Underground hydrocarbons storages in Poland: actual investments and prospects

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A b s t r a c t. Poland has the limited gas and oil resources. Main hydrocarbons supplies are delivered to Poland mostly from Russia by oil and gas pipelines. Very large length of these pipelines as well as the local considerable wearing of devices induces the necessity of reserves storage. Geological conditions in Poland and a considerable quantity of exhausted gas deposits enabling in nearest years to the construction of underground gas storages (UGS) suggest the new investments in this sector of petroleum industry. Capacity amount of present active UGS is 1.58×10^9 m^3 but after finalizing of storages their volume will achieve 2.8×10^9 m^3. Special attention is paid to the Wierzchowice UGS (the biggest one in Poland) and to caverns leaching within the Zechstein salts cavern underground gas storages (CUGS) Mogilno and Kosakowo. Reservoirs of cavern type (expensive under construction) are a very efficient, modern source of gas system supply, particularly in periods of the seasonal demand fluctuations for gas — a very high during the winter season in the central and the northern Europe. Only caverns in salts allow to store both the gas and the liquid hydrocarbons. Construction of the UGS refers mostly to exhausted gas fields, discovered and exploited by the Polish Oil and Gas Company. *Experience and capital of the state company located it as a leader in Poland in the field of construction and exploitation of underground storages. Their construction has the minimum influence on the environment. Utilization of exhausted hydrocarbons deposits (often with the existing mining infrastructure) is not almost at all troublesome for a local population and the environment and it offers considerable practical and economic benefits. The economical boom in the oil and gas market during last years creates new challenges for construction and exploitation of hydrocarbons underground storages.*

Key words: *underground storage, gas, oil, exhausted deposits, salt caverns,* Polish Oil and Gas Company

Poland has the limited resources of gas (228 gas deposits with the total resources estimated at 143×10^9 m^3, production of ca 5.2×10^9 m^3 from 180 deposits provided 40% of the national request in 2006 and most of exploited deposits are over 60% exhausted — Gientka et al, 2007) so the dominant gas volume is imported from other countries (mainly from Russia).

After accession to the European Union Poland is obliged by the Instruction no 98/93/EC (from 14.12.1998) to prove in each year the constant reserves of gas and oil (also gasoline) calculated for at least 90-days national consumption of former year (Kunstmann et al, 2002). Both products could be stored on the surface in special metallic and concrete containers or in the underground reservoirs, natural or artificial ones. The most common are the surface storages but actually the underground investments become more popular (safety and economic reasons). They are very effective for gas storage, considered as the future fuel (less toxic for the environment, much more gas deposits than oil ones in the world, its consumption in 2020 is suspected at 4×10^{12} m^3 — Reinisch, 2000).

Main oil and gas supplies are delivered to Poland mostly from Russia by oil and gas pipelines. Oil and gas fields in Russia providing hydrocarbons to pipelines are located thousand kilometres from the Polish borders. Pipelines were built in different periods and their age sometimes is over 30–40 years. Due to this the local damages have happen which after all are appearing in new devices. The large length of these pipelines as well as the local considerable wearing of devices induce the necessity of reserves storage. *Polish Oil and Gas Company* (POGC) with its great technical and economic experience is a leader in construction of hydrocarbons underground storages within geological structures in Poland. Its activity in this field was initiated in 4 December 1954 when it was started a gas pumping to the exhausted gas field Roztoki (Carpathians) at a pressure of 3.4 MPa, without compressors. This storage was exploited to 1990s when due to leakiness of many boreholes and local exhalations of gas its further exploitation was stopped. Next underground gas storage Tarchały was prepared in 1976, aimed to collect helium, obtained with cryogenic methods from a natural gas. It was the first such object in Europe. Almost all later built underground storages of natural gas are functioning up today. They were constructed to fulfill the highly fluctuating public and industrial demands especially for gas, which are particularly high in a winter when a low temperature violently increases gas consumption for houses heating and what that in turn causes gaps in the industrial supplies.

Building the big gas pipeline in the 1990s from Russia to Europe (Jamal-Europe pipe) created also in Poland the necessity of the underground gas storage constructions with sufficient volume capacities, considered as a component of the European energy security.

Conditionings presented above are additionally limited by technical possibilities of such constructions. Artificial accumulation of large amounts of hydrocarbons requires not only a suitable object volume counted in hundreds and thousands of millions of cubic metres, but also the good natural sealing and permeability of a reservoir enabling a quick recover of stored products.

Geological conditions of hydrocarbons storage

Underground storage has many advantages comparing to the surface method (Czapowski, 2006a):

a) it offers the giant volume of reservoirs (million tons for liquid hydrocarbons and billions cubic metres for gas),

b) it uses the properties of rocks (natural porosity) and the artificial, perfectly isolated chambers prepared in the geological structures,

c) surface infrastructure of the underground reservoir is very limited and used installations of the former mine (only for gas pumping and processing, social buildings).

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Underground gas storage is realized in the world by location such reservoirs within (Reinisch, 2000):

- exhausted gas and oil deposits,
- salt caverns leached within the salt deposits,
- aquifers,
- chambers of old mines and natural caves (rarely).

Underground storage of fluid hydrocarbons is realized only within the artificial salt caverns and (in tanks) within adapted chambers of old mines (in Poland is only a single such case — a metal tank for gas for internal purposes, located from 1990 in the old shaft of coal mine *Morcinek* in Upper Silesia; Reinisch, 2000).

In Poland first two forms of gas storage are actually preceded, reservoirs in aquifers are considered in the future. Fundamental requirements for all underground reservoirs are 1) a total tightness of reservoir and 2) lack of reaction between gas and surroundings rocks (and fluids within). The welcome economic attributes are a) location not so far for the possible gas receivers (city agglomerations and industrial complexes) and deliverers (gas and oil pipes, main road and rail tracts), b) relatively small depth of reservoir and c) its large volume.

Storage within exhausted gas and oil deposits and aquifers is determined by the natural properties of rocks, being the former reservoir for waters and hydrocarbons and gas pumping into such rock bodies requires at least the same pressures (an energy expense) which existed within before exploitation.

In Poland six underground gas storages are situated in exhausted gas deposits (over 85% of total storage volume). There are no storages in underground aquifers. In the caverns leached in the salt diapir Mogilno is stored a gas and this gas storage will be further enlarged.

Characteristics of main geological structures available for storage

Exhausted oil and gas deposits. Dominant and a relatively cheap form of underground gas storage (over 75% of such reservoirs in the world — Reinisch, 2000) is its pumping into closed or almost exhausted oil and gas deposits. The accepted economic limits for such investments are a) the deposit depth less than 3000 m (but in Poland such deposits are located at 1000–1600 m) and b) price of "buffer gas", necessary for delivery the pumped one (the normal ratio of both is 1:1). Such deposits offer the giant volumes (e.g. the total free volume of post-gas deposit Wierzchowice is calculated at over 4×10^9 m^3 — op. cit.) and they could be used as the "strategic reservoirs".

In the area of Polish Permian Basin (SW, central and northern Poland) were discovered and partly (29) exploited 39 oil deposits and 133 gas deposits (Tab. 1). Many of almost exhausted hydrocarbons deposits could be quickly and with low expenses transformed into such reservoirs, both for regional and local requests (e.g. Karlino oil deposit in Pomerania), using the remaining original gas and fluids as "buffers". Most of them are placed within the Permian rocks: the Lower Permian sandstones (Rotliegendes; gas) lying at the depth intervals 1200–3484 m (Fore-Sudetic Monocline in SW Poland, central-western Polish Lowland) to 2843–3856 m (Pomerania in northern Poland; Tab. 1). Some hydrocarbons (gas and oil) deposits occur within the Upper Permian (Zechstein) carbonates (Zechstein Limestone [Ca1] and Main Dolomite [Ca2] units — after the lithostratigraphic scheme of Polish Zechstein by Wagner, 1994) located at the depth intervals of 1000–2986 m in SW and central Poland and at 2250–3805 m in Pomerania. Only few gas deposits are connected with the Upper Carboniferous sandstones, placed in both mentioned above regions at the depth 2770–3164 m and at 2985–3220 m correspondingly. In the Middle Cambrian sandstones, lying at the depth 2695–2740 m in the eastern Pomerania (Karnkowski, 1999), were discovered 3 oil deposits.

Five closed and almost exhausted gas deposits were selected as potential gas reservoirs (Reinisch, 2000). They are located in SW Poland (Fig. 1) and gas-bearing series of two ones: Wierzchowice and Brzostowo includes the Lower and the Upper Permian units (sandstones and carbonates) at the depth from 1323 m to 1452 m but 3 others, Załęcze, Żuchlów and Wilków, contain gas only within the Lower Permian sandstones, lying at 1249–1520 m (Tab. 2). Porosity of sandstones varies from 7.6% to 17.4% and permeability from 1.58 mD to 1000 mD, for carbonates these parameters are 3.6–13.9% and 0.498–11.4 mD correspondingly. Temperature in the deposits varies from 14°C to 32°C depending from a local heat flow. The partly exhausted Wierzchowice deposit was transformed in 1995 into the underground gas reservoir and in 2004 it contained over 600×10^6 m^3 of gas, but its future volume is calculated for ca 4.3×10^9 m^3 (Reinisch 2000). The total volume of described 5 deposits is estimated at ca 28.5×10^9 m^3.

In the Polish part of Carpathians and its foredeep (southern Poland) were discovered and mostly (37) exploited 40 oil deposits with total resources over 309×10^3 t and 116 gas deposits (87 exploited and 5 closed) with total gas resources of 44×10^9 m^3 (Gientka et al, 2007). Five of these exhausted gas deposits located mainly within the Miocene series of the Carpathian Foredeep were managed as the underground gas storages (Fig. 1; Tab. 2) offering a total active capacity of 675×10^6 m^3 and the next 3 ones: Jarosław, Tarnów and Tuligłowy, with active capacity of 4.95×10^9 m^3, are planned to build.

Advantages of such storage method (except listed earlier such as: low costs of investments, giant volumes, quick

Table 1. Age and depth data for gas and oil deposits in the area of Polish Permian Basin (data after: Karnkowski, 1993, 1999; Gientka et al, 2007)

Age of hydrocarbons reservoir rocks	Deposit lithology/depth [m]				Number of gas deposits active/ reserved/ closed	Number of oil deposits active/ reserved/ closed
	SW & Central Poland		Northern Poland			
	Gas deposits (125)	Oil deposits (26)	Gas deposits (8)	Oil deposits (13)		
Middle Cambrian	-	-	-	sandstones/ 2695–2740	84/41/8	29/4/6
Upper Carboniferous	sandstones/ 2770–3164	-	sandstones/ 2985–3220	-		
Lower Permian (Rotliegendes)	sandstones/ 1200–3484	-	sandstones/ 2843–3856	-		
Upper Permian (Zechstein; Ca1, Ca2)	carbonates/ 1470–2420 (mainly Ca2, Ca1)	carbonates/ 1000–2986 (Ca2)	carbonates/ 2842–2930 (Ca2)	carbonates/ 2250–3805 (Ca2)		

and cheap "reconstruction" of former hydrocarbons deposits) include also the prefect geological recognition of such objects, lowering significantly costs of their adaptation for gas storage.

Salt formations. Salt caverns leached within salt bodies become the more popular form for storage and disposing various products (they are ca 9% of gas reservoirs in the world — Reinisch, 2000). Their advantages (except these mentioned earlier) are: a) „buffer gas" is not required (gas is delivered by its own pressure or by pumping brine into cavern — Kunstmann et al, 2002), b) both gas and oil (gasoline) may be stored and very quickly received from cavern, c) salt rocks (mainly rock salt) do not react with hydrocarbons, d) natural convergence of salt caverns creates the additional pressure onto stored products and it also close any fractures within a salt body, e) salt rocks conduct a natural heat very well increasing the pressure of stored gas and f) any shape deformations of cavern could be easily corrected by solution. The valuable aspect of these storages is a possibility to transform them — after finish of storage function — into safety depositories for toxic materials and useless by-products. Due to quick recovery of almost all pumped gas and oil the salt caverns become the perfect reservoirs reacting for rapid fluctuations in gas supply and request.

Polish geological limits for construction the artificial caverns for gas, leached within the salt deposits, are in 1980s (e.g. Brańka et al, 1978; Ślizowski, 1980; Radomski, 1983; Nowicki, 1993; Mazur et al, 1994): a) depth of salt body less 450 m (actually — 1000 m), b) thickness of highly homogenous salt body over 150–200 m and c) deposit area over 0.2–0.54 km^2. Favourable for cavern solution are the salt bodies without insoluble interbeds (clays, carbonates, sulphates) over 1 m thick and without thicker intercalations and concentrations of very soluble potassium-magnesium (K-Mg) salts (both rock types highly deform the planned cavern shape).

In the area of Polish Permian Basin such caverns could be leached only within the Upper Permian (Zechstein) rock salt formations, represented 4 cyclothems (lithostratigraphic units after Wagner, 1994) covering ca 1/3 of country area. Favourable conditions for such investments exist in following structures (e.g. Brańka et al, 1978; Ślizowski, 1980; Czapowski, 2006a):

❑ Salt domes and diapirs continued as a chain of NW-SE orientation through Poland (Fig. 2), up to 7 km high, with undefined total volume of salt (recognized thickness of salt bodies within them are over several hundreds of metres) and a very complicated internal structure.

❑ Locally faulted stratiform salt deposits in SW Poland (Sieroszowice-Bytom Odrzański area; Fig. 2), with 4 almost homogenous rock salt units (several to 295 m thick, at depth from 470 m to 1510 m) and resources estimated at over 2.9 × 10^9 t of rock salt for the Sieroszowice salt deposit (Gientka et al, 2007). Salt caverns for gas (Brańka et al, 1978, 2006) and chambers as disposals for by-products (Kłeczek et al, 1994) are planned there.

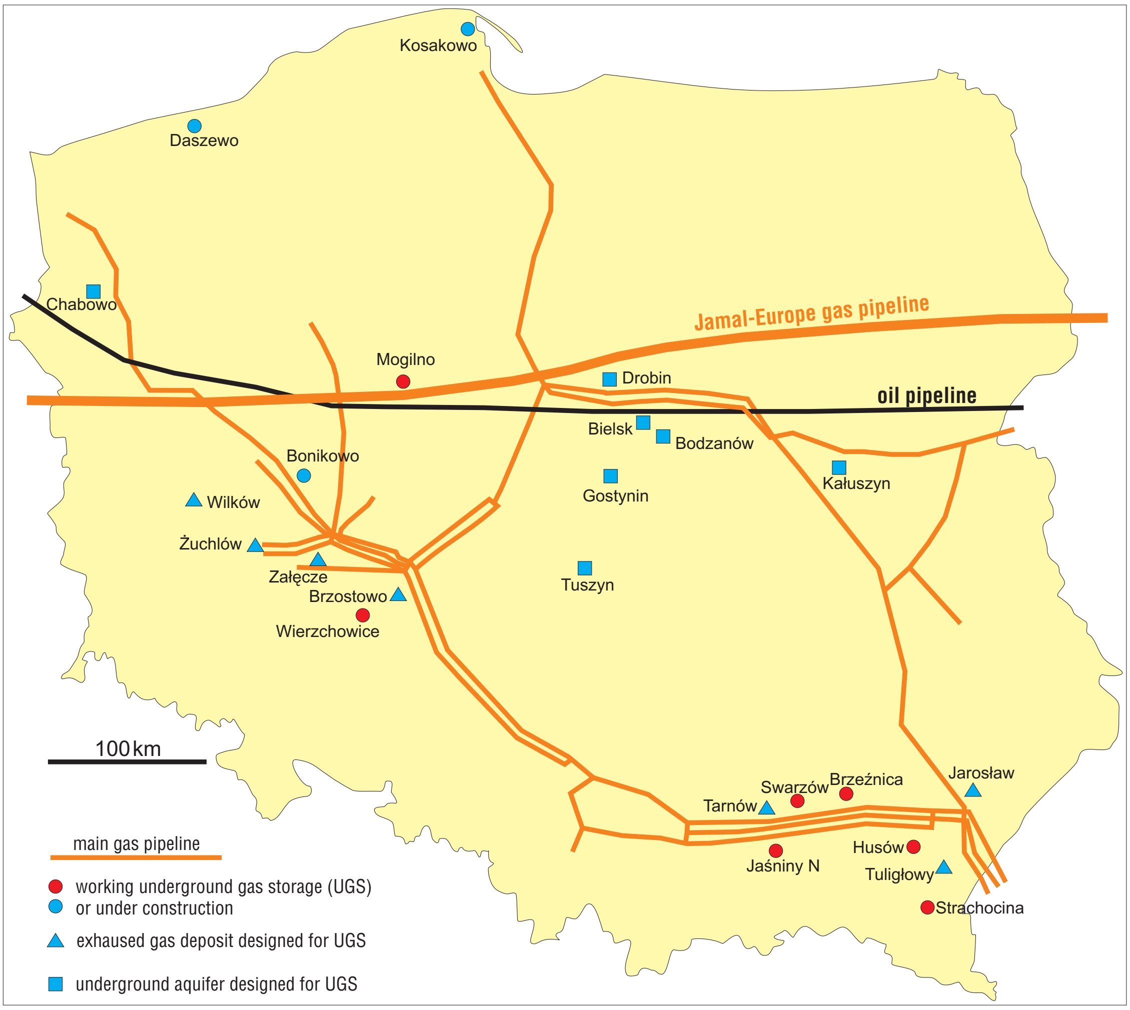

Fig. 1. Location of underground gas storages and selected hydrocarbons deposits and aquifers for gas storage in Poland (after Reinisch, 2000)

Table 2. Characteristics of selected gas deposits planned for underground gas storage in Poland (data after: Reinisch, 2000; Karnkowski, 1993, 1999; supplemented)

Deposit name	Deposit depth/ thickness [m]	Type and age of deposit rocks	Area [km^2]	Porosity [%]	Permeability [mD]	Pressure [MPa]	T [°C]	Storaged gas volume [10^6m^3]	
								actual	planned
Wierzchowice	1323.5–1452/ 128.5	**s**andstones (Lower Permian, Rotliegendes) & **c**arbonates (Upper Permian, Zechstein Limestone)	23	**s:** 10.73 **c:** 3.6–13.93	**s:** - **c:** 0.7–11.4	16.5	47	600	4 300
Brzostowo	1400–1450/ 50	**s**andstones (Lower Permian, Rotliegendes) & **c**arbonates (Upper Permian, Zechstein Limestone carbonate	16.5	**s:** 7.6 **c:** 5.6	**s:** 1.5783 **c:** 0.4976–8.36	16.36	56	0	700
Załęcze	1249–1354/ 35	sandstones (Lower Permian, Rotliegendes)	32	17.4	200	15.1	47	0	9 500
Żuchlów	1275–1345/ 70	sandstones (Lower Permian, Rotliegendes)	25	15	1 000	14.66	49	0	12 500
Wilków	1475–1520/ 45	sandstones (Lower Permian, Rotliegendes)	ca 14	-	-	16.32	53	0	1 500
Brzeźnica	342–400/ -	sands & sandstones (Miocene, Lower Sarmatian)	11.86	24–27	-	4.21	-	65	-
Husów	600–660/ 40–56	sands & sandstones (Miocene, Lower Sarmatian)	15	14–25	370–800	5–12.5	-	400	-
Jarosław	835–1470/ 6	sands & sandstones (Miocene, Lower Sarmatian)	5.51	23	40.6–412	10.3	-	0	950
Jaśniny N	797–841/ -	sands & sandstones (Miocene, Upper Badenian)	3.54	20	ca 2 000	8.49–8.59	-	32	-
Strachocina	ca 750/ 75–90	sandstones (Upper Cretaceous-Paleocene)	ca 1.7	<20	0.1–several hundreds	10.2	-	150	-
Swarzów	620–682/ 10	sandstones (Cenomanian) & limestones (Turonian)	3	3.94–27.5	800–6900	8	-	90	-
Tarnów	462–1725/ ca 120–130	sandstones (Miocene) & **c**arbonates (Upper Jurassic)	10.95	**c:** 6.27–8.41	-	**c:** 18.39	-	0	800
Tuligłowy	-	-	-	-	-	-	-	0	4 200

❑ Stratiform salt deposits in northern Poland at the Gdańsk Bay, consisted of a single (Oldest Halite) salt unit, homogenous, non-tectonized, without significant concentrations of K-Mg salts. There were contoured 3 salt deposits (total area is 157 km^2 and resources — 21×10^9 t) and the salt seam up to 225.5 m thick (average — 127.54 m) is placed at the depth 490.5–1285.3 m. One of the deposits, Mechelinki, with a favourable salt thickness (123.6–185.9 m) at the depth of 946.2–996.1 m, was considered as a cavern reservoir for gas (Werner, 1975, 1978).

Actually in Poland gas is stored within salt caverns leached from 1996 within the Mogilno diapir (central Poland; Fig. 2). Now there are active 8 caverns (ca 250 m high, total volume — 416×10^6 m^3) but are planned next 12 so the final active volume of stored gas is estimated at 1.15×10^9 m^3. From 2002 some small volumes of oil and gasoline were stored within the old caverns of solution mine placed on the Góra diapir (Fig. 2) and finally in 10 caverns (with planned total volume of ca 5×10^6 m^3— Drogowski & Tadych, 2006) there will be located 3.5×10^6 t of oil and 0.75×10^6 t of fluid fuels (Kunstmann et al, 2002).

Among many hitherto non-exploited salt domes and diapirs in NW and central Poland (Fig. 2) only seven structures could be regarded as potential objects for gas storage: Rogóźno, Damasławek, Lubień, Łanięta, Goleniów, Izbica Kujawska and Dębina (Czapowski, 2006a; Czapowski et al, 2006; Czapowski & Ślizowski, 2007). The most perspective for such investments are Rogóźno and Damasławek structures with large areas, salt resources and a shallow depth of salt mirror (325–427 m and 446–539 m correspondingly; Tab. 3). Favourable parameters characterize the twin diapirs Lubień and Łanięta (shallow salt mirror, minor resources and areas) but 2 larger structures, Goleniów and Izbica Kujawska, although of a medium area and accepted technically mirror depth (Tab. 3), are recognised insufficiently. Small diapir Dębina is located in the centre of active lignite open-pit and its exploitation is hazardous. Geological recognition — especially of their internal structure — for majority of discussed diapirs is sill insufficient and requires further studies (Czapowski & Ślizowski, 2007).

The folded Miocene salt deposits in southern Poland (Carpathian Foredeep area) are practically not considered as objects for salt caverns leaching because of their very complicated internal structure, lithological variability and high water hazards.

Underground aquifers. Gas storage in the underground aquifers was only planned in Poland (Reinisch, 2000). Selected 7 aquifers were placed in the central and NW Poland (Fig. 1). The Chabowo aquifer near Szczecin locates within the Lower Jurassic and the Lower Cretaceous sandstones (porosity 18–30%, permeability — 10–1330 mD) at the depth of 670–800 m (Tab. 4). Other 6 aquifers are placed within the Lower Cretaceous sandstones (their porosity varies from 11% to 30%, permeability — from 10 mD to 9848 mD) lying at the depth of 740–1200 m near Warsaw (Kałuszyn, Bielsk, Bodzanów and Drobin) and of 735–900 m near Łódź (Tuszyn and Gostynin; Tab. 4). Total volume of gas pumped into these objects was estimated at $5–12 \times 10^9$ m^3.

Such method of gas storage is quite expensive (numerous wells for control the aquifer parameters, continuous monitoring) and it also eliminates reserves of deep underground waters, necessary for communal and industrial purposes of nearby cities and industrial complexes.

History of the selected underground gas storages (UGS) construction in Poland

UGS Roztoki (active 1954–1980) was built in the Carpathians, in the Ciężkowice Sandstone at depth of ca 1000 m. It worked only with the system pressure of 3.4 MPa. First pumping was in 1954 and in the period 1961–1963 almost the total amount of stored gas was obtained back. In the second cycle of pumping (August 1976 to October 1977) 33.5×10^6 m^3 of gas was stored. Gas recycling started by June 1980 because of its exhalations around boreholes. The expertise in the 1990s confirmed the leakiness of many installations and further exploitation of UGS Roztoki was stopped.

UGS Tarchały (active 1976–1993) was in Europe the first underground storage for helium obtained in Odolanów by a cryogenic process. It was pumped into the exhausted gas field Tarchały where a main reservoir was the Zechstein Limestone unit located at depth ca 1450 m. Since December 1976 till the end of 1993 5.5×10^6 m^3 of helium was recycled. After 1993 helium systematically is being picked up from the "Krio" factory in Odolanów and there is no need to use longer the UGS Tarchały. The worthwhile technical important information is that during the time of pumping and the receipt of helium it never mixed with a buffer gas. It results that melting of gases in UGS is a long-time process and in the buffer zone is worthwhile to use worse gases which probably will not mix with gases from the active zone.

UGS Brzeźnica (active 1979–present) was built in the exhausted gas field located in the Miocene deposits of the Carpathian Foredeep at depth ca 400 m, where sandstones are characterize with 24–27% porosity and a very high permeability. This storage uses only a gas system pressure of 3–4 MPa. Its active volume is ca 70×10^6 m^3 and the buffer gas capacity has ca 75×10^6 m^3. The alpha coefficient (a ratio: recovered/stored gas volume) is 0.98 it means that almost all stored gas is recycled.

UGS Swarzów (active 1979–present) is located at the depth of ca 650 m in carbonates of the Upper Jurassic deposits (the Cenomanian sandstones and the Turonian limestones). For its construction the exhausted gas field was used where bottom waters are very dynamic. Porosity of reservoirs is ca 27% and permeability is 800–3400 mD. Total capacity of storage is ca 200×10^6 m^3, where 90×10^6 m^3 is as an active gas. Working pressure varies from 6 MPa to 8.5 MPa.

UGS Strachocina (active from 1982) is built in the Carpathian sandstones, in two levels: I level at the depth ca 800 m (thickness of reservoir series — 75 m) and II level at the depth ca 900 m with 90 m thick reservoir series. Sandstone porosity is ca 20% and its permeability even to a

Fig. 2. Location of selected diapirs of Upper Permian salt and stratiform salt deposits for gas storage in Poland (salt diapirs after Garlicki & Szybist, 1988)

Table 3. Characteristics of some Permian salt diapir from the Polish Lowland area adapted or planned for hydrocarbons storages (salt caverns) (data after: Ślizowski & Saługa, 1996*; Ślizowski et al, 2004; Czapowski, 2006b; Gientka et al, 2007***)**

Name of salt diapir	Diapir size [km]/ area [km^2]	Salt mirror depth (min–max) [m]	Top depth (min–max) [m]	Thickness of caprock (min–max) [m]	Salt resources [10^9 t]
Goleniów	4.5 × 2/9	888	702.2	186.8	lack of data
Damasławek	3.5 × 5.5/16.5*	446–538.8	184–1050	2.5–294.1	17.69***
Mogilno (gas caverns)	5.8 × 1.5/8.7	220–260	84–100	160–170	5.56***
Góra (solution mine, oil & gas caverns)	1.2 × 1.1/1.32	103–143	19–69	several tens	2.35***
Izbica Kujawska	1.2 × 4.5/4**	224.5–556.5	143–412	27.7–207.2	1.5*
Lubień	2.2 × 3/5.2**	303–441.6	151.5–358	81.5–169	4.07***
Łanięta	3.3 × 3.7/9.5*	235.4–282.5	90–308.6	29.6–241.4	2.13***
Rogóźno	4.1 × 6.7/21**	325–427	54.5–328.8	12.8–286.3	8.61***
Dębina	0.6 × 0.9/0.5*	169.3–215	47.3–121	94–122	0.5*

few hundreds millidarcy. Working pressure of storage is 2.17–3.44 MPa. Present active capacity is 150×10^6 m^3 and in 2009 the 300×10^6 m^3 of active gas volume is planned at the end of investment.

UGS Husów (active 1987–present) is using the exhausted deposit of natural gas in the Miocene sandstones of the Carpathian Foredeep. Originally in the gas field, and recently within the underground gas storage the bottom waters are very dynamic. The storage is located at the depth ca 1250 m with a reservoir thickness 50 m. Sandstones have 26–29% porosity and a very high permeability. Active gas volume is 400×10^6 m^3 and the buffer capacity is estimated at 500×10^6 m^3. Working pressure varies from 6 MPa to 10.5 MPa. 34 boreholes are supporting the storage and 26 of them exploit the active zone.

UGS Wierzchowice (active from 1995 and developing till 2011) is located in the Zechstein Limestone unit, containing the methane-nitrogen gas (southern Fore-Sudetic Monocline). Storage is still under construction and its planned final active capacity will be 4.3×10^9 m^3, creating it the biggest underground gas storage in Poland.

UGS Jaśminy N (active 1999–present) is the small underground storage working out of system, only as a local gas delivery for Tarnów town. It is located in the Miocene sandstone of the Carpathian Foredeep with the active gas volume of 32×10^6 m^3 (alpha coefficient equals 0.97).

CUGS Mogilno (active from 1996 and developing till 2012) is built in caverns leached in the Mogilno salt diapir, in central Poland (Fig. 1), not so far from the Europe-Jamal gas pipeline. It is first cavern gas storage in Poland, which due to a high recovery can cover seasonal and peak of gas demands in the winter period. The storage is now constructed with 8 caverns located mostly at depth 1000 m b.s.l. (between 600 m to 1600 m) and next 12 caverns are planned until 2012 with the total volume of 738×10^6 m^3 (Kunstmann et al, 2002). Gas is stored there at the maximum pressure 21.3 MPa (op. cit.).

In the plans of the POGC is still construction of 2 underground storages for a high nitrogen gas: **UGS Daszewo** (2009) with the active gas capacity of ca 300×10^6 m^3 and **UGS Bonikowo** (2009) with the planned active capacity of 200×10^6 m^3. Near Gdańsk, within the Zechstein salts, the **CUGS Kosakowo** (located in the Mechelinki salt deposit) is planned with a gas capacity of 450×10^6 m^3.

Reinisch (2000) enthusiastically argued and recomended the opportunity of the UGS construction and he drew a scenario of building of sets of UGS with ability of ca 30×10^9 m^3 of active gas. He based on analyses of geological-technical deposits of the natural gas being exploited for a long time, but now almost exhausted. It is possible to state that Poland has serious possibilities of UGS construction and at favourable economic-political conditions activity in guarantying the fuels reserves by underground storage will be intensified, also with the international cooperation.

Environmental impact and economic importance of underground storage: Perspectives and problems

Underground gas storage characterises with a minimum impact on the environment. It "revitalize" the old gas and oil deposits by gas pumping within them (gas returns to "its primary place"), the surface infrastructure of such storages is very limited and commonly uses the former installations (no aerial expansion and possible pollutions).

Table 4. Characteristics of selected aquifers for underground gas storage in Poland (after Reinisch, 2000)

Aquifer name	Aquifer depth [m]	Type and age of aquifer rocks	Area [km^2]	Porosity [%]	Permeability [mD]	Hydrostatic pressure [MPa]	Storaged gas volume [10^9 m^3]
Chabowo	670–800	sandstones/ Lower Jurassic (Liassic) and Lower Cretaceous (Albian)	25	18–30	10–1330	6.5–7	0.5–1.5
Bielsk	1100–1200	sandstones/ Lower Cretaceous (Albian+Barrenian)	9	18–19	-	11–12	1–2.5
Bodzanów	1050–1150	sandstones/ Lower Cretaceous (Albian+Barrenian)	20	15–28	-	10–11.5	1–2.5
Drobin	1050–1150	sandstones/ Lower Cretaceous (Albian+Barrenian)	10	16–20	-	10–11.5	1–2.5
Kałuszyn	740–800	sandstones/ Lower Cretaceous	10	18–20	-	7.4–8	0.5–1.5
Gostynin	800–900	sandstones/ Lower Cretaceous (Albian)	15	19–22	-	8.9–9	0.5–1.5
Tuszyn	735–858	sandstones/ Lower Cretaceous (Albian)	30	11–30	10–9848	7.5–8.5	0.5–1.5

The underground reservoirs are very safety; any failure is limited only to the installation (break of such deep reservoir is almost impossible comparing to metal tanks on the ground surface) and easily repaired, but gas within the storage becomes almost untouched. So these storages are very friendly for the environment and their negative impact (e.g. large volumes of waters necessary for salt cavern leaching and resulted brines) is compensated by advantages. Sometimes these solution brines could be used to improve a local waters stage — commonly they are utilized by special plants — but the direct input of oxidized salt brines into anoxic, almost brackish waters of margin zone of Baltic Sea could revitalize them and enable a bloom of differentiated fauna and flora (e.g. a project for cavern solution near the Gdańsk Bay — after Pieńkowski, 2006).

Poland because of own limited resources of gas and oil has to import them and to locate in safety reservoirs, preparing reserves for short- (buffer ones) and long-time (strategic ones) consumption. The most safety storages (also against terrorist actions) are the underground ones, located in the exhausted oil and gas deposits (strategic gas reservoirs), salt bodies and aquifers. Such geological objects were selected in Poland and they actually guarantee the sufficient volumes for planned gas reserves.

Construction of safety gas storages in Poland allows to: a) mineralize the negative effects of prize fluctuations in the world fuel market, b) choose various gas producers and consequently — to limit any political pressure, c) guarantee the energetic reserves for national economy and — within the European Union energetic system — also reserves for Union members, d) to sell the surplus gas volume to other countries.

Conclusions

1. In Poland acceleration of underground gas storage (UGS) construction was observed from the end of the 1980s. Present active UGS capacity amount is 1.58×10^9 m^3 but after ending of construction processes and expansion of realized objects, this volume will reach 2.8×10^9 m^3.

2. New built UGS are located in western and northern Poland (until now there was no UGS in this part of country). Special attention is paid to the Wierzchowice UGS (the biggest one in Poland) and for leaching of caverns in the Zechstein salts (CUGS Mogilno and CUGS Kosakowo). Reservoirs of cavern type (expensive under construction) are a very efficient, modern source of gas system supply, particularly in periods of the seasonal and top gas demands in the winter period. Caverns in salts enable also to store liquid hydrocarbons.

3. Poland location in the central place in Europe forces the UGS building there for guarantee a safety gas supply in this part of continent. Poland indeed has not so large gas consumption as Ukraine and Belarus on the east and Germany on the west, but the assurance of regular gas and oil supplies worth incurrence of the troubles and costs of the UGS construction.

4. Construction of the UGS takes place mostly in the exhausted gas fields, discovered and exploited by the *Polish Oil and Gas Company*. Experience and capital of the state company make it the leader in construction and exploitation underground storages in Poland.

5. Geological conditions in Poland and a considerable quantity of exhausted gas deposits favourable in nearest years for the UGS construction make the quite real final UGS capacity of 30×10^9 m^3. Economical boom in the oil and gas market during last years created new challenges for construction and exploitation of such storages.

6. Construction of underground storages has the minimum influence on the environment. Utilization of exhausted petroleum and salt (seldom, e.g. the Góra leaching salt mine) deposits, often with the existing infrastructure, is not so troublesome for population and the environment and it brings considerable practical and economic benefits.

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