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DRILLING INTAKE WELLS IN CARBONATE FORMATIONS TO PROVIDE WATER FOR DRILLING PURPOSES

Abstract: The realization of drilling works oriented towards the prospection and extraction of hydrocarbons from conventional and unconventional resources requires the supply of large amounts of water for technological purposes and fracturing jobs in shale formations. One of the important sources of water supply for wellbores may be useful groundwater levels taken in by deep wells.

Technological processes accompanying drilling works and other technological operations require large amounts of water in a short period of time. The possibility of drilling intake wells at the drilling site significantly reduces the costs of acquiring the necessary quantities of water and facilitates its transfer to technological installations. Such wells must have high yields. Accordingly, this necessitates drilling wells with a relatively large diameter to accommodate filters with a large active surface area, a considerably thick gravel pack, and a high-capacity pumping unit.

Drilling large diameter intake wells in difficult geological conditions using the rotary percussion method with simultaneous casing is much more efficient than the water-based rotary mud or percussion methods used to date.

This paper presents principles for selecting technological parameters of drilling large diameter wells in difficult geological conditions using the percussion-rotary method with simultaneous casing. Among the main advantages of this method (as compared to the rotary method with drilling fluid) is its high RPM and the related lower cost of the well. Eliminating water-based drilling mud has a positive effect on the hydraulic efficiency of the well and enhancement work can be omitted in many cases.

Keywords: well drilling, percussion-rotary drilling, down-the-hole hammer, drilling technology, well drilling, wellbore structures

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1. INTRODUCTION

Hydraulic fracturing of rocks, especially in the horizontal borehole sections, is a typical element of drilling operations aimed at extracting natural gas from conventional and unconventional deposits. Such operations require the collection of large quantities of water in advance at the drilling site to prepare the fracturing fluid. One of the most important sources of water for supplying wellbores are useful aquifers which in the Polish hydrocarbon deposit areas lie at a depth of dozens of meters to several hundred.

One of the most promising regions in Poland as far as conventional and unconventional deposits are concerned may be the Lublin Basin with the Mesopaleozoic basement formations (Cretaceous, Jurassic, Triassic, Carboniferous, Devonian, Cambrian) [1–3]. The useful aquifer occurring in that area is mainly connected with the Upper Cretaceous formations represented by marls, chalks, limestones as well as gaizes [4]. Groundwater in such formations may be effectively recovered by rotary drilling with drilling mud and by percussive-rotary drilling with down-the-hole hammers. For drilling formations with high compressive strength, but with well-developed karst or numerous zones of carbonate rock debris, the percussion-rotary method with simultaneous casing is particularly effective. Under such conditions, high values of drilling velocity and high hydraulic efficiency of intake wells can be achieved [5–7].

2. HYDROGEOLOGICAL CHARACTERISTICS OF THE LUBLIN BASIN

Groundwater within the Lublin Basin occurs in the Quaternary, Upper Cretaceous and Upper Jurassic formations [4]. The Quaternary horizon in the analyzed area is of minor importance and is mainly built of gravels, sands with gravels and sands interlayered with silts, loams and clays. These formations occur generally in river valleys deeply wedging into the Cretaceous subsoil. The Quaternary waters are hydraulically connected with waters in the Cretaceous horizon to form a Quaternary-Cretaceous horizon. The Quaternary formations are supplied with infiltrating rain waters and lateral inflows from the Cretaceous horizon in the buried valleys [4]. Figure 1 shows schematically the stratigraphic extent of the main useful aquifer (MUA) under the concession for the exploration and prospecting of natural gas deposits in shale formations [1].

In the predominant part of the Lublin Basin, the useful aquifer is connected with the Upper Cretaceous formations developed mainly as marls, chalks, limestones and gaizes. Rock debris with favourable infiltration parameters occurs in the top of the gaizes to a depth of 2–6 m. The marl and chalk rocks are interlayered with thin and poorly permeable weathered clays. Below the weathered zone, the rock massif is cut by a system of cracks accompanying tectonic dislocations. The assumed depth of the lower boundary of the water circulation zone in the discussed area is 160 m.

The Cretaceous aquifer is recharged mainly by infiltrating rain waters, which get into the aquifer directly, and water gradually soaking through the permeable Quaternary cover. The water level of the Upper Cretaceous aquifer on uplands is usually free, and sporadically slightly tight. It stabilizes at a depth of 37 m to 66 m. Depending on the local geological and hydrogeological conditions, the depth of intake wells in this region ranges from 50 m to 120 m [4]. The yield of the wells in this region is very diversified and ranges from 0.2 m^3/h to 230 m^3/h (average 20–40 m^3/h).

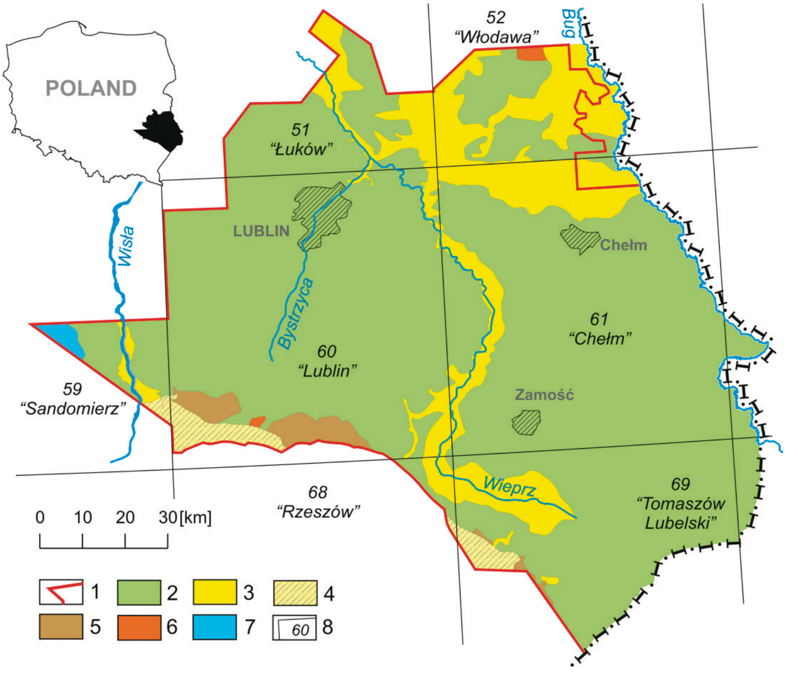

Fig. 1. Range of MUA stratigraphic units in the Lublin Basin concession area [1]:
1 – concession area as of 30.04.2013, 2–7 MUA in: (2) Upper Cretaceous, (3) Upper Cretaceous and Quaternary, (4) Quaternary, (5) Upper Quaternary and Tertiary, (6) Tertiary, (7) Upper Jurassic, 8 – boundary, sheet number and name from *Mapa hydrologiczna Polski w skali 1 : 200 000*

3. WELL CONSTRUCTION FOR GROUNDWATER EXTRACTION FROM CARBONATE FORMATIONS

An intake well consists of one or more casing columns and a filter column. The number of casing columns depends on the depth of the well, its purpose, geological and hydrogeological conditions, adopted drilling method, type and scope of tests performed in the well and the water extraction method [5, 8]. In many intake wells, especially in the shallow ones, the role of the casing is overtaken by the filter column driven up to the surface. Each intake well should be equipped with a housing on the ground surface to protect the well against structural damage or contamination of the aquifer. It also facilitates proper installation of the technical elements, i.e. valves, pressure gauge, water meter, etc.

When drilling intake wells with the rotary-percussion drilling method with down-the-hole hammers, two-column structures with surface casing and production casing are most often implemented. Other columns are used rarely, mainly in the following situations [1, 4, 9]:

- opening out deep-seated aquifers.
- need to isolate aquifers with unfavourable hydrochemical parameters,
- escapes of drilling mud,
- complications and drilling failures associated with crumbling of eroded carbonate rocks and loose material filling the drilled caverns.

Figure 2 shows the most common casing schemes for intake wells drilled with the rotary-percussion drilling method with down-the-hole hammers.

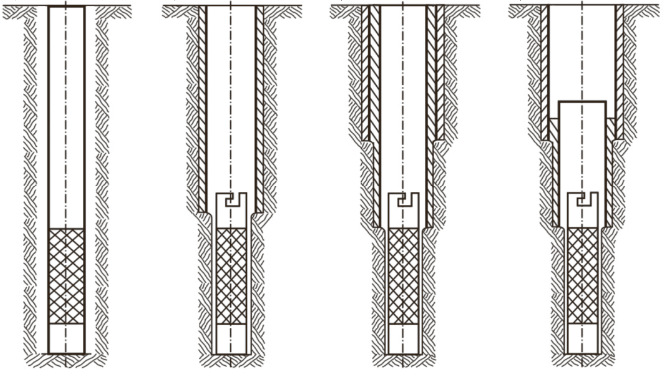

Fig. 2. Schematics of hydrogeologic well with filter [8]

Due to the considerable variability of geological and hydrogeological conditions in the Lublin Basin area, groundwater may be extracted by means of normal and large diameter wells (Tab. 1). Normal diameter wells should be drilled when intaking water from low permeability formations with a filtration coefficient $k > 1 \cdot 10^{-5}$ m/s [3]. In the case of highly permeable water-bearing formations, i.e. when there is a permeability coefficient $k = 1 \cdot 10^{-3}$ to $k = 1 \cdot 10^{-4}$ m/s, groundwater production should be carried out by large diameter wells. In such wells it is possible to install large diameter filters with a thick gravel pack. This solution allows for the installation of high rate pump units.

Table 1

List of standard and large diameter intake wells designs performed with the rotary-percussion drilling method with down-the-hole hammers, proposed for the Lublin region

Type of well	Design variant	Casing column	Drill bit diameter D_B [m]	Outer diameter of casing D_C [m]	Clearing [m]
Normal diameter	I	Surface casing Filter casing	0.478 0.374	0.457 0.195	0.021 0.179
	II	Surface casing Filter casing	0.530 0.374	0.508 0.305	0.022 0.069
	III	Surface casing Conductor casing Filter casing	0.580 0.478 0.374	0.559 0.457 0.280	0.021 0.021 0.094
Large diameter	I	Surface casing Filter casing	0.687 0.580	0.660 0.406	0.027 0.174
	II	Surface casing Conductor casing Filter casing	0.784 0.687 0.580	0.762 0.660 0.406	0.022 0.027 0.174

4. SELECTION OF TECHNOLOGICAL PARAMETERS FOR DRILLING INTAKE WELLS

The proper selection of an effective drilling method, rig design and optimal technical parameters of an intake well in the existing geological conditions allows for safe performance of the well, high RPM values and the significantly lower cost of the well. One of the most effective methods of drilling wells in carbonate formations occurring within the Lublin Basin is the rotary-percussion drilling method with down-the-hole hammers and casing-while-drilling technology. This method of drilling a well is possible using symmetrical bits with extendable blades. The borehole is then completed according to the following technological scheme. At the first stage, a drill bit with retractable blades is introduced on the drill string into the casing column. The process of introducing the bit into the casing is possible because the diameter of the drill bit with retracted blades is smaller than the inner diameter of the pipes. Then, the string extending below the bottom edge of the casing is given clockwise rotations. Then the bit blades move apart, increasing the diameter of the drilling tool. Next, aided by the strokes of a hammer installed at the bottom of the drill string, the bit penetrates the well cutting out a larger diameter than the outer diameter of the casing. If the drilling tool needs to be replaced, the drill string is put into a left-handed motion, causing the bit blades to slide off. Reducing the diameter of the rock cutting tool at the bottom of the hole allows it to be pulled into the casing and removed from the borehole (Fig. 3).

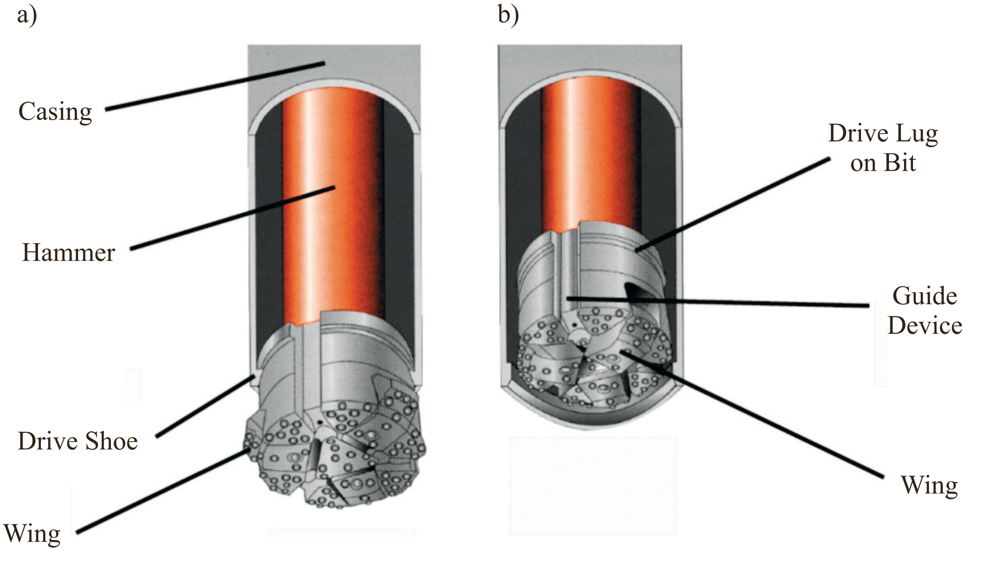

Fig. 3. View of a set for drilling a well with simultaneous casing using a symmetrical drill bit with extendable blades [10]: a) drilling position; b) retracted position

The compressed air stream from the downhole hammer also acts as an air mud. After the bottom of the borehole is cleaned of the cuttings it brings them to the surface through the annular space. The pumped air flow rate must be high enough to maintain a flow velocity >10 m/s in the annular space, allowing for smooth and uninterrupted lift of the cuttings to the surface [11–13]. The mechanical and hydraulic parameters of the drilling technology were selected to drill normal- and large-diameter intake wells with the designs proposed in Table 1. The selection of mechanical and hydraulic drilling technology parameters for Numa's down-the-hole hammers is presented below.

The first of the mechanical parameters is the proper selection of axial stress on the bit according to the empirical relationship [14–16]:

$$P = 88.3D_B \tag{1}$$

where:

P – axial stress on bit [N],
D_B – bit diameter [mm],
88.3 – unit stress [N/mm].

Another mechanical parameter that should be selected for the optimal rate of penetration is the rotational speed of the down-the-hole hammer (RPM). NUMA recommends for its down-the-hole hammers that the RPM is selected according to the empirical relationship [10]:

$$RPM = 1.6V_m \tag{2}$$

where:

RPM – rotational velocity of the down-the-hole hammer [rpm],
V_m – mechanical rate of penetration [m/h].

Hydraulic parameters of percussion drilling, i.e. air consumption to drive the lower percussion hammer, air pressure, and air velocity in the annular space are selected based on the data provided by the percussion hammer manufacturer. Table 2 shows the hydraulic and mechanical parameters of Numa hammers.

Table 2

Summary of mechanical and hydraulic parameters of drilling technology for intake wells in the Lublin region using the bottom hammer percussion method [9]

No.	Hammer	Bit diameter [mm]		Stress on bit [N]	Rotational velocity [rpm]	Air consumption [l/s]	Pressure [bar]
		Retracted	Closed				
1	T710 Patriot 240	0.784	0.704	69.2	10.00–65.00	897–1864	6.8–13.6
2	T610 Patriot 240	0.687	0.603	60.7	10.00–65.00	897–1864	6.8–13.6
3	T510 Patriot 185	0.580	0.503	51.2	10.00–65.00	566–1142	6.8–13.6
4	T455 Patriot 1125	0.530	0.452	46.8	10.00–65.00	585–1133	6.8–13.6
5	T410 Patriot 125	0.478	0.410	42.2	10.00–65.00	614–1086	10.2–17.0
6	T315 Patriot 120	0.374	0.313	33.0	10.00–65.00	503.897	10.2–17.0

Figure 4 shows a view of the borehole drilling setup with simultaneous casing column casing.

Fig. 4. View of the Numa Hammer – SuperJaws kit [12]

5. CONCLUSIONS

1. The application of rotary-percussion drilling with down-the-hole hammers for drilling intake wells in Mesopaleozoic rocks of the Lublin Basin significantly shortens the time of their realization (4–8 times) and reduces their cost.
2. The introduction of a new technology of drilling intake wells with down-the-hole hammers significantly reduces damage done to the permeability of rocks in the near-wellbore zone. Accordingly, the value of factor C, measured in the course of pumping jobs which precede putting the well to operation, is considerably decreased.
3. The percussion-rotary method of drilling intake wells with concurrent casing in the zones of karst and debris in carbonate rocks significantly reduces the number of complications and drilling failures related to the seizures.
4. Due to the continuous lowering of the groundwater level in the analysed area, it will be necessary to continuously improve the method of drilling intake wells with the percussion-rotary method of drilling with simultaneous casing of the borehole.

REFERENCES

[1] Duda R., Macuda J.: *Feasibility analysis of groundwater abstraction for gas shale fracturing in the Lublin Basin (eastern Poland)*. Archives of Mining Sciences, vol. 60, no. 1, 2015, pp. 303–312.

[2] Helcel-Weil M., Dzięgiełowski J., Florek R., Maksym A., Słyś M.: *Wyniki złożowe dotychczasowych prac poszukiwawczych w basenie lubelskim w aspekcie nowych możliwości poszukiwań złóż węglowodorów*. Biuletyn Państwowego Instytutu Geologicznego, t. 422, 2007, pp. 51–62.

[3] Karnkowski P.H.: *Karboński etap rozwoju basenu lubelskiego jako główne stadium generacji węglowodorów w utworach młodszego paleozoiku Lubelszczyzny – wyniki modelowań geologicznych (PetroMod)*. Przegląd Geologiczny, t. 51, nr 9, 2003, pp. 783–790.

[4] Wiater Z.: *Studnie wiercone i hydrogeologia Lubelszczyzny*. Norbertinum, Lublin 2004.

[5] Bieskie E., Rubbert W., Treskatis C.: *Bohrbrunnen*. R. Oldenburg Verlag, Munchen –Wien 1998.

[6] Macuda J.: *Reverse Circulation Air Lift Methods for Big Hole Drilling in Brown – Coal Mines*. 9th International Scientific and Technical Conference „New Knowledges in Sphere of Drilling, Production and Gas Storages", Technical University Kosice, Kosice 8–10 October 1996, Slovak Republic, pp. 44–52.

[7] Sterrett R. (ed.), *Groundwater and Wells.* Johnson Screens/a Weatherford Company, New Brighton, MN 2007.

[8] Gonet A., Macuda J.: *Wiertnictwo hydrogeologiczne*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2004.

[9] Macuda J., Zawisza L., *Metodyka wyznaczania parametrów hydrogeologicznych warstw chłonnych*. Wiertnictwo, Nafta, Gaz, t. 28, nr 1–2, 2011, pp. 273–281.

[10] Numa Hammer: Technical manual. 2020.

[11] DTH: *Part 1: Introduction. Hammer and drill bit development, Application, Advantages and Comparative Coast*. Halco papers, 2018.

[12] Halco Rock Tools: *A–Z of Drilling*. 2020, https://www.halco.uk/app/uploads/2020/06/A-Z-Drilling.pdf [12.01.2020].

[13] Semco materials. 2020.

[14] Macuda J.: *Analysis of Efficiency of Drilling of Large-diameter Wells with a Profiled Wing Bit*. Archives of Mining Sciences, vol. 57, no. 2, 2012, pp. 361–371.

[15] Macuda J.: *Efficiency of drilling large diameter wells with cutter bits on Szczerców opencast*. AGH Drilling, Oil, Gas, vol. 30, no. 1, 2015, pp. 405–413.

[16] Australian Drilling Industry Training Committee Limited: *The Drilling Manual*. 5 ed., CRC Press, Boca Raton 2015.