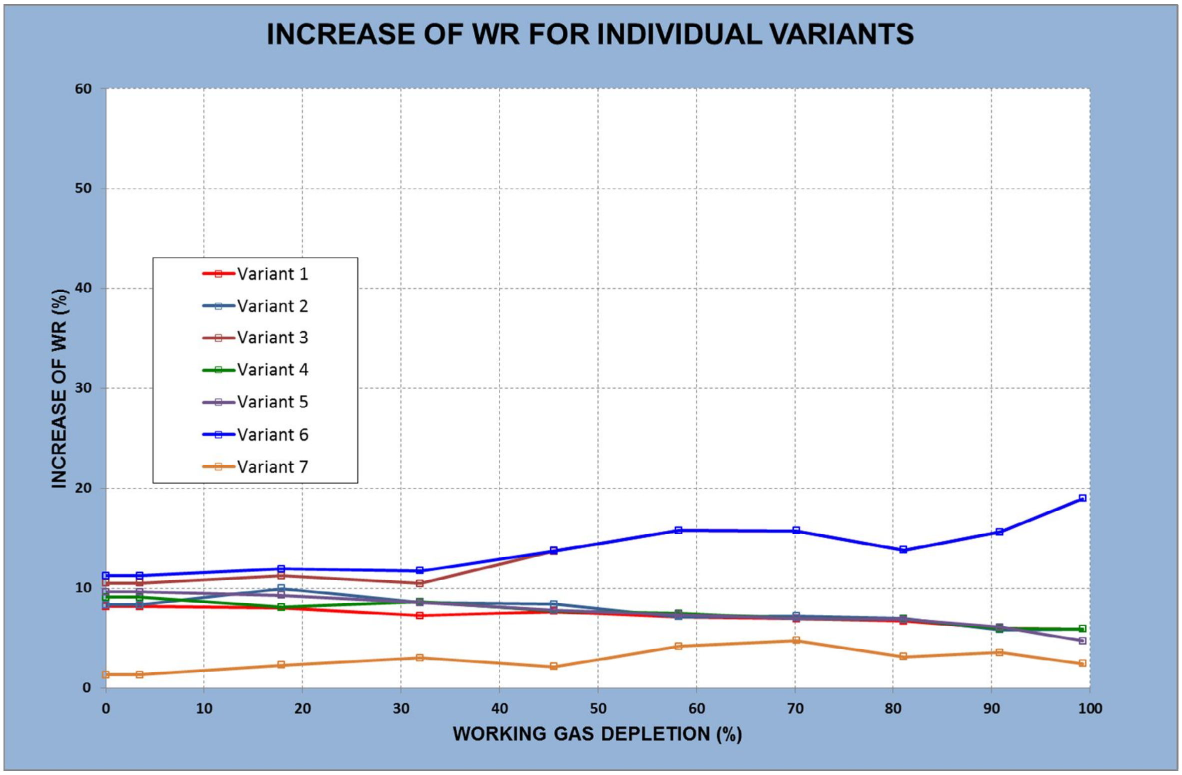
To assess the attractiveness of variants we ranked them according to the criteria above, plus according to one extra criterion – 'increase of deliverability' (deliverability = the number of days needed for storage capacity withdrawal; increase of deliverability means decreasing the number of days needed for storage capacity withdrawal). The weighting criteria were adjusted as follows:

- Amount of CAPEX per unit of withdrawal rate increase (weighting 20 %)
- Complexity of preparation and realization of construction investment (weighting 10%)
- Absolute amount of CAPEX (weighting 15%)
- Increase of withdrawal rate (weighting 40%)
- Deliverability (weighting 15%)

Then we analysed the results and selected the variants feasible for realization. To confirm the economic viability we calculated the NPV of selected variants.

The withdrawal curve of alternative "A" was used as a reference case for comparison of the all variants. The increase of WR of individual variants is clear from Figure No.3. Increase of WR to reference case for each variant is expressed in percentage along the whole withdrawal curve.

Figure No.3



At the point where withdrawal curve of variants is closest to the reference case we derived the increase of WR for each variant, which was considered as minimum increase of WR (flat rate for economic evaluation) for the whole storage capacity.. We evaluated the rest of available WR using the parameter "deliverability".

The results of ranking the variants are shown in Table No.3.

Table No.3

	INCREASE OF WR			CAPEX		CAPEX PER UNIT OF WR INCREASE		COMPLEXITY OF PREPARATION AND REALIZATION OF CONSTRUCTION INVESTMENT		DELIVERABILTY				
VARIANTS	(%)	Order	Weighting 40%	Order	Weighting 15%	Order	Weighting 20%	Order	Weighting 10%	Increase of deliverabilty (days)	Order	Weighting 15%	Total points according to weighting	Total order
Variant 1	6.0	2	0.8	1	0.15	2	0.40	1	0.10	4	3	0.45	1.90	1
Variant 2	6.0	2	0.8	3	0.45	3	0.60	2	0.20	4	3	0.45	2.50	3
Variant 3	15.6	1	0.4	6	0.90	1	0.20	5	0.50	6	2	0.30	2.30	2
Variant 4	6.0	2	0.8	4	0.60	5	1.00	4	0.40	4	3	0.45	3.25	6
Variant 5	6.0	2	0.8	3	0.45	3	0.60	3	0.30	4	3	0.45	2.60	4
Variant 6	15.6	1	0.4	6	0.90	4	0.80	6	0.60	6	2	0.30	3.00	5
Variant 7	2.3	3	1.2	2	0.30	6	1.20	7	0.70	8	1	0.15	3.55	7

The analysis shows that regarding the increase of WR only Variants 1, 3 seem to be reasonable. The increase of WR for variant 1 is in the range 6.0 – 8.1% and for variant 3 is in the range 10.5-18.9% depending upon the working gas depletion. For Variants 1 and 3 we used NPV to check the economic viability. The calculated NPV confirmed economic feasibility of those variants.

The Variants 2, 4, 5, 6, 7 rank below Variant 1 and 3.The Variants 2, 4 ,5 have similar WR like Variant 1 but higher CAPEX . Variant 1 includes only CAPEX for interconnection with CAG and Variants 2, 4, 5 have extra CAPEX for increasing the dehydration capacity, but bottleneck in these variants is not dehydration capacity, but pressure loss or compressor work. The increase of WR in Variant 7 is too low to the amount of CAPEX, therefore Variant 7 has the lowest ranking. Variant 6 is extended option of Variant 3 about dehydration capacity but again the bottleneck is somewhere else and not in dehydration system.

As the second step for debottlenecking of UGS Lab 3, the realization of the interconnection with CAG (Variant 1) has been undertaken. Variant1, in fact, is a part of Variant 3 and has also strategic meaning. The selected Variant1 was constructed making extra capacity available to the market.

Besides the possibility to use the compressors for UGS Lab 3, the new interconnection ensures strategic diversification of exit/entry points, higher reliability of storage services, realization of flexible services and broader possibilities for optimal storage management.

5. Summary/Conclusions

The interconnection of UGS Lab 3 with CAG was realized last year and the tests are under way during the withdrawal season 2011/2012. Interconnection of UGS Lab 3 and CAG essentially enhances possibilities of NAFTA to increase withdrawal rates, provides flexible usage of its storage and offers a variety of entry- exit options.

The debottlenecking analysis represents the tool for a flexible response to higher WR demand in the market. The further challenge for debottlenecking analysis is evaluating the limits of individual exit/entry points (NAFTA a.s. has several exit/entry) and analysis of limits for flexible services (e.g. switch from injection to withdrawal and vice-versa). Having a robust well-tuned integrated model (reservoir and surface) for analysing all the possible scenarios makes fulfilment of this challenge real in the very short time and enables us to meet the customers' needs in flexible and efficient manner.