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THE TECHNICAL AND TECHNOLOGICAL ASPECTS OF COMMISSIONING A NEW INTAKE WELLS***

1. INTRODUCTION

Investments relating to the opening out of groundwater resources require a rational and responsible approach to their realization as far as technological, economic and also environmental factors are concerned.

A correctly intaken aquifer is a warranty of long life of the well, giving possibility to optimize the production parameters, and before all, maintain groundwater resources in good qualitative and quantitative condition. What is most important from an investor's point of view is the result of geological works, i.e. well ready for production, with properly established production potential and diagnosed technical condition.

Determining commissioning conditions of a drilled well should account for the qualitative verification of drilling works and evaluation of its hydraulic efficiency. All these data create a bases for working out a hydrogeological documentation on the basis of which the resources are established.

The use of new diagnostic technologies considerably facilitates the qualitative evaluation of drilling and justifies the need of performing additional repairs or enhancements. The activation jobs of newly drilled wells are frequently omitted in the plans of geological works (apart from clean-up pumping), despite the fact that drilling technologies frequently include this element [1, 2, 10]. As a consequence, contractors are not obliged to perform them and the activation itself is treated as additional cost which has not been included in the budget. Therefore in most cases both the contractor and the investor tend to omit this procedure.

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2. CONDITIONS OF COMMISSIONING

Importantly, the proprietor of the well should know the principles of commissioning the well both in the financial aspect (including the cost of post-completion diagnostics) and also production from the well – correct recognition of technical condition and establishing the production resources of the well. The drilling of a well greatly depends on local geological and hydrogeological conditions, frequently poorly recognized, therefore at an early stage of designing one should account for a detailed evaluation of technical and hydraulic condition of the well after it has been performed. The planned scope of diagnostic works should be detailed out in geological works schedule, which is performed prior to commissioning. The results of these analyses are also used for working out the post-completion documentation on the basis of which the productive resources of the well and conditions of well's operation are established.

The Polish legislature on commissioning of drilled wells is limited to a branch standard of 1994 PN-G-02318 'Drilled wells – principles of designing, performance and commissioning', which has been the basis for most of the tender procedures [7, 15]. The document standardizes the most general principles of realization of the entire investment (i.e. performing of a new well) and specifies the qualitative parameters for commissioned wells.

Specifications provided in the documents required in the tender procedures for new groundwater intakes most frequently are based on guidelines in the plans of geological works, which create the bases for drilling works, and also the calculation of costs. As far as the commissioning of drilled wells is concerned, they frequently include requirements defined in the standard.

It is important for the investor to achieve the planned production parameters of the well, which stem from the calculated water demand. In industrial practice and in most of the cases the contractors were only asked to follow stick to the plan (analogous to the construction law).

3. PARAMETERS DEFINING THE QUALITY OF A WELL

The correct commissioning of a drilled well and qualifying it fit for production should be based on the assumption of a number of conditions regulating work parameters. Among the major ones are productible resources, the technical condition of the well, hydraulic efficiency, and also water quality proving that the aquifer has been intaken correctly.

The basic parameter characterizing the operation of the well are properly established production parameters deciding about the maximum water productivity from the well. When determining them, one should analyze the predicted character of the well's operation to provide the most efficient production. The quality of performing and activating the drilled well is determined by the hydraulic efficiency. It is expressed by the amount of additional resistance of water fluxes to the well. The degree of colmatation of the well and quality of performance of the well are determined on the basis of the Walton classification. These parameters are calculated on the basis of the results of measurement pumping, the methodics of which is broadly discussed in the literature [2, 3, 5].

The branch standard PN-G-02318 'Drilled wells' gives the boundary value of coefficient *C*, at which the well can be commissioned and put to use. It is worth noting that this condition should be met for the planned production yield. In industrial practice the production efficiency is frequently lowered as compared to the planned value to achieve sufficiently low water resistance and required well capacity [7]. Such an approach to the evaluation of well's efficiency is incorrect and unacceptable.

A few methods of evaluating hydraulic efficiency of a well have been worked out and they are based on the interpretation of the results of pumping (multigrade, short-term, multiple etc.), which brings about diverse values of resistance coefficient *C* [13]. For this reason the hydraulic resistance of a well should be calculated on the basis of tests conducted in conditions resembling planned production conditions. Furthermore, the plan of geological works should contain a clearly defined methodics of pumping and evaluation of hydraulic efficiency.

The criterion of water quality is most frequently defined on the basis of physicochemical parameters characterizing the quality of waters coming from the intaken aquifer. The observed anomalies in water quality against the established hydrogeochemical background are sufficient to state that the well or the intake was performed incorrectly (filtered aquifer which was not included in the plan). Bacteriologically, the intaken water should not reveal any presence of living microorganisms, because the well may turn out a potential source of contamination of the aquifer. The Polish standard allows for sand content in the pumped water at most 0.5 g/dm^3. This should provide correct 'desanding' of the well, without creating hazard for the technological infrastructure (operation of pump aggregates and sanding up of transport infrastructure) [10].

Another parameter which is very important for the investor, is the technical condition of the drilled well, and which considerably determines the principles of its exploitation. The quality of the installed casing columns and filter column considerably affect the achieved parameters of intake operation, and also the management of the entire waterworks system. Diagnosed failures in the performed well prior to commissioning and putting it to production, create the basis for having the contractor reactivate or workover the construction. In this way the costly repairs of water devices and waterwork infrastructure (sanding up of water storage reservoirs, pipelines, failed pumps) can be avoided. Some failure situations can be encountered in the course of drilling operations, They result in construction failures which cannot be fully removed. It is worth noting that early recognized construction errors and minor failures can be eliminated to a great extent by complying with the production principles [12].

4. METHODS FOR DIAGNOSING TECHNICAL CONDITION OF A WELL

Measurement pumping and productivity tests

Determining hydraulic resistance frequently does not suffice to correctly establish the hydraulic efficiency of a well, because depending on the character of the production and the intaken aquifer one has to test the productivity of the well; in this way the maintaining of assumed parameters is verified, i.e. production efficiency at a defined depression for a defined span of time. The productivity test gives a prediction of a long-term extraction from the intake, especially when a continuous exploitation of municipal intakes is planned [7, 9].

TV inspection

The TV inspection is a cheap and fast visual method used for verifying the condition of the well. During inspection the congruence of the performed well with the project assumptions can be verified, especially the quality of the applied materials, depth and centricity of the foundation of particular elements (especially the filter), filtration pack and ultimate depth of the well. Moreover, the eccentricity of the wellbore axis from vertical can be easily verified as it has a considerable influence on the size and depth of the installed pump aggregates. During TV inspection one can macroscopically assess the degree to which the well has been enhanced after prior cleaning pumping jobs, and also define conditions of test pumping during which the productible resources are established. This mainly applies to the passability of wells for water in the active part of the filter or mesh of the filtration lattice, which depending on the applied technology of drilling can be colmatated with solid phase in mud or cuttings. Misperformed (or inefficient) enhancement jobs may result in lower hydraulic efficiency of the well even at the beginning of the production, and increase the rate of aging of the well. Another important issue is the fishing of 'sunk' objects or pump aggregates which may shadow and decrease the active filtration surface of the filter, significantly hindering the water flow. The sunk equipment and also fine objects may be a source of microbiological contamination of the well [12].

Geophysical logs

Among the newest techniques used for diagnosing drilled wells for hydrogeological purposes are geophysical well logs, which are used not only for the correct recognition of hydrogeological conditions but also for assessing the quality of drilling jobs. The gamma-gamma density profiling is used for localizing, e.g. lacks in the filling of the annulus with gravel pack, whereas the laterolog provides information about possible untight connections. Electromagnetic methods are used for determining the technical condition of the steel casing used in the wells.

Flow profiling provides important knowledge about the enhancement of the well. This profiling allows for a quantitative analysis of water inflow especially to the working part of the filter and evaluation of permeability of the near-filter zone. Moreover, from the point of view of groundwater protection, one can also verify the tightness of sealing of aquifers with the use of a dynamic gas test [6, 9, 14].

5. PURPOSEFULNESS OF DIAGNOSING TECHNICAL CONDITION OF WELLS ON AN EXAMPLE OF THE WATERWORKS AND SEWAGE UTILITY IN ŁÓDŹ

The 90 years' experience of the Waterworks and Sewage Utility in Łódź collected during the exploitation of groundwater intakes proves the significance of recognition of the technical condition of drilled wells at the stage of commissioning. The use of resources from various aquifers with wells reaching to a depth of 50 to 900 m, evidences that regardless the magnitude of the investment (*de facto* depth of the well), the diagnostics of the technical condition and verification of the performed drilling with the project and post-completion documentation is absolutely necessary to make the use of groundwater safe. The Waterworks and Sewage Utility in Łódź pays much attention to adjust the production conditions to the condition of the well, elongate the life of the well and comply with the environmental protection rules [8].

The modern methods applied for recognizing the technical condition of wells were already used in the middle of the 1990s when they started to be available on the home market. TV inspection was then used for investigating the condition of wells overtaking intakes belonging to rural waterworks (the city area of Łódź was broadening at that time). Apart from visualizing the actual technical condition of the well, the inspection films also showed the necessity to remove the sunk objects, pump aggregates, cables, etc. or created bases for liquidating the well.

The purposefulness of a detailed diagnostic analyses of wells preceding their commissioning was exemplified by an intake of 1995 located in the city of Łódź, which has been used for the production of groundwater from a Quaternary aquifer. After drilling a well (with a steel casing column ϕ 406.4 mm to a depth of 68 m and a PVC filter liner of diameter 280 mm to a depth of 84.0 m, with a fractured filter 18 m long) the cleaning pumping was administered: water yield of 32.0 to 122 m^3/h for 21 hrs [4]. Then followed a three-grade measurement pumping, and on the basis of the obtained results, the hydraulic parameters of the well were defined following the Rorabaugh–Jacob procedure. The results of pumping and the evaluation of hydraulic efficiency of the well are presented in Table 1.

Table 1

Results of measurement pumping and evaluation of hydraulic efficiency of well no. 3 after it has been drilled

Yield Q [m^3/h]	Depression s [m]	Unit yield q [$m^3/h/m$]	Unit depression s/Q [mh/m^2]	Coefficient of laminar flow resistance B^* [h/m^2]	Coefficient of turbulent flow resistance C [h^2/m]	Depression in aquifer s_w [m]	Hydraulic drop Δs [m]	Efficiency of well η [%]
39.8	2.55	15.61	0.06407	0.0578	0.00015755	2.30	0.25	90.21
79.8	4.85	16.45	0.060777		0.00003731	4.61	0.24	95.10
122.0	7.6	16.05	0.062295		0.00003684	7.05	0.55	92.78

B^* – coefficient of laminar flow resistance determined graphically

The analysis of the obtained results reveals that during measurement pumping (I and II degree) the well was enhanced, manifesting itself in the increase of unit yield q, drop of resistance coefficient C and increase of efficiency from 90% to 95%. For the third degree of measurement pumping at 122 m^3/h the efficiency of the well was observed to decrease from 95% to 92%. After performing a physicochemical analyses of water the diagnostics of the well was finished and the object was commissioned with the maximum yield of Q_e = 122.0 m^3/h, at the achieved depression of 7.6 m.

However already in the first year of exploitation, the wells started to sand up excessively as a result of which the waterworks infrastructure was sanded up and the pump aggregates damaged. For the sake of eliminating these inconveniences and establishing a safe yield value, another measurement pumping was performed at lower yields and with measurement of sanding in the well. For obtaining the required standard value for removed sand the exploitation efficiency of the well was reduced to 50 m^3/h. Despite lower yield, further exploitation only deteriorated the situation. The consecutive measurements of sand content in the pumped water conducted in the years 1996, 1997 and 1999 revealed that the sand content gradually kept on increasing (Fig. 1).

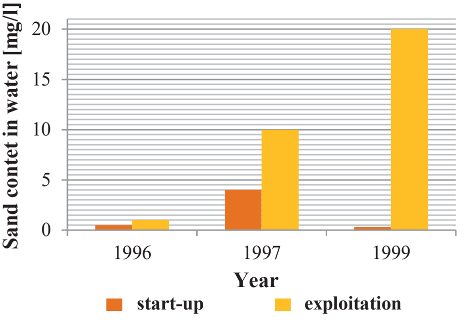

Fig. 1. Increase of sand content in water extracted from well no. 3 in the years 1996–1999

The removal of sanding and successive lowering of the yield to 35 m^3/h also failed to bring about positive results. For the sake of finding the cause of sanding up, a decision was made to diagnose the well with a TV camera. The inspection revealed the eccentricity of the filter liner and incorrectly performed filtration pack (varying coarseness in the annular space). As a result the contractor responsible for the well was obliged to workover the well within the warranty. The workover lied in drilling out the existing filter column, making the well shallower by 4.2 m and introducing a new filter column of smaller diameter (225 mm). Another type of filter was introduced to the well with another pack. Further cleaning pumping and measurement pumping at a yield of 23.0 to 46.8 m^3/h revealed that there were no signs of sanding up and the hydraulic efficiency of the well was good after the workover. The results of the measurement pumping and the evaluation of the hydraulic efficiency of the well after workover are presented in Table 2.

Table 2

Results of measurement pumping and evaluation of hydraulic efficiency of well no. 3 after workover

Yield Q [m^3/h]	Depression s [m]	Unit yield q [m^3/h/m]	Unit depression s/Q [mh/m^2]	Coefficient of laminar flow resistance B^* [h/m^2]	Coefficient of turbulent flow resistance C [h^2/m]	Depression in aquifer s_w [m]	Hydraulic drop Δs [m]	Efficiency of well η [%]
15.8	1.34	11.79	0.08481	0.08425	0.00003545	1.33	0.01	99.34
30.0	2.56	11.72	0.085333	0.08425	0.00003611	2.53	0.03	98.73
46.8	4.02	11.64	0.085897	0.08425	0.00003520	3.94	0.08	98.08

B^* – coefficient of laminar flow resistance determined graphically

The analysis of the results of the measurement pumping showed to high hydraulic efficiency of the well after workover and correct enhancement. Attention should be paid to the fact that the high hydraulic efficiency of the well was obtained at considerably lower exploitation efficiency (below 50 m^3/h) than it was established before commissioning.

Because of the problems with establishing the quality of newly drilled wells, since 2007 the TV inspection has been the constant point of inspections and supervision works realized on intakes owned by the Waterworks and Sewage Utility. A constant monitoring of the technical condition of the wells was introduced thanks to which the construction of all wells could be verified with post-completion documentation and the actual technical condition presented. In a number of cases, after a very long period of exploitation, the design shortcomings described in the documentation, and previously established with diagnostic methods (mainly measurement pumping, measurement of depth of the well or analyses of water quality) could be finally diagnosed or confirmed. The proposed interpretation of the results of the archival analyses and the recent diagnostic ones allows us to find the causes of production problems, and before all, to eliminate their consequences by assuming optimum work conditions of the well.

The described technical and production problems observed in water intake no. 3 prove that from the point of view of the ordering party, the diagnostic tests preceding commissioning of the well give a chance to quickly remove the design and enhancement shortcomings. This has also a great influence on obtaining a high production yield at high efficiency which in the long run shall help avoid exploitation problems and costly workovers. Therefore bearing in mind problems with correct investment procedures in the execution of intake wells, the following scheme is proposed (Fig. 2).

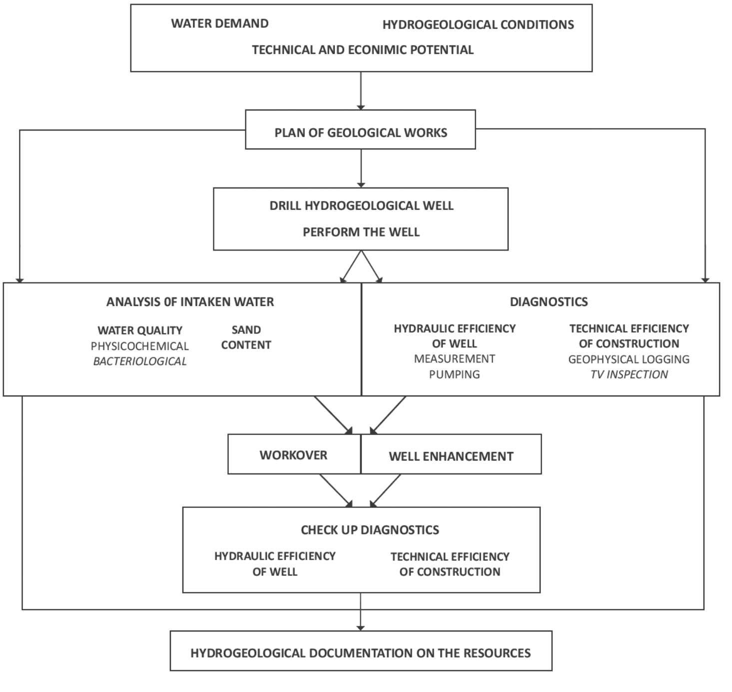

Fig. 2. Algorithm of investment procedures in the execution and commissioning of a drilled well

6. CONCLUDING REMARKS

The commissioning of a newly drilled well requires special responsibility on the part of investor as far as the evaluation of a well's technical condition is concerned, especially in terms of a well as a water supply intake. Performing full diagnostics of the well guarantees obtaining knowledge about the present technical condition of the well and gives the possibility of selecting optimum parameters of work.

All information about the technical condition and hydraulic efficiency of the well is crucial for establishing optimum conditions of work of the well and failure-free operation of the object. The purposefulness of performing a post-completion diagnosis is beyond dispute. The analysis of the technical condition of the well and the enhancement jobs should be included in the schedule of geological works, and in the investment budget at the further stage of realization of the investment process.

The data obtained during diagnostic works can help find the most efficient work conditions and provide a long life of the object. The lack of logs on this type of diagnostics in the documentation results in failing significant hydrogeological tests, as a result of which the commissioned wells will not have sufficient recognition of technical conditions or will not be correctly enhanced. The production in wells, whose parameters were not adjusted to the actual conditions of water intaking may lead to failures of the well and the waterworks infrastructure.

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