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Drilling of geothermal boreholes and casing design in Poland

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ABSTRACT

Geothermal boreholes have to be designed and done as engineering facilities, i.e. they have to meet requirements resulting from their location and aim so as to ensure durability, maintenance and conditions for proper exploitation. The construction of the borehole is one of key elements which need to be designed.

In the paper, geothermal boreholes are boreholes for production and injection of thermal waters for heating and recreation. Boreholes for geothermics in spas (crenotherapy, bathing, balneotherapy) and geothermal boreholes involving heat pumps were not analyzed. Construction of existing geothermal boreholes in Poland is presented. The focal point is the piping and materials used for it. The paper presents dates of construction, method of aquifer production and type of closure for boreholes. Additionally, production boreholes are presented along with their efficiency and the temperature of produced water measured at the head.

1. INTRODUCTION

In many cases of geothermal systems, a geothermal doublet is being used, which consists of two wellbores: one for injection and the other for production, which are interconnected with a pumping pipeline (Biernat et al. 2012a, Kowalski 2014).

Geothermal boreholes may be vertical or directional. Casing pipes constituting particular columns are normally made of steel. The material, however, is prone to corrosion. Thus, plastics and fiberglass has been increasingly used for building geothermal boreholes in recent years (Sapińska-Śliwa et al. 2013).

Upon the selection of materials, the project should account for their chemical and thermal resistance when facing thermal waters, as well as mechanical resistance and durability, which is a significant issue for proper production (Kępińska et al. 2011). A proper selection of materials for casing pipes, especially for those in the production columns, should take into account prevention and/or reduction of corrosion as well as the precipitation of secondary minerals and their consequences (Kowalski 2014).

In Poland and other countries, geothermal boreholes are most often fitted with steel pipes. While selecting the type of steel used for casing pipes, one should avoid carbon steel and low-alloy steel, because they are highly vulnerable to corrosion. In many cases, non-alloy steel, namely J–55 and N–80 types, found its use. The former was used in Pyrzyce GT-4 (Biernat et al. 2010b), while the latter in Lidzbark Warmiński GT–1 (Biernat et al. 2010c).While selecting steel pipes, one should take special care about the physico-chemical properties of thermal waters; especially the type and volume of mineralization, share of gases and the mechanical durability of the steel (Kępińska et al. 2011).

Furthermore, lining the inside of steel pipes with plastic has found wide application. Apart from eliminating the corrosion, this procedure aims to improve the hydraulic properties of the water flow. Applying an inner coating is becoming more popular in reconstruction of operating boreholes, recovering their injectivity and productivity. An example of steel pipes with an inner coating are Pyrzyce GT–2 and Pyrzyce GT–4 boreholes, property of Geotermia Pyrzyce Sp. z o. o. Highly dense polyethylene was used as the coating. Covering steel pipes with HDPE happened in 2007 – 2009, several years after the boreholes had been launched (Biernat et al. 2012a).

Another type of pipes that found its use in the construction of geothermal boreholes is pipes made of plastic (e.g. polyethylene). However, they are used only in shallow wells and borehole heat exchangers, and surface geothermal installations (e.g. pumping pipeline between Uniejów PIG/AGH–2 and Uniejów PIG/AGH–1 boreholes). Given the small mass, they are cheaper in transportation and need a device with a lower load upon submersion. Plastic pipes deform quicker and their durability heavily relies on the temperature. They may be irreversibly squeezed by the hydrostatic pressure during drilling upon extra low level of the reservoir fluid. The majority of plastics is permeable for gases, including oxygen, which is detrimental in the production of thermal waters (Sapińska-Śliwa 2010, Kowalski 2014).

Another method preventing corrosion is fitting the geothermal borehole with a production column made of fiberglass (Ungemach 2004). Fiberglass pipes are more vulnerable to mechanical damage than steel pipes, which is their biggest disadvantage. They require special procedures while being transported and stocked. It relates mostly to securing the pipes, because any damage done to their surface influences their strength negatively.

However, the advantages of such pipes include high resistance to corrosion during production and injection of thermal waters. The lifetime of the installation is longer and the cost related to anti-corrosion procedures is reduced. Thanks to low weight, one may also reduce the cost of transportation and setting the pipes inside the borehole. Another advantage is the minimization of flow resistance owing to the fact that pipes reinforced with fiberglass have a smooth inner surface (Busser and Sliwa 2004). Fiberglass reinforced pipes are being used more often in geothermal installations all over the world (Kowalski 2014). The comparison of materials for casing pipes used in geothermal borehole installations and production columns is presented in table A.

The main issue while designing and exploiting geothermal resources is corrosion and precipitation of secondary minerals in the water circuit installation (Banaś et al. 2006). Corrosion of geothermal systems is an electro-chemical process involving the mineral ingredients of water; it is the result of numerous interrelated reactions of oxidation and reduction (Banaś et al. 2010). Thermal water is in many cases is chemically aggressive. The aggression of thermal water relies predominantly on its chemical composition and production parameters, such as: flow rate, temperature and pressure (Biernat et al. 2010b). The main cause of corrosion of steel elements in geothermal systems is the presence of dissolved carbon dioxide and hydrogen sulfide. Their presence causes severe corrosion even in thermal waters with low mineralization (Banaś et al. 2006).

The phenomenon of corrosion is noticed mainly in injection boreholes and surface pipelines. Exploitation of surface pipelines leads to spot corrosion. Its occurrence results in damage to the inner surface of pipes. It may lead to perforations, which consequently results in leaks. It is, however, possible to eliminate or limit the influence of corrosion on colmatage of the reservoir area. It may be achieved by selecting corrosive-resistant filters and pipes. In new geothermal borehole projects, which will be carried out, the issue of corrosion may be solved by using fiberglass pipes or pipes coated inside with highly dense polyethylene (Biernat et al. 2010 b).

When exposed to thermal water flow, steels, which are used in geothermal borehole piping, are subjected to general corrosion with tightly adhering sediment (corrosion product). General corrosion is characterized by even loss of the outer layer of the material resulting from reactions of components of the metal with aggressive components of thermal waters. This kind of corrosion may be prevented through the proper selection of materials for water production, use of corrosion inhibitors and electro-chemical protection (Surowska 2002).

Apart from corrosion, there is another detrimental phenomenon in geothermal boreholes – precipitation of secondary mineral substances. Its intensity depends on the chemical composition of water. It results in colmatage of installations and reservoir rocks. It worsens the conditions of production and injection of thermal waters. It mainly influences the cost of equipment and exploitation of geothermal plants. The precipitation of secondary mineral compounds occurs in Polish and foreign geothermal installations to a different extent. Forecasting the possible precipitation of mineral substances from thermal waters is possible thanks to the water thermo-dynamic state modeling in water – rock system. It should be investigated and considered not only at the early stage of designing the geothermal installation but also opening and testing the reservoir, as well as at the stage of production and injection (Tomaszewska 2008, Kępińska et al. 2011).

There are many methods limiting processes and results of corrosion, and precipitation of secondary mineral substances in geothermal installations. They are mainly used for stimulation and reconstruction of boreholes and geothermal reservoirs. Their aim is to recover production parameters in geothermal systems. These methods include: application of inhibitors, soft acidizing treatments and processes using non-organic and organic acid solutions (Kępińska et al. 2011).

2. GEOTHERMAL BOREHOLE INSTALLATION REVIEW

Collective data referring to parameters of geothermal boreholes in Poland is presented in table B.

A geothermal doublet (triplet etc.) includes injection and production boreholes. The purpose of production boreholes is to harvest thermal water present in the aquifer. They often involve a pumping chamber. Injection boreholes are used for injecting the thermal water into the aquifer, which it was produced from, having harvested the energy contained within (Biernat et al. 2012a, Kowalski 2014).

Boreholes used for harvesting geothermal energy may be boreholes drilled specially for geothermal purpose as well as ones drilled earlier for other reasons (e.g. oil wells or prospecting boreholes). After their reconstruction and adaptation for geothermal needs, they are used as geothermal wells. Currently in Poland, the majority of boreholes is drilled for geothermal purposes. There is a differentiation between archival and new wells. Archival wells are boreholes drilled for geothermal needs, which needed several years of reconstruction to produce thermal waters and prospecting boreholes for oil and gas, and then adapted for geothermal purposes. Exemplary wells are in Uniejów: Uniejów PIG/AGH-1 and Uniejów PIG/AGH-2. New wells are wells made nowadays for thermal water production. For example Toruń TG-1 and Bańska PGP-3. The majority of geothermal boreholes is vertical, but there are also directional boreholes in Poland: type J (Stargard Szczeciński GT-2) and type S (Bańska PGP-3). While analyzing the construction of geothermal boreholes, one should also pay attention to the type of construction of the bottom section. It may be a barefoot section (uncased) with a normal or widened diameter in the aquifer zone, a filtered section or a cased section with perforations after cementing (Sapińska-Śliwa et al. 2013, Kowalski 2014).

Tab. A. Comparison of materials used in the construction of geothermal boreholes for casing pipes,the production column, and the surface installation (Biernat et al. 2010b, Biernat et al. 2012a, Kowalski 2014, Sapińska-Śliwa et al. 2013)

Type of material	Description	Example of application
STEEL	Non-alloy highly durable steel was mostly used. Carbon and low-alloy steel was not applied due to corrosion.	Lidzbark Warmiński GT-1, Poddębice GT-2, Mszczonów IG-1, Piaseczno GT-1
STEEL WITH INNER COATING	Using an inner coating made of polymer plastic enables the application of steel pipes even in conditions that would otherwise require much more expensive, high quality materials. Polymer plastics for steel pipe lining should fit the temperature of thermal waters. One should also pay attention to the permeability of polymers and gas absorption, including oxygen and carbon dioxide. Pipe columns with an inner coating are installed as production columns after the drilling is finished.	Pyrzyce GT-2, Pyrzyce GT-4
PLASTIC	They are highly resistant to corrosion. Pipes made of plastic deform quicker and their durability relies heavily on the temperature of the flowing medium.	pumping pipeline between Uniejów PIG/AGH–2 and Uniejów PIG/AGH–1
FIBERGLASS	Most important advantages of applying fiberglass pipes in geothermal boreholes and surface installations are resistance to H_2S – CO_2 corrosion, no need for cathode protection, low specific weight, and smooth inner surface (ensuring low flow resistance). Fiberglass is a better thermal insulator than steel. It enables the reduction of heat loss while transporting geothermal waters.	Toruń GT-1, KleszczówGT-2

Construction of geothermal boreholes requires proper design and selection of (Sapińska-Śliwa et al. 2013):
– a pumping chamber, upon lack of self-flow, to increase the efficiency of the thermal water or sustain a proper pressure,
– a production column, which should be selected in concord with environmental conditions and be resistant to high temperatures and certain level of mineralization,
– the type and the construction of a screen, which greatly influences the hydraulic efficiency of the borehole,
– sealing resistant to high temperatures and brine activity.

The list below presents the construction of geothermal boreholes in Poland.

2.1 Bańska IG-1

The borehole was piped in the following way (Sokołowski 1992):
– from 0 to 29 m – casing pipes 18 5/8",
– from 0 to 423 m – casing pipes 13 3/8",
– from 0 to 2545 m – casing pipes 9 5/8",
– from 2372 m to 3389 m – pipes 6 5/8"inserted in the drill string and cemented. After perforation and probing the aquifers, column 6 5/8" was inserted from 2372 m to the top and cemented. The top was fitted with a production head.
– in the interval 2740 – 5261 m the borehole was liquidated.

2.2 Bańska PGP-1

The borehole was piped in the following way (Wardzała and Kilar 2009):
– from 0 to 20 m – casing pipes 20",
– from 0 to 508 m – casing pipes 13 3/8",
– from 0 to 2681 m – casing pipes 9 5/8",
– from 2660 to 2722 m – casing pipes 7",
– from 2722 to 3032 m – perforated casing pipes 7 5/8".

2.3 Bańska PGP-3

The borehole was piped in the following way (Wartak 2013):

- from 0 to 50 m – pipes 18 5/8”,
- from 0 to 494 m MD (from 0 to 492.4 m TVD) – pipes 13 3/8”,
- from 0 to 2744 m MD (from 0 to 2624.8 m TVD) – pipes 9 5/8”,
- from 2706.2 m to 3500.0 m MD (from 2587.1 m to 3380.7 m TVD) – pipes 7”.

2.4 Biały Dunajec PAN-1

The borehole was piped in the following way (Jaromin et al. 1992a):

- from 0 to 23 m – pipes 20” cemented to the top,
- from 0 to 295 m – pipes 13 3/8” cemented to the top,
- from 0 to 2135 m – pipes 9 5/8” cemented to the top,
- from 0 to 2121 m – siphon pipes 2 7/8”.

2.5 Biały Dunajec PGP-2

The borehole was piped in the following way (Wardzała and Kilar 2009):

- from 0 to 19 m – casing pipes 20”,
- from 0 to 495 m – casing pipes 13 3/8”,
- from 0 to 2051 m – casing pipes 9 5/8”,
- from 2040 m to 2450 m – casing pipes 7 5/8”, perforated from 2051 m.

2.6 Lidzbark Warmiński GT-1

The borehole was piped in the following way (Biernat et al. 2010c):

- from 0 to 260 m – pipes 473.0 mm made of steel N-80,
- from 0 to 350 m – pipes 339.7 mm made of steel N-80,
- from 250 m to 850 m – pipes 244.5 mm made of steel N-80,
- from 832 m to 856 m – pipes 169 mm,
- from 856 m to 1018 m – working part of Johnson’s screen,
- from 1018 to 1030 m – pipes 169 mm.

2.7 Mszczonów IG-1

The borehole was piped in the following way (Bujakowski 2015):

- from 0 to 49 m – pipes 20”,
- from 0 to 508 m – pipes 13 3/8”,
- from 26 to 3105 m – pipes 9 5/8”.

2.8 Poręba Wielka IG-1

The borehole was piped in the following way (Bujakowski et al. 2010):

- from 0 to 3 m – pipes 24” cemented to the top,
- from 0 to 14 m – pipes 20” cemented to the top,
- from 0 to 305.2 m – pipes 13 3/8” cemented to the top,
- from 0 to 928 m – pipes 9 5/8” cemented to the top,
- from 0 to 1804.2 m – pipes 6 5/8” cemented to the top,
- from 1749.8 to 2002.4 m – pipes 4 ½” screen column left uncemented. (or 1749.8 to 1797.3 m pipes 4 ½”, 1797.3 to 1898.1 m filter perforated pipes 4 ½”, 1898.1 to 2002.4 m pipes 4 ½”).

2.9 Poronin PAN-1

The borehole was piped in the following way (Jaromin et al. 1992b):

- from 0 to 23 m – pipes 20” cemented to the top,
- from 0 to 399 m – pipes 13 3/8” cemented to the top,
- from 0 to 2014 m – pipes 9 5/8”, cemented in the interval 1460-2014 m, the extra-pipe space above was filled with dense drilling fluid,
- from 0 to 1752 m – pipes 6 5/8”, II section cemented to the top,
- from 1905 m to 2995 m – pipes 6 5/8”, I section cemented on the whole length,
- from 0 to 1768 m – siphon pipes 2 7/8”.

2.10 Pyrzyce GT-1 and Pyrzyce GT-3

Pyrzyce GT-1 and Pyrzyce GT-3 boreholes have the same piping scheme (Biernat 1993, Wardzała and Kilar 2009,):

- from 0 to 6,5 m pipes 28”,
- from 0 to 200 m – casing pipes 18 5/8”,
- from 0 to 507 m – casing pipes 13 5/8”,
- from 394 m to 1480 m – casing pipes 9 5/8”,
- from 1451 m to 1612 m – Johnson’s screen 6 5/8”with a gap 0.5 mm.

2.11 Pyrzyce GT-2 and Pyrzyce GT-4

Pyrzyce GT-2 and Pyrzyce GT-4 boreholes have the same piping scheme (Biernat 1993, Wardzała and Kilar 2009;):

- from 0 to 147 m – casing pipes 13 5/8”,
- from 0 to 1408 m – casing pipes 9 5/8”,
- from 379 m to 1523 m – Johnson’s screen 6 5/8”.

2.12 Skierniewice GT-1

The borehole was piped in the following way (Wardzała and Kilar 2009, Kępińska et al. 2011):

- from 0 to 30 m – casing pipes 20”cemented to the top,
- from 0 to 640 m – casing pipes 13 5/8”cemented to the top,
- from 500 m to 2775 m – casing pipes 9 5/8”,cemented with overlap,
- from 2675 m to 3000 m – Johnson’s screen set, no cement,
- from 2864 m to 2940 m – wire filter 6 5/8”.

2.13 Skierniewice GT-2

The borehole was piped in the following way (Wardzała and Kilar 2009, Kępińska et al. 2011):

- from 0 to 37 m – casing pipes 20”, cemented to the top
- from 0 to 882 m – casing pipes 13 5/8”, cemented to the top
- from 777 m to 2797m – casing pipes 9 5/8”, cemented with overlap
- from 2771 m to 2886m – Johnson’s screen set in gravel pack.

2.14 Stargard Szczeciński GT-1 and Stargard Szczeciński GT-2K

Stargard Szczeciński GT-1borehole was piped in the following way (Wardzała and Kilar 2009):

- from 0 to 32 m – casing pipes 18 5/8”,
- from 0 to 411 m – casing pipes 13 3/8”,
- from 322 m to 2421 m – casing pipes 9 5/8”.

Stargard Szczeciński GT-2Kborehole was piped in the following way (Wardzała and Kilar 2009):

- from 0 to 60 m – casing pipes 20”,
- from 0 to 425 m – casing pipes 13 3/8”,
- from 320 m to 2780 m – casing pipes 9 5/8”.

2.15 Toruń GT-1 and Toruń GT-2

Toruń GT-1 borehole was piped in the following way (Wardzała and Kilar 2009):

- from 0 to 82 m – casing pipes 24”,
- from 0 to 403 m – casing pipes 16” made of fiberglass,
- from 0 to 1894 m – casing pipes 9 5/8”,
- from 1794 m to 2770 m – casing pipes 7” liner.

In Toruń GT-2 borehole, based on a project, the piping was designed in the following way (Sapińska-Śliwa et al. 2013):

- from 0 to 100 m – casing pipes from steel N-80 18 5/8” in diameter,
- from 0 to 1928 m – pipes made of fiberglass 9 5/8” of outer diameter and 209 mm of inner diameter,
- from 1898 m to 2352 m – Johnson’s pipe-and-wire screen 6 5/8” with the working section 274.5 m.

2.16 Trzęsacz GT-1

The borehole was piped in the following way (Trzęsacz GT-1):

- from 0 to 58 m – pipes 18 5/8”,
- from 0 to 292 m – pipes 13 3/8”,
- from 205 m to 1036 m – pipes 9 5/8”,
- screen below.

2.17 Uniejów IGH-1

The borehole was piped in the following way (Sapińska-Śliwa 2010):

- from 0 to 11 m – pipes 20” cemented to the top,
- from 0 to 100 m – pipes 13 3/8” cemented to the top,
- from 0 to 848 m – pipes 9 5/8” cemented to the top,
- from 678 m to 1882 m – pipes 6 5/8” cementedin the interval 678 m to 1882 m,
- from 1842.40 m to 1927.46 m – pipes 4 5/8”,
- from 1927.46 m to 2078.6 m – active section of the screen 4 5/8”,
- from 2078.6 m to 2100.00 m – pipes 4 1/2”.

2.18 Uniejów PIG/AGH-1

The borehole was piped in the following way (Sapińska-Śliwa 2010):

- from 0 to 65 m – pipes 13 3/8” cemented to the top,
- from 0 to 541 m – pipes 9 5/8” cementedin the interval 125 m to 541 m,
- from 0 to 2065 m – pipes 6 5/8”,
- from 1918 m to 2045 m – perforated pipe screen, with gaps 150x8 mm,
- from 2045 m to 2065 m – pipes.

2.19 Uniejów PIG/AGH-2

The borehole was piped in the following way (Sapińska-Śliwa 2010):

- from 0 to 30 m – pipes 13 3/8” cemented to the top,
- from 0 to 457 m – pipes 9 5/8” cemented to the top,
- from 200 m to 2031 m – pipes 6 5/8”,
- from 200 m to 1892 m – pipes,
- from 1892 m to 2025 m – perforated pipe screen,
- from 2025 m to 2031 m – pipes,
- from 0 to 87 m – production pipes 5”.

Tabela B. Collective data on geothermal borehole parameters in Poland (based on Biernat 1993, Biernat et al. 2010c, Biernat et al. 2012a Bujakowski 2010, Bujakowski et al. 2013, Bujakowski 2015, , Dubielet al. 2012, Jaromin et al. 1992a, Jaromin et al. 1992b, Jasnos et al. 2012, Kępińska 2004, Kępińska and Ciągło 2008, Kępińska et al. 2011, Kleszcz and Tomaszewska 2013, Mazurkiewicz 2012, Noga et al. 2011, Noga et al. 2013b, Sapińska-Śliwa 2010, Sapińska-Śliwa et al. 2013, Sokołowski 1992, Ślimak and Okularczyk 2014, Wardzała and Kilar 2009, Wartak 2013)

Borehole name	Year of construction	Depth, m	Reservoir, m^3/h	Aquifer opening	Thermal water temperature at the head, °C	Borehole type	Borehole purpose	Spatial orientation	Construction material: technical column/pumping column	Borehole bottom
Bańska IG-1	1979/81	5261	120	Middle Triassic	82	Archival	Production	Vertical	Steel/-	Perforated in borehole
Bańska PGP-1	1997	3242	550	Middle Triassic	87	New	Production	Vertical	Steel/-	Perforated on surface, 3032-3242 m uncased
Bańska PGP-3	2012/2013	3500	290	Middle Triassic	85.5	New	Production	Directional	Steel/-	Filtered
Biały Dunajec PAN-1	1989	2394	200*	Middle Triassic	-	New	Injection	Vertical	Steel/-	Perforated in borehole, 2132-2394 m uncased
Biały Dunajec PGP-2	1996/97	2450	400*	Middle Triassic	-	New	Injection	Vertical	Steel/-	Perforated on surface
Gostynin GT-1	2007/08	2734	120	Lower Jurassic	82	New	Production	Vertical	Steel/steel	Widened, bare foot
Kleszczów GT-1	2009	1620	200 or 150	Lower Jurassic	52	New	Production	Vertical	Steel/steel	Non-widened, bare foot
Kleszczów GT-2	2010/11	1725	240.6****	Lower Jurassic and Mid Jurassic	45.9****	New	Injection	Vertical	Fiberglass/-	Widened, filtered
Lidzbark Warmiński GT-1	2011	1200	120	Lower Jurassic	24	New	Production	Vertical	Steel/steel	Widened, filtered
Mszczonów IG-1	1976	4119	60	Lower Cretaceous	40	Archival	Production	Vertical	Steel/steel	Perforated pipes
Piaseczno GT-1	2011/12	1982	120	Lower Jurassic	45	New	Production	Vertical	Steel/steel	Widened, filtered
Poręba Wielka IG-1	1973/75	2002.4	12.1 self-flow in 1976	Upper Cretaceous	42	Archival	Production	Vertical	Steel/-	Filtered
Poddębice GT-2	2009/10	2101	115	Lower Cretaceous	72	New	Production	Vertical	Steel/steel	Widened, filtered
Poronin PAN-1	1988/89	3003	90	Middle Triassic	63	New	Out-of-order	Vertical	Steel/-	-
Pyrzyce GT-1	1992	1632	340	Lower Jurassic	61 or 63	New	Production	Vertical	Steel/steel	Widened, filtered
Pyrzyce GT-2	1992/93	1523	340	Lower Jurassic	61 or 63	New	Injection	Vertical	Steel/-***	Widened, filtered

Pyrzyce GT-3	1992/93	1632	-	Lower Jurassic	-	New	Production	Vertical	Steel/steel	Widened, filtered
Pyrzyce GT-4	1992/93	1523	-	Lower Jurassic	-	New	Injection	Vertical	Steel/-***	Widened, filtered
Skierniewice GT-1	1990/91	3001	59.8**	Lower Jurassic	57.2**	New	Out-of-order	Vertical	-	Filtered
Skierniewice GT-2	1996/97	2900	57.4**	Lower Jurassic	56.1**	New	Out-of-order	Vertical	-	Widened, filtered
Stargard Szczeciński GT-1	2001	2670	200	Lower Jurassic	87	New	Production/injection	Vertical	Steel/steel	Widened, filtered
Stargard Szczeciński GT-2K	2003	3080	-	Lower Jurassic	-	New	Injection/ production	Directional	Steel/steel	Widened, bare foot
Tarnowo Podgórne GT-1	2010	1200	220	Lower Jurassic	44	New	Production	Vertical	Steel/steel	Widened, filtered
Toruń GT-1	2008/09	2925	350	Lower Jurassic	64	New	Production	Vertical	Steel/fiberglass	Widened, filtered
Toruń GT-2	2009	2352	-	Lower Jurassic	-	New	Injection	Vertical	Fiberglass/-	Widened, filtered
Trzęsacz GT-1	2012	1200	180	Lower Jurassic	27	New	Production	Vertical	Steel/steel	Widened, filtered
Uniejów IGH-1	1978	2245	55.8	Lower Cretaceous	-	Archival	Injection	Vertical	Steel/-	Filtered
Uniejów PIG/AGH-1	1990/91	2065	80.5*	Lower Cretaceous	-	New	Injection	Vertical	Steel/-	Perforated pipes
Uniejów PIG/AGH-2	1990/91	2031	120	Lower Cretaceous	68 or 69.2	New	Production	Vertical	Steel/steel	Perforated pipes

*injectivity; **in 2010; ***at the turn of 2008/09 HDPE plastic pipes were installed inside steel pipes; ****In the case of Kleszczów GT-2 borehole, the recorded production efficiency is 240.6 m^3/h. The temperature recorded at the output in Kleszczów GT-2 (45.9°C) is lower than the one recorded in Kleszczów GT-1 (52.2°C) despite the bigger depth (Kleszczów GT-1 - 1620 m, Kleszczów GT-2 - 1725 m).

Additionally, there are other boreholes in Poland: Gostynin GT-1, Kleszczów GT-1, Kleszczów GT-2, Piaseczno GT-1, Poddębice GT-2, Tarnowo Podgórne TG-1, Poręba Wielka IG-1, which were not included in the bibliography. Geothermal wells in Krynica Zdrój and in Celejów did not give expected thermal water efficiency and were not included in the description. There are numerous intakes of underground waters of high temperatures, which are used solely for balneo-therapeutic purposes and are not presented in the paper.

The total heating efficiency (excluding heat pumps) amounts to 98.84 MW. The amount of sold geothermal energy is 742.6 TJ, out of which 633 TJ is for space heating. In 2014 six geothermal space heating plants were operational: in the Podhale region (since 1994), in Pyrzyce (since 1996), in Mszczonów (since 1999), in Uniejów (since 2001), in Stargard Szczeciński (since 2012, re-opened after closure in 2008) and in Poddębice (since 2013) (Kępińska 2015).

3. CONCLUSIONS

Currently there are 29 geothermal boreholes in Poland.

First geothermal boreholes in Poland were only vertical and made of steel pipes. Currently, there are directional boreholes and fiberglass pipes are used, which reflects the development of techniques and technology.

During production, the construction of boreholes is often changed. Reconstructive works include cutting pipes out, anti-corrosive coating, milling, additional cementing etc. According to this, the presented constructions may not reflect the real state. Reconstructive works are not always described in literature.

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