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OVERVIEW OF COMMON WELL REGENERATION METHODS

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Overview of Common Well Regeneration Methods

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Thank you!

Content

1 Introduction

1.1 Objectives

The purpose of this document is to provide an overview of common well regeneration methods. It should be used as an information source about the methodology, requirements, limitations and the general procedures of regeneration technologies and assist with regeneration method selection.

1.2 Terms and definitions

Well regeneration includes all methods and technologies used for recovering or improving well performance lost due to biological or mechanical factors associated with well ageing processes. It does not refer to any change in construction or repair due to structural damages (well reconstruction or sanitation).

Caution is advised when referring to American literature. In contrast to European nomenclature, the term well rehabilitation is typically used for regeneration methods. In Europe, rehabilitation refers to both, regeneration and reconstruction work.

1.3 Applicability

Unless it is noted otherwise, wells are referred to as vertical filter wells constructed with a casing, screen and gravel pack. The fact sheets apply to the regeneration of vertical filter wells used for drinking water extraction. Currently, they do not apply to horizontal filter wells as these may require different technical settings, although same methods are often applied to both vertical and horizontal wells.

The intention of this document is to provide comparative information of regeneration methods. The selection of the most suitable method for a given context however is still the responsibility of the operator together with the rehabilitation company after the careful evaluation of well condition and assessment of performance problem.

1.4 Overview

Despite the availability of many patented technologies, there are only a few basic principles that determine success when attempting to clean a well in order to keep or restore its performance. The overall process is more important than any particular technology alone. Based on the primary process for generating energy which results in the desired removal of material reducing well performance, methods are classified either as mechanical or chemical. They can be further subdivided as summarized in Table 1.

This classification has been adopted for the fact sheets presented in chapter 5.

Table 1: Overview and classification of common regeneration methods

Mechanical				Chemical			
Classical	**Hydro-mechanical**	**Impulse**	**Thermal**	**Inorganic acids**	**Organic acids**	**Oxidants/ Biocides**	**pH-neutral agents**
Brushing	Isolation pumping	Compressed air	CO_2 injection	Hydrochloric acid	Acetic acid	Hydrogene peroxide	pH-buffered blends
Bailing	Low pressure jetting	Shock blasting	Heat/ Pasteurization	Phosphoric acid	Oxalic acid	Chlorine	
Surging	High pressure jetting	Ultrasound		Sulfamic acid	Citric acid	Glycolic acid	
		Oxyhydrogen gas					

2 Special remarks

2.1 The "German approach" on chemical regeneration

Compared to other countries, German companies can be regarded as pioneering the field of hydromechanical well maintenance. Decades of practical experience in well maintenance have promoted a high innovation potential to replace chemical methods because of their known negative impacts, such as e.g.

- the dissolution of protective coatings of casing and screen, which makes them prone to corrosion;
- the dissolution of carbonate aquifer material leading e.g. to caving; or
- the formation of unwanted reaction by-products and drift of chemicals with the groundwater movement during regeneration.

In Germany, the handling and introduction of potentially hazardous substances into the groundwater is regulated by the Federal Water Management Act (WHG 2009). Chemicals used for well regeneration are considered potentially hazardous and are thus in general prohibited to be introduced into the groundwater. Any chemical regeneration therefore requires a comprehensive authorization procedure.

Basic obligation is to minimize impacts on the well and the aquifer. A limited permission is granted only after demonstrating compliance with the following requirements:

1) extensive mechanical and/ or hydromechanical pre-treatment;
2) dissolution tests to ensure the use of the most efficient treatment fluid;
3) safe disposal of rinse water and residues (after neutralization); and
4) complete documentation including specific well capacity before and after application; type, volume and concentration of chemical; volume and pH of residues etc.

Chemical regenerations cannot always be avoided. If applied, the above-mentioned requirements should always be taken into account.

2.2 Fact sheets classification

Please note that

1) similar hydromechanical technologies are sold under various brand names by different contractors. The fact sheets presented consider the modes of action and not proprietary names one of similar technologies.

2) *the chemicals used for well treatment as listed in Table 1 are rarely used on their own, but sold as blends under different brand names, for which the providers do not reveal the exact compositions. The fact sheets presented here consider the main ingredients, which are basically inorganic or organic acids.*

3 Practical considerations

Selecting a suitable method for well regeneration requires the precise knowledge of site conditions, well characteristics and the ageing processes. The decision should be made by the well operator, in conjunction with a hydrogeologist, and the rehabilitation company. The decision should be based on previous experience with the well or similar wells in the area.

The questions to be answered in planning maintenance are:

- How much can or must the well be mechanically and / or chemically stressed?
- What types of regeneration are feasible and most cost effective?

Depending on the actual condition of the well, it may be useful to apply multiple mechanical methods as part of the regeneration process. If successful in improving well performance using hydromechanical methods, chemical treatment may not be necessary. This implies that the well is treated early and thoroughly enough.

3.1 Technical aspects

Prior to applying any regeneration technology it needs to be carefully evaluated, if the well:

1) requires regeneration (e.g. exclusion of other causes, e.g. pump failure); and
2) its condition is suitable for regeneration (e.g. able to withstand the applied forces)

Accessory factors to consider prior to regeneration are:

- the physical condition of the well head, type and condition of screen, hydraulic and geochemical properties of aquifer;
- maintenance history and;
- practical issues such as the accessibility, clarification of responsibilities, authorization requests etc.

Some regeneration technologies can lead to a compression and subsidence of the artificial gravel pack due to well (re-)development and desanding. Depending on the well construction, gravel will need to be added to fill the annular space back up to the designed level.

In stainless steel wells, equipment involving black steel or materials of different composition that may cause electro galvanic effects must not be used to avoid corrosion reactions.

☞ *Table 2 lists the applicability of certain regeneration methods versus well design.*

3.2 Economic aspects

Beside consideration of technical suitability, an economic feasibility analysis should evaluate the prospect of success and determine the cost-benefit-ratio. The questions to be answered are:

- Is the expected capacity increase high enough to balance the costs for rehabilitation?
- Is additional effort for structural reconstruction or substitution of parts of the equipment expected?
- Is authorization required?
- At what time and for how long can the well be taken out of operation without impacting supply demands?

The need for regeneration is indicated by a declining specific capacity of a well, that is its current specific capacity Qs compared with the initial value (Qs_{ini} =100 percent).

Although there is no systematic correlation of remaining capacity and regeneration success, in general it is recommended to regenerate as early as possible, because greater the loss of performance, the more complex and costly it becomes to rehabilitate.

Generally, regeneration is recommended if the well yield, efficiency, or specific capacity declines by more than 25% (ADITC, 2002), but due to the cost of these procedures, well rehabilitation is often initiated only when well yields decline by 50 to 75% (practical experience).

3.3 Methods aspects

Regardless of which method is applied, there should be minimal impacts on the groundwater environment, and the well construction.

3.3.1 Hydromechanical methods

During method selection, the mechanical resistance of the screen material needs to be considered. This applies especially to the structural integrity of comparatively weaker materials such as wood, ceramics and PVC. Depending on the constructive condition of the well it may be necessary to reduce the power for the technology chosen (e.g. less pressure for jetting or impulse devices).

3.3.2 Chemical methods

Chemical methods involve the movement or circulation of treatment fluids, which usually consist of an acid, a biodispersant, and sometimes additives such as corrosion inhibitors etc.

1) Any of these treatment fluids used must

- be approved for use in potable water (obey national regulation); and
- have less than 1 percent impurities.

2) The consumption of chemicals must be minimized by

- the application of dissolution tests prior to well regeneration;
- hydromechanical pre-treatment to improve connection between the well and the outside formation material;
- the use of combined pump-packer systems (so-called “gravel washers”) to avoid dispersion;
- an optimized treatment focusing on the screen sections with reduced permeability.

3) The selection of the chemical agent must provide that

- neither the well construction nor the aquifer material are unintentionally attacked and/ or dissolved;
- no harmful by-products (e.g. haloforms) are generated.

Inorganic acids provide less material for bacterial growth than organic acids and/ or additives. HCl and H_2O_2 are most widespread, as they have the advantage to dissolve iron and manganese as well as carbonates.

The manufacturer must present at least the following information:

- application concentration or dilution ratio
- characteristics of the solution capacity with information on pH
- required maximum and minimum contact time
- information on the neutralization and safe disposal

Table 2: Applicability of regeneration methods with regard to well construction [reassembled after Houben and Treskatis 2007 & DVGW 2001]

Construction	**Mechanical rehabilitation methods**										**Chemical rehabilitation methods**		
	Brushing	**Over-pumping**	**Surge blocks**	**Low pressure jetting**	**High pressure jetting**	**Short-circuit pumping**	**Detonating gas/ compressed air**	**Explosives**	**Ultrasound**	**CO2 injection**	**Single chamber devices**	**Multi chamber devices**	**Multi chamber devices with reversal flow**
Casing	++				++			-	-				
Wire-wound screen	++	++	+	++	++	++	++	++	++	++	++	++	++
Slot bridge screen	++	++	++	++	++	++	++	++	++	++	++	++	++
PVC screen	++	++	++	+	+	+	++	-	++	++	++	++	++
Ceramics	++	++	+	++	+	+	+	-	++	+	+	++	++
Laminated wood (OBO)	++	++	-	+	+	+	+	-	++	-	+	++	++
Preglued gravel pack	++	+	-	-	+	-	+	+	+	-	+	++	++
Single gravel pack		++	++	++	++	++	++	++	++	++	++	++	++
Differentiated gravel pack		++	+	-	+	+	+	+	+	+	+	+	++
Depth-differentiated gravel pack		++	+	+	+	+	+	+	++	+	++	++	++

Key:

++	Fully applicable and useful
+	Applicable and partially useful, Check for potential damages of the well construction required prior to treatment
-	Not applicable or not recommended
no entry	Application not useful or not possible

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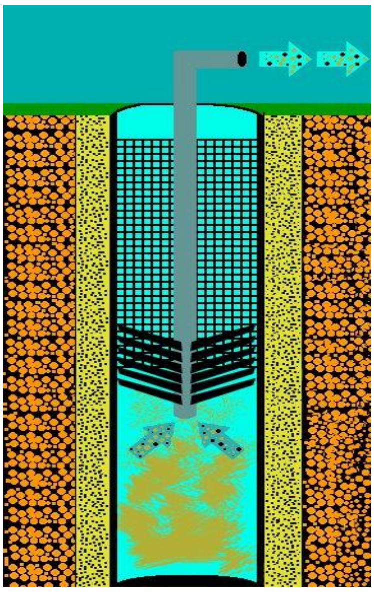
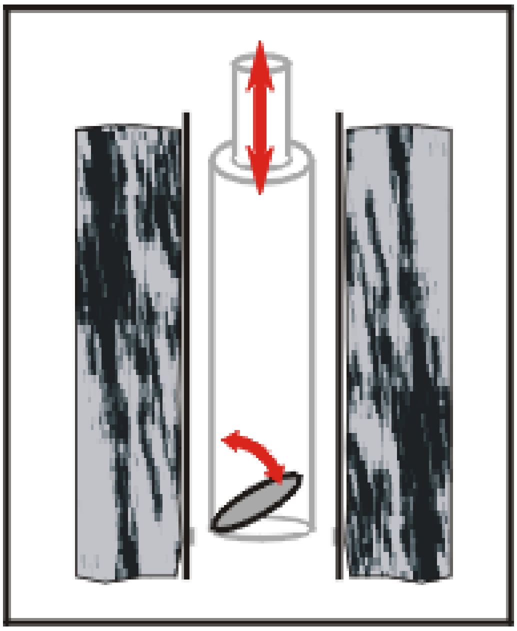
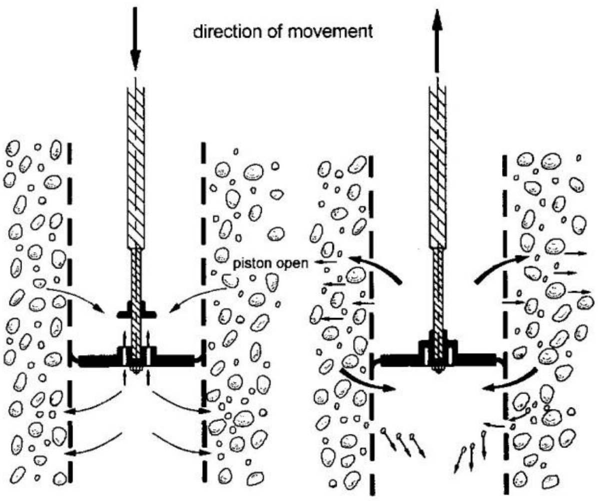
US-National sanitation foundation NSF-60 list of certified drinking water treatment chemicals:
http://www.nsf.org/certified/PwsChemicals/

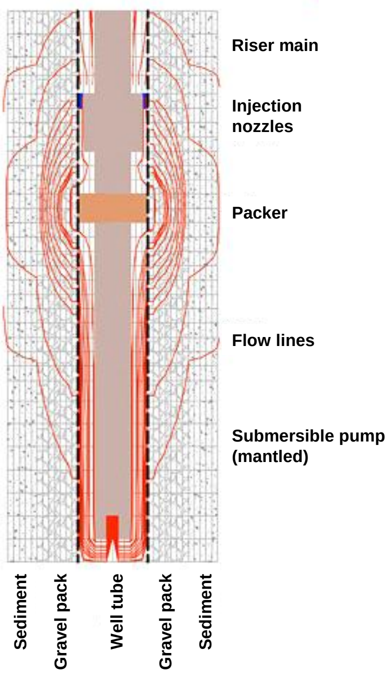
Brushing	
Classification	Mechanical
Method description	Vertical or rotational movement of brushes made from PVC or steel Material and diameter of the brushes need to be selected according to well design and material to provide i) the brush lying against the screen and ii) effectively removing soft to hardened deposits without damaging the screen material
Range of application	Effect limited to well interior & screen openings Suitable for all well construction materials & soft to hardened deposits Must be followed by bailing or airlift pumping to remove debris Usually combined with chemical or hydromechanical or impulse generation
Risks & limitations	Low risk in case of controlled application and use of PVC bristles Damage to protective coatings of the screen or casing possible
Procedure	1. Remove well pump 2. Video inspection to verify well condition 3. Brush, selected according to well diameter and screen material, is moved repeatedly with rotational movements through the well 4. Bailing or airlift pumping to remove debris
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume Stop, if well material (e.g. gravel) is observed in discharged
Evaluation	Recommended as initial- or intermediate treatment, only Metal bristles are not recommended as they may damage older well casing
Illustration	1)  2)  1) http://www.waterwelltechnology.com/brush_files/Hydro-Jet-Brush-Ani.gif 2) http://www.pigadi.com/uploads/pics/buersten_235x235_01.jpg

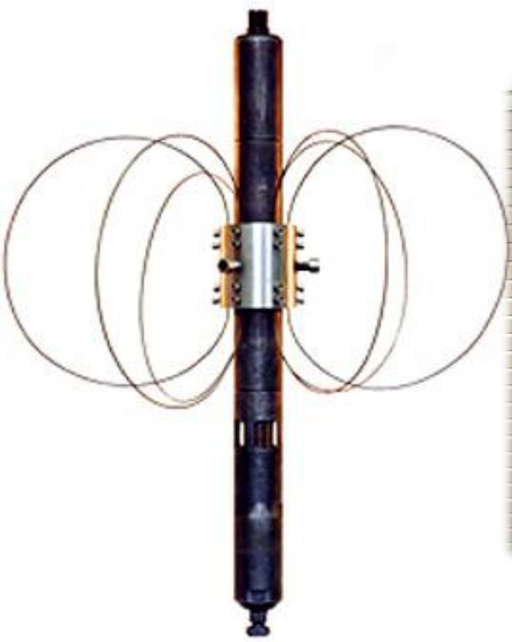
Bailing	
Classification	Mechanical
Method description	Removal of material from the bottom of the well screen or sump. Usually applied during and after well (re-)development to remove material brought into the well but not discharged via pumping.
Range of application	Effect limited to well interior Typically only used to remove material accumulated in the bottom of a well Suitable for use in all vertical well construction materials and diameters
Risks & limitations	Low risk if used appropriately Could cause damage if allowed to fall to fast in well Not efficient method to remove hardened materials
Procedure	1. Removal of Pump 2. Video inspection to verify well condition 3. Bailer is moved up and down within the material zone at the bottom of the well
Process Criteria& Warning signs	Periodic depth measurements to monitor sediment removal & well depth Stop, if too much gravel pack material (e.g. gravel) is seen in discharge
Evaluation	Useful as pre-treatment to provide access to full well depth or during and after well development or rehabilitation to remove accumulated material Other measures are needed to prevent future sand intake and clean gravel pack
Illustration	 Bailer: long steel tube with a spring loaded valve moved up and down in the well, i.e. at the well bottom  ©Jim Bailey http://www.briodydrilling.com/welldes2.htm, accessed: 13-07-201

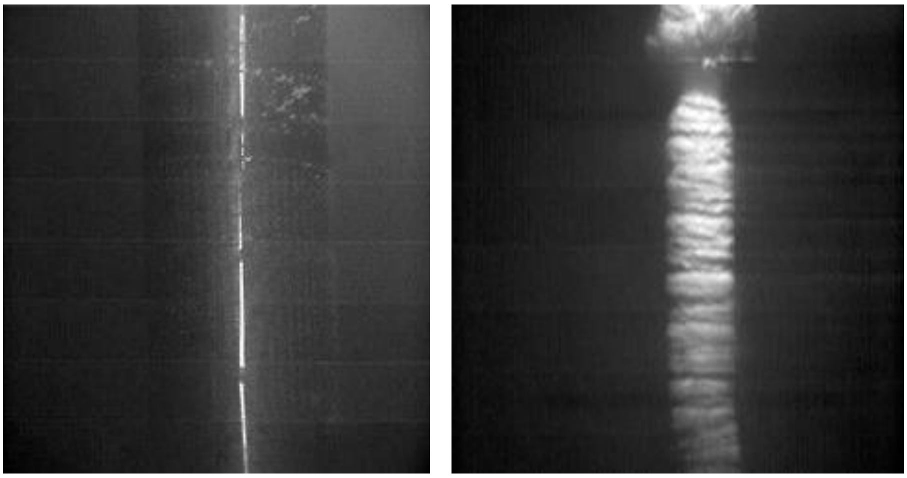
Surging / Swabbing	
Classification	Mechanical
Method description	Repeated vertical movement of a disk leading to a piston effect that displaces water into the gravel pack (down) and back into the well (up). Used primarily to clean fines from the gravel pack Screen should be brushed or flushed with a jetting device before to clean screen openings
Range of application	Depending on open area of screen and diameter of borehole, may reach outer portions of gravel pack up to borehole wall Loosens soft clogging deposits from the gravel pack Suitable for all well construction materials and diameters
Risks & limitations	Difficult to measure or control the force of application Moderate risk Mobilization of fine material from the aquifer may lead to relocation and replugging of pore spaces
Procedure	1. Remove well pump 2. Video inspection to verify well condition 3. Surge/Swab disk slightly smaller diameter than well screen is moved repeatedly up 7 down in 3-foot intervals through the screen interval 4. Process proceeds from top to bottom 5. Ideally there is simultaneous pumping to remove debris 6. Periodic bailing to remove material from bottom of well
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume Stop, if well material (e.g. gravel) is observed in discharged
Evaluation	Generally, not effective enough to breakup mineral encrustations or biofilms Limited effectiveness in the gravel pack with small slot size screens
Illustration	  ©Jim Bailey Houben and Treskatis 2007: Water Well rehabilitation and reconstruction, p210

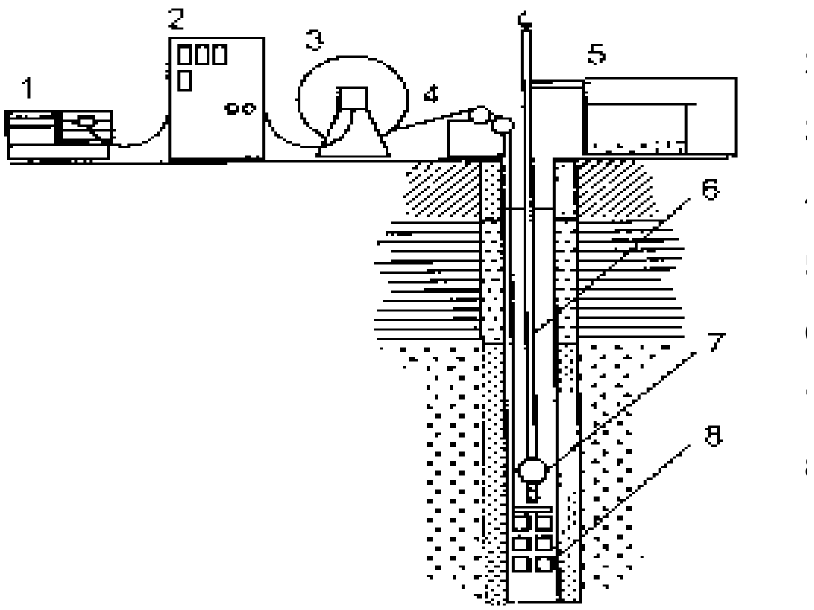
ISOLATION PUMPING	
Classification	Hydromechanical
Method description	Submersible pump above two packers to focus hydraulic force
Range of application	Effect reaches screen openings & gravel pack Removes soft deposits Suitable for all well construction materials & diameters
Risks & limitations	Medium risk High volume of water is removed Mobilization of fine material from the aquifer may lead to relocation and pore space plugging Not suitable for pre-packed gravel screens
Procedure	1. Remove well pump 2. Video inspection to verify well condition 3. Disks sized to just under well diameter moved through the screen interval, pump discharge and disk spacing sized according to specific capacity of the well
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume. Stop, if well material (e.g. gravel) is observed in discharged
Evaluation	More effective and safer than overpumping (with up to five times higher discharge rate) as it provides controlled, screen interval treatment Suitable for use during development or rehabilitation to remove material loosened by other methods Most effective if applied while moving unit and pump up and down
Illustration	 ©Jim Bailey

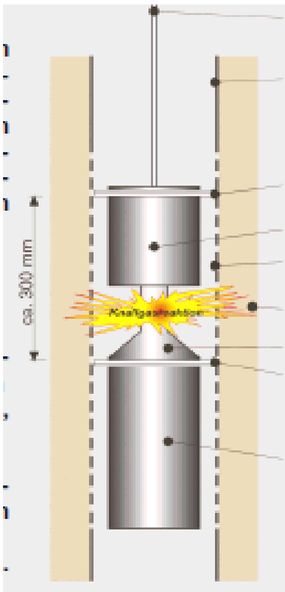
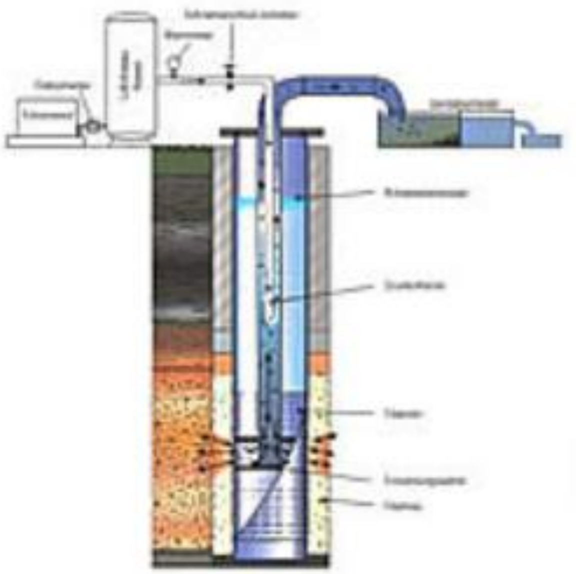
High-Pressure Jetting	
Classification	Hydromechanical
Method description	Loosens deposits from well screen and casing by water injected through rotating nozzles Pressure >> 10 bar, Flow rates up to 20 m^3/ h
Range of application	Treats well interior, screen openings (and to a lesser extent gravel pack if larger screen openings) Suitable for removal of medium hard deposits Limited suitability for wells made from wooden or ceramics materials Not suitable for pre-packed gravel screens
Risks & limitations	High consumption of fresh water High risk Depending on the water pressure, either less effective in the gravel pack or risk of potential damage to the screen, especially if well is already affected by structural damage.
Procedure	1. Remove well pump 2. Video inspection to verify well condition 3. Adjustment of pressure and flow rate 4. Jetting device is moved through the well 5. Simultaneous (or subsequent) pumping to remove loosened material
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume. Stop, if well material (e.g. gravel) is observed in discharged
Evaluation	More effective for screens with high open area, i.e. wire-wound screens, than on slot-bridge or PVC screens Gravel pack hardly affected in slot sizes less than 20mm.
Illustration	 Source: www.pigadi.com/uploads/pics/duesenkopf_01.jpg, accessed: 19-04-2010

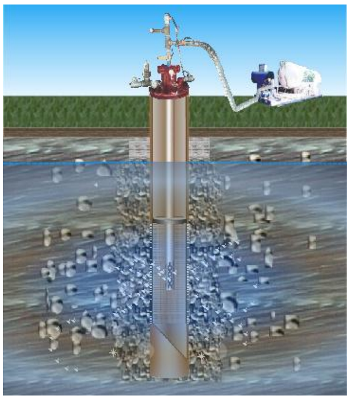
Low-Pressure Jetting	
Classification	Hydromechanical
Method description	Separates deposits from well casing by thin and fast water jets injected by nozzles Pressure < 5 bar, Flow rates between several tens to hundreds m³/h
Range of application	Well interior, screen openings (& gravel pack to less extent) Suitable for removal of soft to medium hardened deposits Not suitable for pre-packed gravel screens
Risks & limitations	Low risk High consumption of fresh water
Procedure	1. Remove well pump 2. Video inspection to verify well condition 3. Adjustment of pressure and flow rate 4. Move jetting device through the well 5. Simultaneous (or subsequent) pumping to remove loosened material
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume. Stop, if well material (e.g. gravel) is observed in discharged
Evaluation	High pressure loss between source, nozzle and screen, therefore minimally effective in the gravel pack.
Illustration	 www.pigadi.com/index.php?id=22, accessed: 13-07-2010

IMPULSE GENERATOR	
Classification	Hydromechanical, Impulse method involving compressed gas (usually nitrogen or air)
Method description	Continuous accumulation of compressed gas and its repeated sudden pulsed release into the well to generate a shock wave disconnecting deposits from screen and gravel Impulse strength can be regulated
Range of application	Well interior, screen openings & gravel pack up to borehole wall Suitable for all well construction materials, as working pressure is adjustable Suitable for removal of soft to hardened deposits Usable in combination with chemicals
Risks & limitations	Medium to high risk Mobilization of fine material from the aquifer may lead to transport of fines and plugging of pore spaces
Procedure	1. Pre-cleaning (brushing) & video inspection to check well condition 2. Placement of the device in the well and treatment of screen interval from top to bottom 3. simultaneous or subsequent pumping to remove loosened material
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume Stop, if solid fraction increases suddenly and/ or well material (e.g. gravel) is discharged
Evaluation	Most effective technology in penetrating the gravel pack (tested under laboratory conditions)
Illustration	  ©Jim Bailey http://www.pigadi.com/uploads/pics/impulsgener_001_235.jpg

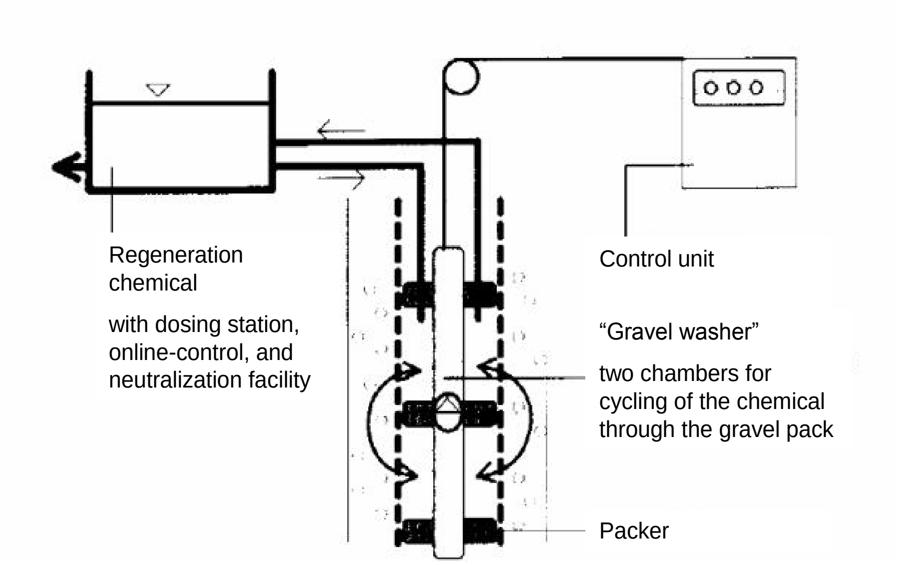
SHOCK-BLASTING	
Classification	Hydromechanical Impulse method involving explosives
Method description	Ignition of TNT to generate gas bubbles (reaction product) leading to a rapid volume increase
Range of application	Reaches screen openings, gravel pack and borehole wall Loosens soft- to high-hardened deposits Not suitable for corroded steel, PVC, wooden and ceramic screens Mobilization of fine material from the aquifer may lead to transport and plugging of pore spaces
Risks & limitations	High risk: Potential damage especially to pre-damaged casing or screens Potential dislocation of annular seal due to gravel pack settling/compaction Gas development at the well head
Procedure	1. Pre-cleaning (brushing) & video inspection to check well condition 2. Preparation and placement of detonation cord 3. Detonation and subsequent pumping to remove loosened material Treatment of whole screen section in one operation step
Process Criteria & Warning signs	Indirect control: Monitor discharge water during pumping using an Imhoff cone to determine sediment volume. No warning criteria during process. If possible, check well condition between applications
Evaluation	Higher efficiency on hard mineral deposits than on biofilms Transport, storage, and handling require special training
Illustration	 Source: www.pigadi.com /index.php?id=22, accessed: 14-07-2010; left: detonation cord in stainless steel screen; right: expanding gas bubble after detonation

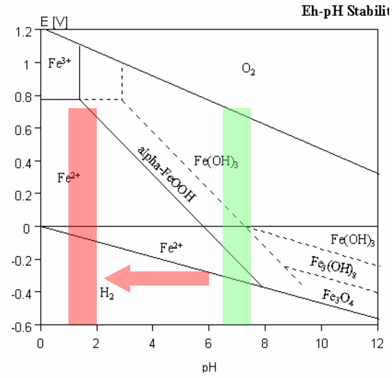
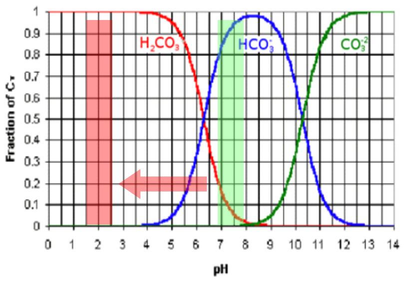
ULTRASOUND	
Classification	Impulse method
Method description	A block oscillator creates low-frequency, high-energy ultrasound waves causing oscillation of gravel and deposit introducing mechanical forces Frequency: 20 kilo Hertz; Energy: 68 kW/m²
Range of application	Well interior, screen and openings, gravel pack up to borehole wall Suitable for all screen materials; well diameters: DN150 to DN800; depths up to 200m Soft- to medium hardened deposits
Risks & limitations	Low risk to well construction Not suitable for pre-packed gravel screens May lead to transport of fines and plugging of pore spaces
Procedure	1. Pre-cleaning (brushing) & video inspection to check well condition 2. Placement of the device in the well and treatment of screen interval from top to bottom 3. Simultaneous or subsequent pumping to remove loosened material
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume. Stop, if solid fraction increases suddenly and/ or well material (e.g. gravel) is discharged
Evaluation	Recommended for iron ochres, biofilms, carbonate scales; not recommended for sediment plugging Less efficient in bridge slots and louvred screens
Illustration	 www.sonic-umwelttechnik.de/html/das_system.html, accessed: 14-07-2010

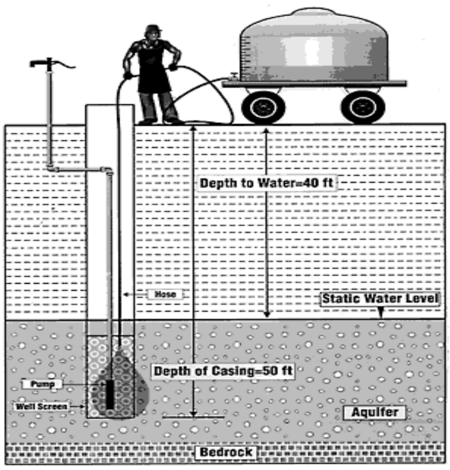
OXYHYDROGEN GAS	
Classification	Hydromechanical Impulse method involving oxygen and hydrogen gas
Method description	Hydrogen and oxygen are generated by electrolysis “Knallgas”-reaction is started by ignition, producing steam bubbles, which implode leading to a piston effect
Range of application	Well interior, screen openings & gravel pack up to borehole wall Suitable for all well construction materials, as working pressure is adjustable; Well diameters between DN125 and DN1.500 Suitable for removal of soft to hardened deposits
Risks & limitations	Medium to high risk: Only suitable, if well has no structural damages Pressure and pulse rate need to be adapted to screen material Treatment of screen section(s) only Mobilization of fine material from the aquifer may lead to transport of fines and plugging of pore spaces
Procedure	1. Pre-cleaning (brushing) & video inspection to check well condition 2. Treatment of screen interval from top to bottom 3. Simultaneous or intermittent pumping to discharge loosened material
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume Stop, if solid fraction increases suddenly and/ or well material (e.g. gravel) is discharged
Evaluation	As for the other impulse methods: Higher efficiency expected for hard mineral deposits; Potential material relocation for wells plugged by sediment
Illustration	  www.celler-brunnenbau.de/pdfs/brunnenreg.pdf, accessed: 14-07-2010

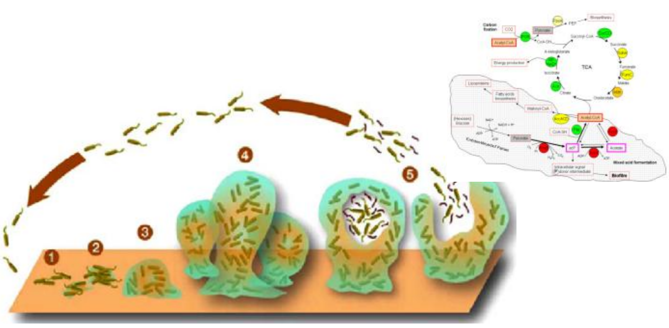
Deep Freezing (“Aqua Freed”)	
Classification	Thermal method
Method description	Two principles of action work together: 1) Gas expansion, freezing and thawing: Injection of cryogenic liquid CO_2 at pressure higher than 12 bar and temperature of -40°C causes, due to the pressure release and subsequent evaporative energy loss, the water in the well to freeze, which is connected with a rapid volume increase as water is turning to ice resulting in mechanical stress, which loosens incrustations 2) Formation of a mild acid: The gaseous CO_2 used to displace the water in the well forms carbonic acid, which has a broad reach and dissolves calcium carbonates
Range of application	Suitable for all well designs, but not recommended for wooden, ceramic, PVC and coated screens Removes soft to highly hardened mineral and biofouling deposits Because of poor thermal conductivity of aquifers, effect limited to gravel pack
Risks & limitations	High amount of CO_2 necessary Injected CO_2 dissipates -> non-harmful residuals may reach neighbour wells via the aquifer (leading to temporal changes of the water quality) Gas development at the well head
Procedure	1. Pre-cleaning (brushing) & video inspection to check well condition 2. Installation of packers (otherwise pressure loss and gas development at the well head) 3. Injection of gaseous CO_2 producing a highly abrasive carbonic acid solution 4. Repeated injection of liquid CO_2 (> 12 bar and -40°C), resulting in rapid extension coming into contact with water 5. Subsequent removal of loosened material
Process Criteria & Warning signs	Monitor discharge water during pumping using an Imhoff cone to determine sediment volume. No warning criteria during process. If possible, check well condition between applications Stop, if CO_2 pressure drops below 5bar
Evaluation	Microbicidal effect. pH and hardness of water will change due to CO_2 dissolving in the water. Less effective in screened wells with limited open area
Illustration	 www.subsurfacetech.com/Aqua_Freed_Process.php, accessed 14-07-2010

Application of heat	
Classification	Thermal method
Method description	1) Steam is injected into the well. When the uplift exceeds the gravitational force of the water column, the well will erupt like a geyser. The cleaning effect is achieved by thermal expansion and strong erosion during eruption. 2) 54°C warm water is circulated over several days. 3) For tubing made of conductive metals: Inductive heating of the well tube 4) In combination with chemical treatment: Injection of heated chemicals
Range of application	Suitable for all well construction materials (unsusceptible to heat and/ or chemicals) Effective against biofouling deposit
Risks & limitations	Very high amount of energy needed Heat can enhance biological activity away from the thermal shock zone, as well as cause drying and shrinking of clays such as bentonite grout Heat might affect well material, e.g. coatings
Procedure	1. Pre-cleaning (brushing) & video inspection to check well condition Repeated injection of steam (1) or heated water (2) 2. Subsequent pumping to restore normal well environment and remove debris
Process Criteria & Warning signs	Control temperature
Evaluation	Very low energy efficiency
Illustration	

Double Surge Block for the Application of Chemicals	
Classification	Device to apply chemicals (so-called "gravel washer")
Method description	Double surge block, consisting of two chambers separated by packers, from one chemical is injected, from other it is abstracted Repeated reversal of flow direction to intensify "washing"
Range of application	Screen materials and incrustation types depending on applied chemical Extension of operating distance into the gravel pack Precise spot dosing possible Online-control of amount & concentration of chemicals, pH, removed deposits (by analyzing concentrations of dissolved iron/ calcium)
Risks & limitations	Low to medium strain (from device, chemicals not considered) Needs to be adjusted (in size and flow rates) to the well condition
Procedure	1. Pre-cleaning & TV inspection to check constructive condition 2. Dissolution capacity test with deposit sample and calculation of necessary concentration & volume of acid to be added 3. Placement of the device in the well 4. Section-wise treatment by injection of chemicals and repeated reversal of flow direction, 5. Recovery of device 6. Neutralization and disposal of used chemicals 7. Measures to evaluate success & well assembly
Progress control & abort criterion	pH control and ion balancing for removed iron/ calcium Comparison of progress with previously carried out dissolution test Stop, if sudden decrease in regeneration agent concentration indicates loss of chemicals
Evaluation	Reduced environmental impact by less consumption of chemical
Illustration	 translated from www.geschmeidigst.de/ut2000/kreit/referat/, Access date:15-07-2010

Mineral Acids	
Most frequently used for well treatment	Hydrochloric acid (HCl, volatile liquid) Sulfamic acid (H_2NSO_3H, granular) Phosphoric acid (H_3PO_4, liquid)
Range of application	Powerful on mineral scales, especially carbonates and iron hydroxides Not effective for biofilms
Active principle	Strong pH decrease from normal groundwater pH of about 7 to 1-2 The pH change moves the chemical equilibrium from precipitation to dissolution (figure on the left: Iron stability fields; on the right: Calcium saturation states)   Iron: http://www.soils.wisc.edu/courses/SS325/stabilityFe.gif Carbonates: http://water.me.vccs.edu/courses/ENV211/lesson7_print.htm
Additives in commercial blends	Corrosion inhibitors Dispersants (to improve particle separation and prevent settling) In combination with organic acids, the mineral acids work as chelating agent, fixing the iron to keep it in solution
Risks & limitations	Handling: Hazardous, easily overdosed By-products: Toxic fumes Corrosive effects: Inhibitors needed to reduce corrosive effect on metal surfaces (casing, screen, pump etc.); presence of manganese enhances corrosive effect Can contain contaminants, e.g. heavy metals Waste disposal: Wastewater highly corrosive, can contain sulfamates/ phosphates
Procedure	1. Dissolution test on deposit sample to determine concentration and residence time 2. Calculation of necessary volume depending on water volume in the well 3. Pre-cleaning (e.g. brushing, jetting etc.) to remove deposits from the well interior and open the flow paths for the treatment fluid 4. Targeted application using jetting device, impulse generators and/ or double surge block 5. Neutralization and disposal of brine
Progress control & abort criterion	Control pH, maintain pH<3 to prevent re-precipitation of iron Balance removed mineral scale in the brine Compare progress with dissolution test results Stop, if sudden pH change or loss of regenerate is observed
Evaluation	Effective for mineral scales Not recommended for preventive treatment Efficiency increased by controlled, targeted application

OXIDANTS	
Most frequently used for well treatment	Chlorine (Cl_2, Pellets ($Ca(ClO)_2$) or liquid ($NaClO$)) Hydrogen Peroxide (H_2O_2, liquid) Dithionite ($Na_2S_2O_4$, crystal)
Range of application	Disinfection Biofilm removal
Active principle	Usually as "shock" treatment to remove and limit biological activity Reaction step 1: Disperses slimes by breaking down organic polymers Reaction step 2: Once, the biofilms is cracked, oxidant reacts with the organic compounds  http://www.p2pays.org/ref/20/images/shock-3.gif
Additives in commercial blends	None; disinfectants used alone May be succeed to or followed by acidification
Risks & limitations	Handling: Hazardous, especially chlorine might cause potentially explosive situations with eruption of chemicals at the surface By-products: in case of chlorine haloforms Corrosive effects: Medium to high depending on chemical and concentration Waste disposal: to be neutralized; chlorine brine can disrupt wastewater treatment processes
Procedure	1. Pre-cleaning (brushing, jetting etc.) to remove deposits from the well interior and open flow paths for the treatment fluid 2. Calculation of needed volume, initial concentration and target concentration in the well 3. Preparation of treatment solution 4. Targeted application using jetting device, impulse generators and/ or double surge block 5. Neutralization and disposal of brine
Progress control & abort criterion	Maintain target concentration, repeat treatment cycles, as chemical is consumed reacting with iron deposits before it reaches the micro organisms Stop, if sudden pH change or loss of regenerate is observed
Evaluation	Applicable as preventive or reactive treatment Oxidative effect increases the redox potential, which can cause mineral precipitation

Organic Acids	
Most frequently used for well treatment	Glycolic acid (also: Hypoxyacetic acid; (HO) CH_2 (COOH); liquid) Acetic acid (CH_3COOH; liquid) to a lesser extent: Ascorbic acid ($C_6H_8O_6$; crystal) Oxalic acid ($C_2H_2O_4$; granular)
Range of application	Biofilm removal Biocidal effect
Active principle	Weakening of the deposit matrix and reduction of its mechanical strength to facilitate detachment.  l: http://www.advancedhealing.com/blog/wp-content/uploads/2009/09/biofilm.png r: http://www.biomedcentral.com/content/figures/1471-2164-11-404-4.jpg
Additives in commercial blends	Dispersants In combination with strong mineral acids, the organic acid provides deterioration of the bacterial exopolymers destroying biofilms and making the iron oxides accessible for dissolution
Risks & limitations	Handling: Relatively safe (weak acid, non-oxidative) By-products: Toxic fumes Corrosive effects: non-corrosive Residues provide a readily available carbon/ food source for re-growth of bacteria Acetic and oxalic acid not to be used, if raw water contains > 50 mg/l calcium, because of potential acetate formation
Procedure	1. Dissolution test on deposit sample to determine concentration and residence time 2. Calculation of necessary volume depending on water volume in the well 3. Pre-cleaning (e.g. brushing, jetting etc.) to remove deposits from the well interior and open the flow paths for the treatment fluid 4. Targeted application using jetting device, impulse generators and/ or double surge block 5. Neutralization and disposal of brine
Progress control & abort criterion	Control pH, maintain pH<3 to prevent re-precipitation of iron Stop, if sudden pH change or loss of regenerate is observed
Evaluation	Slow reaction compared to mineral acids All organic acids provide carbon source for enhanced bacterial activity and fast re-growth of biofilms

Annex 1: Overview of common well regeneration treatment fluids and their characteristics

Characteristic	Mineral acids			Inorganic biocides (Oxidants)			Organic biocides (Acids)				
	Hydro-chloric acid	**Phosphoric acid**	**Sulfamic acid**	**Chlorine**	**Hydrogen peroxide**	**Dithionite blend**	**Glycolic acid**	**Acetic acid**	**Oxalic acid**	**Ascorbic acid**	**Citric acid**
Appearance	Slightly yellow, volatile liquid	Clear liquid	White crystal	Pellets (Ca-Hypochlorite) Liquid (Na-hypochlorite)	Clear, volatile liquid	White crystalline powder	White crystalline powder	Caustic liquid	Granular	white-yellow crystalline powder	White crystal
Formula	HCl	H_3PO_4	H_2NSO_3H	Cl_2	H_2O_2	$Na_2S_2O_4$	$(HO)CH_2(COOH)$	CH_3COOH	$C_2H_2O_4$	$C_6H_8O_6$	$C_6H_8O_7$
Relative strength	Strong	Strong	Strong	Strong	Strong	Strong*	Weak	Weak	Strong	Strong	Weak
Relative reaction time	Fast	Moderate	Moderate	Fast	Fast	Fast*	Moderate	Slow	Moderate	Moderate	Moderate
Corrosiveness to metals	Very high	Slight	Moderate	High	None	None*	None	None	None	None	None
Hazardous by-products	Toxic fumes	Toxic fumes Phosphates	Sulfamates	Haloforms	None	None*	Toxic fumes	Toxic vapor	Poisonous salts	None	None
Handling safety	Hazardous Easily overdosed	Hazardous	Safe (because of pellet form)	Hazardous Potentially explosive	Moderate	Safe*	Moderate (weak acid, non-oxidative)	Moderate	Safe (because of pellet form)	Safe (because of pellet form)	Safe (because of pellet form)
Residues	Corrosive	contain Phosphates	contain Sulfamates	Low pH brine Haloforms	None	pH neutral	Bio-degradable	Bio-degradable	Bio-degradable	Bio-degradable	Bio-degradable
<u>Reactivity against</u> **Carbonates** **Iron** **Biofilms**	 Very good Very good Poor	 Very good Good Poor	 Very good Fair Poor	 None Poor Very good	 None Oxidating Good	Depending on additives	 Poor to fair Good Moderate	None Chelate-forming Very good	None Chelate-forming Good	 None Poor Good	Poor Chelate-forming Poor
Evaluation	Most universal Issue of Handling & Corrosive-ness	Substitute of HCl, as it does not attack stainless steel	Easy transport & handling -> Good for small wells To be applied in confined wells, as there is no CO_2 degassing	Most common biocide Consumed by reactions with biofilm matrix Decreases efficiency at higher pH Increases redox potential	Common disinfectant Consumed oxidizing dissolved iron and organic complexes Can enhance re-growth due to oxygen	* all according to provider: pH-neutral (buffered) No re-deposition of iron oxides (neutral pH) No dissolution of carbonates	Most frequently used Carbon source for re-growth	Long contact time needed Carbon source for re-growth Not usable, if calcium >50 mg/l because of acetate formation	Most efficient organic acid Carbon source for re-growth	Carbon source for re-growth Expensive	Carbon source for re-growth Not re-commended