Glass bead filter packs in wells for higher efficiency and lower lifecycle costs

Technical and economic aspects compared to mineral gravel

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NGWA Great Plains Aquifers
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• 2 Theoretical requirements
• 3 Material Properties of Filter Gravel
• 4 Filter gravel characteristics as an aging factor
• 5 Comparative material characteristics
• 6 Hydraulic Properties
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• 9 Advantages of glass beads
• 10 Economic Issues
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1 Introduction

Until late 2007, sand and gravel, have been exclusively used as filling compound in the annulus of water extraction wells.

The rapidly decreasing quality of natural material means an explicit decline in hydrological and hydro chemical functionality of extraction wells also in terms of lifetime and maintenance efficiency.

Glass beads are a significant improvement in water well construction and functionality, reducing operation and maintenance costs and enhancing a longer lifetime cycle.

Why ?
2 Theoretical requirements:

2.1 Function of a filter pack

• Establish a stable porous filter column with the ability to let pass specified undersized grain according to aquifer grading curve

• Avoid clogging of borehole / filter pack

• Avoid constant intrusion of finer particles from the aquifer
2.2 Influencing factors

- Effective bedding density and irregularity of grading curve determine specific capacity and rehabilitation ability. Specific capacity decreases from 100 % down to 30 % from loosely to densely packed.

- Hydraulic permeability is to a certain amount a function of filter grain size. Coarser grain means higher permeability. (a filter grain bed of MESH 25 - 18 has only 50% of the permeability compared to one of 16 – 10.

- Filter gravel has a boundary layer to formation and well screen. Hence, bedding density and irregularity determine the size of the passable grain.

Sustainability means Consistency
2.3 Aims of an optimized filter pack in wells

- Stable bedding
- Sand removal in pores until and beyond boundary (borehole)
- Sorted grain framework at boundary
- Highest possible effective pore space
- Increasing hydraulic permeability from borehole to well screen
2.4 Requirements for the filter pack in water wells

- Homogeneous Composition
- Purity
- Smooth Surface
- Sphericity
- Uniformity
- Stable Bedding
- Isotropy
- Homogeneous Pore Volume
- Maximum effective Porosity
- Maximum Permeability
- Inhibition of Biofilms and Incrustations
- High Mechanical Resistivity
- High Chemical Resistivity
- **Consistency**
2.4 Requirements for the filter pack in water wells

Theoretical base:

Spherical Grain!

Which product meets the specifications?
3 Material Properties of Filter Gravel

Reality:

- no spherical shape, platy or lentil shaped grains
- high share of dust and insufficient materials (up to 10%)
- high amount of undersized and oversized particle shares (> 10%)
- no satisfactory rigidity
- uneven and large inner surface
- Disintegration and compaction during use
3 Material Properties of Filter Gravel

Sample of US filter gravel
3 Material Properties of Filter Gravel

III 2 Parts of a slot bridge filter with trapped pieces of gravel and splintered quartz grains in the openings.
As a porous medium from a natural mixture of grains, the gravel pack, with its interface to the wellscreen and to the formation, is the crucial space for well ageing processes and the hydraulic performance of a well. The following characteristics of the filter gravel and its adjacent media have a strong influence on well ageing:

- grain shape (deviation from the ideal bead form);
- inner surface of the grains (coarseness);
- size, geometry and volume of pore channels resulting shape and bedding density;
- fine grain share in the water from the aquifer and from the filter pack, which accumulates in the pore canals out of range of desanding and rehab techniques,
5 Comparative material characteristics

Several R & D projects with universities and other independent institutions were initiated to see if glass beads are an alternative to gravel.

Physical Properties:
• roundness
• specific weight
• fill weight
• grading
• max. breaking load during static stress
• breaking properties during static stress
• breaking properties during dynamic stress
• abrasion resistance
• surface relief
• surface profile
• peak-to-valley heights
• specific surface
• chemical resistance to pH-controlled regenerants

For full description see literature. The subsequent diagrams show some excerpts of the laboratory tests.
5 Comparative material characteristics

SiLi Beads exceed in every category the specifications of natural sand and gravel.

Source: Authors

Fig. 3: Load curves for filter gravel (here: 5.6 to 8 mm) and glass beads (here: 5.6 to 8 mm) as a function of the path of the testing stamp. In the case shown here, the glass bead can only be deformed by 0.3 mm, the gravel grain of the same size only by 0.09 mm before it breaks up into smaller pieces for the first time.

Source: Authors

Fig. 4.1 and 4.2: REM image of a glass bead compared to a filter gravel grain of the same grain size. The “smooth” surface of the glass bead prevents the formation of tensile stress when the load is applied and reduces the agglomeration of incrustations.

Source: Authors

Fig. 5: Loss of mass due to mechanical abrasion of glass beads (1.25 to 1.65 mm) and of two similarly graded, commercially available types of filter gravel (1 to 2 mm and 1.4 to 2.2 mm)

Source: Authors

Fig. 6: Overview of resistance to regenerants: Solution B (4/4) (glass beads type M 12 mm/filter gravel no. 5 (8-12 mm))

Elements dissolved out

Fig. 7: Distribution of the elements dissolved out of glass beads and gravel grains after 15 h of treatment with a solution of synthetic hydrochloric acid 1:5

Source: Authors
5 Comparative material characteristics

Adsorption capacity of dissolved iron

Under determined framework conditions, a comparison of the sedimentation of iron ochre in different filter materials was conducted.

In the filter gravel, approx. 40% more iron mass was embedded as in glass beads. Thus a clearly lower incrustation tendency is to be expected when using SiLi glass beads in the annular space of the well.
6 Hydraulic Properties

Comparative tests in the laboratory of Bau ABC (National training academy for construction staff and well drillers) showed also better properties of SiLi glass beads for:

- Packing Properties / Compression Set
- Pore Volume
- Permeability

Comparative Hydraulics.docx
7 Hydrodynamic Properties
7 Hydrodynamic Properties

Summary:

• Glass beads will always have a slightly better flow, and thus a higher sand discharge during development
• In all tests regarding glass beads soil material was discharged.
• Glass beads generate a faster and more efficient sand discharge
• Glass beads had a clearer separation between the grain capable to discharge sand and impermeable grain remaining in the ground

• The "sand discharge" in gravel packs consists not only of soil material, but also of the undersized of the pack itself
• Filter gravels tend to form sub-grain and autochthonous dead end pores in which remain the undersize grain and incrustations
• gravel filter show low discharge rates derived from the soil itself
8 Field results

To date more than 3000 metric tons of SiLi glass beads were used in more than 120 water wells in Germany, Italy and the USA, covering the whole hydrogeologic spectrum from unconsolidated to solid rock and various groundwater chemistry proving the benefits and advantages mentioned above.

Also these positive results could be confirmed:

- Time and volume for sand removal and clear pumping is down to 10 - 20 % compared to gravel
- Reduced drawdown of water table compared to former well layout
- Higher specific capacity
8 Field results

- Lower tendency of iron ochre incrustation in filter pack in exchange for higher rates inside the well screen. Costs for well rehabilitation can be reduced as the cleaning of the interior of the well screen is significantly cheaper.

- Intervals between rehabilitation can be stretched, which means lower expenses for O & M
8 Field results

Rehabilitation Water Well Steelmill Annahütte, Aintring/Hammerau

Before:
• Screen: 20 m, bridged slots, DN 600/700
• Filter pack: Gravel
• Capacity: 1,140 gpm, drawdown: 9 ft, spec. capacity: 126.7 gpm * ft

After:
• Screen: 20 m continuous wire wrapped, DN 800
• Filter pack: SiLi Glass Beads
• Capacity: 1,584 gpm, drawdown: 2.62 ft, spec. capacity: 604.5 gpm*ft

• Performance Enhancement: >300 %
8 Field results

Rehabilitation Water Wells  Haldensleben

Hdl (US).xls
8 Field Results

SiLi in the Desert

[Diagram of a well with details on casing and materials used, including:
- 36-inch LCS Surface Casing (0.375-inch wall thickness)
- 40-inch Surface Borehole
- Sand Cement Grout Seal
- 28-inch Borehole
- Formation Stabilizer (pea gravel fill with 6-foot thick bentonite seals at 100-foot intervals)
- 18-inch HSLA Blank Casing (0.375-inch wall thickness)
- HSLA Casing Centralizers (40-foot spacing installed from 40 feet to 320 feet)
- Dissimilar Metal Connectors
- Pozzolan Cement Grout Seal
- Approx. Static Water Level 440 Feet
- Bentonite Seal
- #30 Fine Sand (2-feet thick)
- Sigmund Lindner Glass Beads - Type 5 45/10, (2-4.29 mm size)
- 18-inch SS Blank Casing (0.312-inch wall thickness)
- 2-inch I.D. LCS/SS Sounding Tube (0.184-inch wall thickness, perforated with 0.060-inch slots below 510 feet, with bottom cap, with dissimilar metal connector at 330 feet)
- 18-inch SS Full-Flu Louvered Well Screen (Roscoe Moss 5,200-inch louvers, 0.375 actual slot openings, 0.312-inch wall thickness)
- Silica Sand Filter Pack (0.060 mesh)
- SS Casing Centralizers (40-foot spacing from 330 feet to 610 feet)
- Pilot Borehole (with bentonite and native sediment fill)

Notes: LCS = low carbon steel
HSLA = high strength low alloy steel
SS = stainless steel
O.D. = outside diameter
All diameters are O.D. except the sounding tube and well screen, which are nominal.

FINAL DESIGN
City of Phoenix
Cave Creek ASR Well -1
Phoenix, Arizona

23
8 Field Results

Well Development Analysis - Glass Beads (2.4 - 2.9 mm) versus Silica Sand (6 x 9), Cave Creek ASR Well, Northeast Aquifer
**8 Field Results**

**FLOWMETER ANALYSIS**

<table>
<thead>
<tr>
<th>DEPTHS</th>
<th>FLOW RATE</th>
<th>GPM</th>
<th>PRODUCTION</th>
<th>% OF FLOW</th>
<th>ZONES</th>
<th>GPM/FT</th>
<th>THICKNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>510-600</td>
<td>547.98</td>
<td>63%</td>
<td>6.31</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>670-800</td>
<td>567.92</td>
<td>17%</td>
<td>4.74</td>
<td>120</td>
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</table>

**GEOLOGY EXPLANATION**

- **Pozzolan Cement Grout Seal**
- **Approx. Static Water Level 436 Feet**
- **Bentonite Seal**
- **#30 Fine Sand (2.5-feet thick)**
- **Sigmund Lindner Glass Beads – Type S 4510, (2.4-2.9 mm size)**
- **28-inch Borehole**
- **18-inch SS Ful-Flo Louvered Well Screen (Roscoe Moss 0.075 slot openings)**
- **Silica Sand Filter Pack (6-9 mesh)**

Geology generalized from lithologic log.

- Silty Sand
- Clayey Silty
- Gravelly Sand
- Sandy Gravel
8 Field results

Installation of Gravel
8 Field results
Installation of Glass Beads
10 Economic Issues
10 Economic Issues

Comparison Well Layer Gravel/Glass Beads
results cost analysis (acc. to KVR-guidelines)

- deep well – considered period 40 years;
- interest: 3%; inflation 2%

- layer – Gravel
- layer Glass beads

Investment costs
- 372,512
- 387,632

Costs with Inflation
- 835,905
- 744,794

Project cost value with inflation
- 1,208,417
- 1,172,426

Project cost value („individual case“)
- 1,328,355
- 1,223,537

Ausgangspunkt: gleiche Betriebskosten für Energie/gleiche Regenerierintervalle;
Well mit Gravel-Ausbau hat pro Jahr um 1% höhere Betriebskosten als Well mit Glas-
kugelausbau
## 10 Economic Issues

### Energy costs raw water conveyance

<table>
<thead>
<tr>
<th></th>
<th>glass beads</th>
<th>Well A old</th>
<th>Well A new</th>
<th>Well B old</th>
<th>Well B new</th>
<th>Well C old</th>
<th>Well C new</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs per kilowatt hour on average</td>
<td>(Euro/KWh)</td>
<td>0,15</td>
<td>0,15</td>
<td>0,15</td>
<td>0,15</td>
<td>0,15</td>
<td>0,15</td>
</tr>
<tr>
<td>Discharge on average (M³/h)</td>
<td></td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Discharge (collection) (M³/a)</td>
<td></td>
<td>500.000</td>
<td>500.000</td>
<td>500.000</td>
<td>500.000</td>
<td>1.800.000</td>
<td>1.800.000</td>
</tr>
<tr>
<td>Level of effectiveness (µ) on average (%)</td>
<td></td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
<td>60%</td>
</tr>
<tr>
<td>Special yield on average (according to available data) (M³/h/m²)</td>
<td></td>
<td>5,4</td>
<td>10,2</td>
<td>8,6</td>
<td>10,9</td>
<td>92,5</td>
<td>411,4</td>
</tr>
<tr>
<td>Relative conveyance depths (only referring to strict reduction) (mWS)</td>
<td></td>
<td>11,2</td>
<td>5,9</td>
<td>7,0</td>
<td>5,5</td>
<td>2,2</td>
<td>0,5</td>
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<tr>
<td><strong>Total of energy costs pumping</strong> (EUR/a)</td>
<td></td>
<td>3.818</td>
<td>1.997</td>
<td>2.389</td>
<td>1.878</td>
<td>2.651</td>
<td>596</td>
</tr>
<tr>
<td><strong>Savings</strong> (EUR/a)</td>
<td></td>
<td>1.821</td>
<td>511</td>
<td>2.055</td>
<td></td>
<td></td>
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</tbody>
</table>
# Cost benefit analysis

<table>
<thead>
<tr>
<th></th>
<th>Old Well</th>
<th>New Well</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added costs filter pack $</td>
<td></td>
<td>26,000</td>
<td>-26,000</td>
</tr>
<tr>
<td>Rehab costs 5 yrs. $</td>
<td>65,000</td>
<td>2,000</td>
<td>63,000</td>
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<tr>
<td>ROI yrs.</td>
<td></td>
<td></td>
<td>1.7</td>
</tr>
<tr>
<td>Total Savings 5 yrs. $</td>
<td></td>
<td></td>
<td>37,000</td>
</tr>
</tbody>
</table>
Summary:

- Despite 3-10% higher costs for the investment even with 1% energy cost savings and 25% stretched intervals for well rehab at identical price, glass beads achieve total lifecycle cost savings up to 13%.

- Real Example shows energy savings between 50 and 80%/year. ROI for the higher invest costs in 3.5 / 8 yrs. with energy savings only.

- First experience with well rehab show that glass bead filter pack can be treated at lower costs.
11 Future Prospects

Using glass beads in water wells is a progress in well construction and shifts the state of the art to a higher level. This application received positive reviews from Professional Associations, scientific institutions and in 2010 the Innovation Award of the Bavarian Construction Confederation.

For the first time, the physical, hydrological and chemical properties of a filter pack can stay consistent for the entire well lifetime cycle. Savings of electrical energy and O & M costs for rehab, are a major step to real Sustainability.

Promising results and positive feedback are coming also from the wastewater and water treatment sector. To date there is a Patent pending from a manufacturer of filters for swimming pools, test applications in various water filtration applications are also initiated.
11 Future Prospects

Water treatment: Public swimming pools

Advantages compared to sand /gravel:

• more precise filtration due to regular capillary tubes
• less drop in pressure in filter bed
• higher permeability
• higher operation time and filter capacity
• better hygienic properties, (50 % reduced germ growth rate)
• improved backwashing, reduced filterbed expansion
• significant savings of water and energy
12 Certifications

NSF International
RECOGNIZES
Sigmund Lindner GmbH
Germany

AS COMPLYING WITH NSF/ANSI 61 AND ALL APPLICABLE REQUIREMENTS.
PRODUCTS APPEARING IN THE NSF OFFICIAL LISTING ARE
AUTHORIZED TO BEAR THE NSF MARK.

June 1, 2012
Certificate# C0104872 - 01

David Purkiss, General Manager
Water Distribution Systems
SiLi is a fifth generation family enterprise. Our company philosophy is based on tradition, innovation and sustainability, and we strive for stable, long-term cooperation with our customers, employees and business partners. We have produced and developed high-quality glass beads for over 150 years and grinding beads of zirconium oxide and zirconium silicate for over 10 years. Our quality management, based on DIN ISO 9001, proved itself years ago; we also carry out work and tests with DIN ISO 15378 for pharmaceutics.