Sustainable rehabilitation strategy of water well gallery on Elbe river bank

The applicability of different methods of well rehabilitation is predetermined by well design, geology of the well field, previous maintenance measures and their results, in addition to the constructional condition of a well itself.
Sustainable well maintenance does not only take quantitative and qualitative parameters of different techniques and treatments into consideration, but also pays special attention to achieved results and their long-term effects.
This case study documents how a change of a rehabilitation method helped to secure the water supply of a chemical plant, and lengthened the operation time of a water well gallery due to concerns regarding the physical stability of the wells as the majority of them are older than 80 years. The outcome of the revision of methods proved most beneficial to the well owner due to both the unexpected high increase of well yields and to the remarkable financial advantages.

Site-specific preconditions and previous maintenance measures

Wacker Chemie AG abstracts groundwater from a well gallery for the self-supply of process water on the left river bank of the Elbe at Nünchritz near Dresden. The water catchment system consists of 31 syphon wells built in 1934 and 6 pump wells which date back to 1984 which produce mainly bank filtrate from the Elbe. The abstracted groundwater is transferred to the plant from a central shaft through subterrestrial intake pipes which run under the river. The prequaternary substratum adjacent to the water catchment system consists of granular soil, amongst other clay, sand and gravel. The boreholes were drilled down to Paleozoic granite which lies at a depth of approx. 20 m. The thickness of saturated groundwater varies from 11 m to 13 m in the area of the extraction wells and even exceeds this around the pump wells.
According to the technical drawings dated September 1933 in Leipzig, each well is covered with a closed shaft with a total height of 5 m. The wells have a total depth between 15 m and 18 m with a borehole diameter of 800 mm. The screens start at approx. 10 m – 12,5 m from the shaft cover. The casings are made of cast iron, the screens of the pump wells being stone wear and those of the syphon wells made of cast iron plates with built-in gravel pockets. Both the casings and the screens have a diameter of DN300.
In the early 2000's the syphon wells had been rehabilitated successfully by using a hydraulic impulse method. Considering the age and the constructional characteristics of the catchment system, high energy impacts may easily harm brittle or predamaged materials. Furthermore, impulses can lead to settling of the gravel pack which could decrease the hydraulic conductivity and possibly dislocate the annular seal.
The well site itself made special demands on the technical equipment as the gallery is located on an agricultural area in use. The time slot between the seasons limited the entry to the wells and the weather conditions in late autumn softened the fields to such a state that the access with standard heavy duty machinery for rehabilitation was hardly possible.

Hydraulic rehabilitation by multi-chamber gravel washer

The state-of-the-art technical equipment of the rehabilitation company selected for the job fulfilled all requirements even managing to avoid damaging the surrounding arable farm land. The 6 x 6 off-road truck was not only equipped with tractor tyres for marshy terrain, but also had the complete infrastructure integrated on the rack body including a 50 kVA generator (**Figure 1**).
Frames for rising mains and additional pipes, a number of pumps, the multi-chamber gravel washer, a screw compressor together with a covered mixing unit for the chemical agent also used for storing spare parts and well brushes, were all on board. A crane mounted in the rear of the truck enabled both a comfortable erection of the rehabilitation site, and a fast and efficient execution of each working step.
An off-road van equipped with a complete CCTV camera gear was on site and provided well inspections at a moment's notice without

Figure 1: Well site on the river bank. © Rudolf Lange Brunnenbau KG, 2013

any interruptions of work flow or stand-by time. Following the first optical survey of a well it was pre-cleaned mechanically by means of brushing. The loosened particles, including silt accumulations in the well sump, were removed by a mammoth pump and discharged on defined areas of the river bank.

The multi-chamber gravel washer with reversal flow direction and flow control, consists of two submersible pumps located one on top of the other in a stainless steel mantle. The frequency controlled lower pump circulates a chemical agent with a maximal flow rate of 150 m^3/h between the packered chambers, forcing it simultaneously deep in the gravel pack. An additional pump mounted above the mantel discharges the exhausted agent from treated screen section.

Zero values of each well and its raw water were measured and recorded prior to rehabilitations including the respective drawdown, specific yield, temperature, pH-value, specific electrical conductivity and turbidity.

pH-neutral removal of iron incrustations

Well incrustations were analysed in a mineralogy laboratory during the planning phase to identify a matching chemical agent with a high dissolution capacity. Based on their high concentration of iron(III) it was obvious to use a pH-neutral reducing agent which transforms easily and cost-efficiently insoluble iron in iron(II) in a soluble form. This crystalline powder has a 50 times higher dissolution capacity of iron(III) than hydrochloric acid at a pH-value of 1,0 in an identical molar concentration.

Prior to the chemical treatment of a screen section a corresponding amount of the agent was mixed with water and pumped in the lower chamber of the washer. The efficiency of a gravel wash is based on a large circulating flow which forces the chemical agent in remote pore spaces between grains deeper than any other hydraulic device. The screen was treated in sections by paying special attention to a sufficient overlap to make sure that the washing of the well exterior was gapless.

Water samples were taken every 15 minutes from the lower chamber of the gravel washer to monitor the chemical process by measuring specific electrical conductivity and the concentration of dissolved iron(II) during the reaction time of the agent (**Figure 2**). After 45 minutes the pumping of each treated section was continued as long as the conductivity and the iron(II) concentration had reached the zero values again.

In a number of screen sections the concentration of dissolved iron(II) jumped up and remained high during the chemical reaction, and it was decided to repeat the treatment. Due to autocatalysis of iron it is of utmost importance to remove ferric iron oxide phases as thoroughly as possible, otherwise they can quickly precipitate and adhere to the surface of gravel grains again ($r = k_1\{Fe^{2+}\}(O_{2(aq)})\{H^+\}^{-2} + k_2\{Fe^{(III)}\}\{Fe^{2+}\}(O_2)\{H^+\}^{-1}$)*. In the worst case this could mean that an incomplete rehabilitation accelerates natural well ageing instead of slowing it down.

After clear pumping of the treated screen section, the gravel washer was lowered to the next untreated segment. Each rehabilitation was finished by a step-drawdown pump test in order to determine the newly achieved capacity of each well and to document the actual success of the cleaning operation (**Figure 3**). They had to be extended by further pumping rates, e.g. wells no. 33 and 35 from 3 steps of 15 – 30 – 50 m^3/h before to 4 steps 15 – 30 – 50 – 70 resp. 75 m^3/h after the rehabilitation due to improved well hydraulics. An optical inspection with the CCTV camera completed the measure and provided the well owner with a final confirmation of the job well done.

The original reducing agent is completely exhausted during the time of the chemical reaction leaving no trace in the liquid to be disposed of. The waste water is neutral and

Figure 2:
Process control of hydraulic-chemical rehabilitation.
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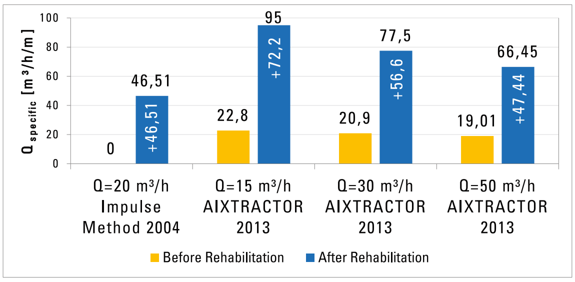

Figure 3: Well No. 11 – Comparison of rehabilitation results in specific yield. © Wacker Chemie AG, 2013

Figure 4: Discharge out of the well. © Rudolf Lange Brunnenbau, KG 2013

does not require any further treatment. In this case it was pumped on defined areas on the river bank in agreement with the local environmental authorities (**Figure 4**).

All reaction products originating from the reducing agent in contact with hydroxides of iron and manganese occur in groundwater itself and are classified as totally harmless. Soluble iron(II) and/or manganese(II) can be found in combination with sodium, hydrocarbonate and sulphite which is quickly transformed in sulphate exposed to free-air. Analogous to other rehabilitation agents the values of conductivity vary and the discharged water can be murky due to mechanically loosened particles such as sand and ochre.

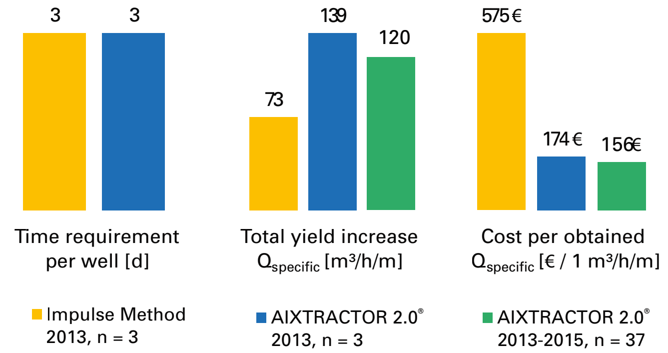

Figure 5: Evaluation of results AIXTRACTOR 2.0 & Multichamber system vs. Impulse method. © Wacker Chemie AG 2013, 2015

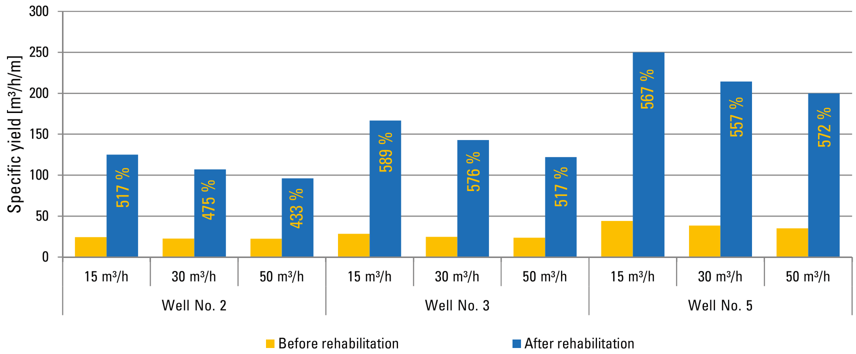

Figure 6: Excerpt of the evaluation of results AIXTRACTOR 2.0 & Multichamber system. © Wacker Chemie AG 2015

Improved cost-yield ratio

Prior to introduction of pH-neutral iron(III) removers it was self-evident that the cost of a combined hydraulic-chemical well rehabilitation would exceed that of a purely hydraulic measure. Large amounts of liquid acid, extensive health and safety protection together with time-consuming and costly disposal of the acidic remains often overburdened the budget.

The extensive documentation on the part of the well owner not only confirmed that the time frame remained identical regardless of the rehabilitation method i.e. a high-performance gravel washer enabled both a hydraulic and a chemical treatment within the same period of time than traditional hydraulic rehabilitation only. The respective yield increase of the individual wells reassured the well owner that the revision of his rehabilitation strategy had been justified (**Figure 5**).

Furthermore, remarkable economic advantages resulting from the initial test rehabilitations in 2013 were revealed by a final cost analysis as the savings of more than 70% compared with the impulse method were unexpected high. The financial benefits of the rehabilitation work in 2015 surpassed those of the test series (**Figure 5**). The total rehabilitation cost per well by a combined hydraulic-chemical treatment was 9% lower than that of the test series in 2013. Furthermore, the overall savings of the total project reached theoretically 73 % if compared with the former rehabilitation procedure. Taking into account the number of 37 wells which are being operated on a permanent basis the savings can be considered quite substantial.

Sustainability in focus

During the planning phase it was already obvious that any superfluous stress on the well construction materials should be avoided. Both the original casings and the screens of cast iron plates with gravel pockets are more than 80 years old. The alternative of a large flow of circulating water in comparison to impulses of compressed gas was therefore favoured as a hydraulic method of treatment to avoid any damage, even the slightest hair cracking. Scientific studies, e.g. the Research project W55/99 of the German Gas and Water Association (DVGW, Deutsche Vereinigung der Gas- und Wasserwirtschaft e.V.) in 2000 confirmed the ratio of effectiveness of technical devices to the volume of circulation flow in the gravel pack.

Acidic rehabilitation agents were historically considered as a universal remedy to incrustations of all types, ages and consistencies. Since the late 90's, however, iron and manganese incrustations have been removed by environmentally friendly pH-neutral reducers as on the one hand their dissolving capacity exceeds by far that of any acid even at pH 0,5 and on the other hand the dissolution process does not damage any other minerals in gravel packs and adjacent aquifers. A matching agent with the mineralogy not only ensures a high dissolution capacity within an acceptable period of time but also a cost-effective ratio between dissolved substances and the price of chemicals.

The next cycle of rehabilitations in 2015 on the banks of the Elbe confirmed the achieved advantages of the test series in 2013 by applying an optimized combination of a high performance hydraulic device with a made-to-measure chemical agent. The respective increases of yield, from the average of 196 % up to 589 % (**Figure 6**), underlined the successful introduction of the new sustainable strategy providing for a larger volume of water and a longer operation time than ever before.

Last but not least, the economic benefits to the well owner's budget achieved sustained success in respect of financing of the entire project. His water supply for the future had been secured for less than three quarters of the budgeted expenditure – and all this without any hazard either to his wells or to the environment. Individual wells require individual strategies, stepping outside trodden paths can turn out to be most rewarding.

[1] "Well Rehabilitation and Reconstruction" G. Houben & C. Treskatis, McGraw Hill, NY 2007

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