SiLi SIGMUND LINDNER

SiLibeads®

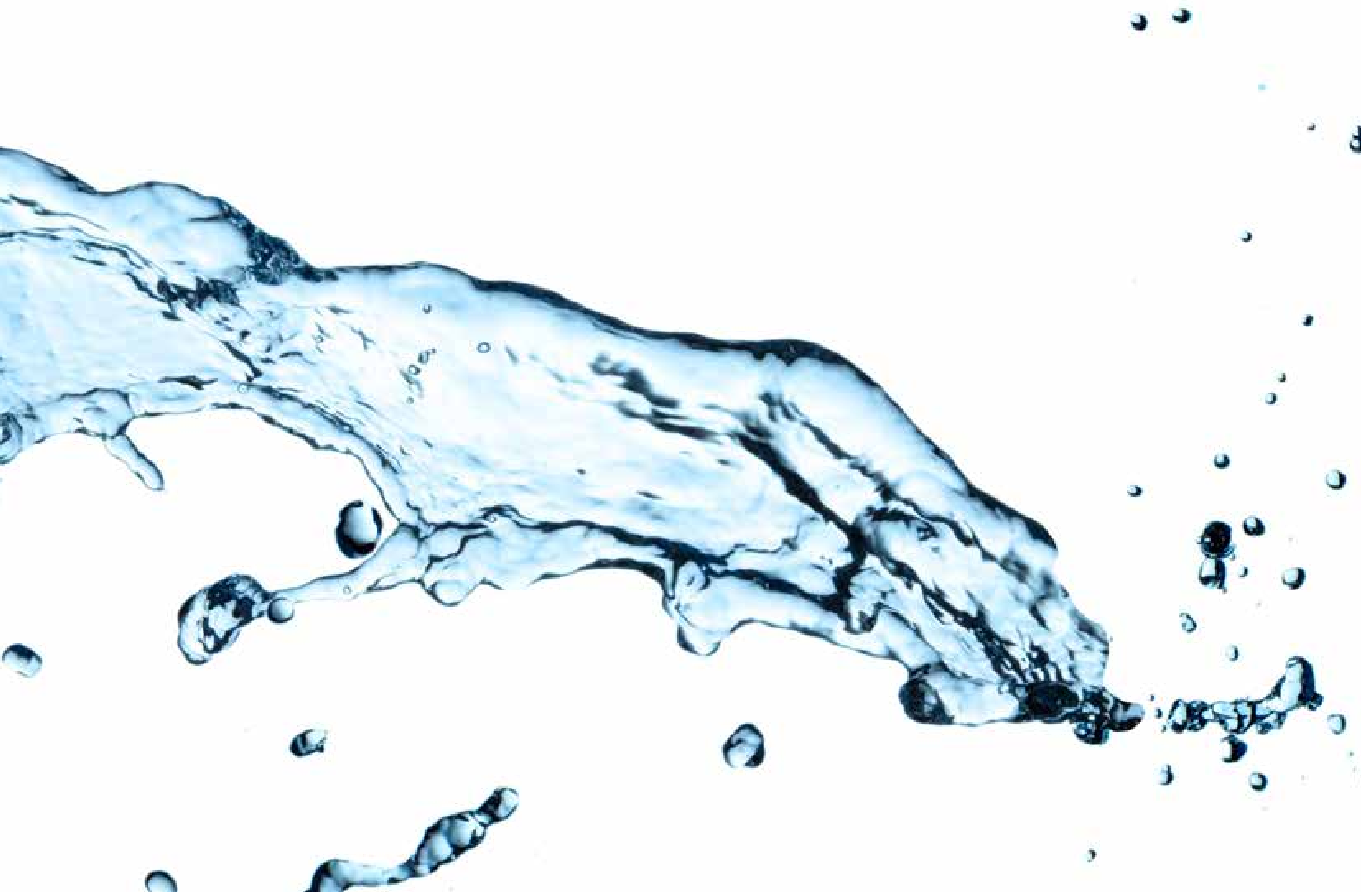
...crystal clear water

NSF®

Certified to NSF/ANSI 61

SiLibeads®

...crystal clear water



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Helpful Information
and
important Formulas
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7 Advantages
of SiLi glass beads compared with gravel as filter in water wells

1 Clean delivery

- no impurities
- no desinfection necessary before use

Meet or exeed
- AWWA A100 & B100 standards for water wells and filtration
- ANSI / NSF61 certification for quality and purity

2 Precisely spheric grains and homogenous size

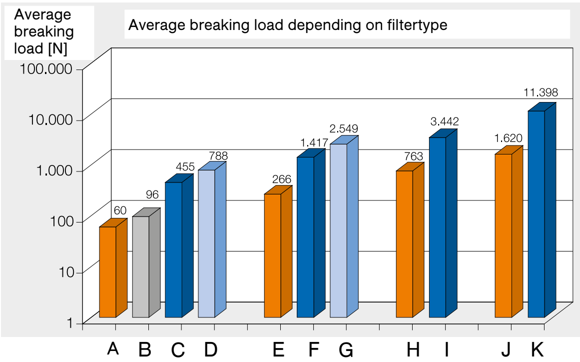
- no bridging or jamming when installed
- uniform grading curve allows maximum screen openings
- greatest possible pore space and permeability
- no secondary subsidence, steady pore volume and hydraulic permeability over entire life time cycle
- optimum well rehabilitation due to wider and regular pore channels

3 Large diameter variety

- best adaption to nominal grain of the aquifer

4 4 to 16 times higher crushing strength than gravel

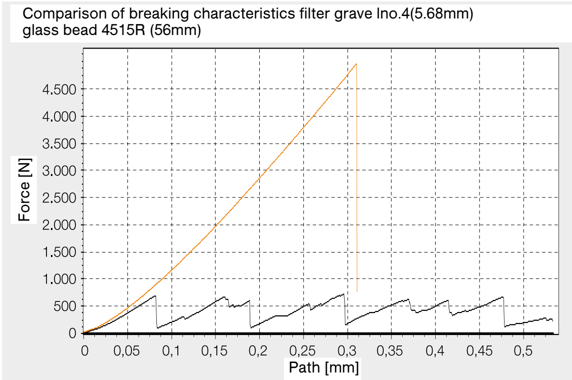
· very high fracture strength during installation
· no plugging of screen slots with debris
· no plugging of filter pack
· no sand removal pumping after installation



A = Filter gravel no. 1 (1.42.2 mm); B = filter gravel no. 2 (12 mm); C = glass bead type S (1.251.65 mm) part no.: 4505 #923033; D = glass bead type S (1.50+0.2) part no.: 4505A #8200291; E = filter gravel no. 3 (2.03.15 mm); F = glass bead type S (2.853.45 mm) part no.: 4511 #920032; G = glass bead type S (3.00+0.3) part no.: 4511A #820022); H = filter gravel no. 4 (5.68 mm); I = glass bead type S (56 mm); J = filter gravel no. 5 (812 mm); K = glass bead type M (12 mm) part no.: 50189924 #85505720 Filtertype

Inspection lot n=20; Breaking load determination: at 90
Machine type inspect table 20kN (Hege% >Fmax.
Hegewald & Peschke) Tester: Michael Danhof
Test velocity: from 0 = 50 mm/min
Fig. 2: Magnitudes of breaking load of filter gravel and glass beads at different granulation and bead sizes and mixtures at static load handling.
Source: Authors

DVGW 1/2010



— Filter gravel no. 4 (5.68 mm) — Glass bead 4515R #953059 (56 mm)

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.

DVGW 1/2010

5 Least possible and smooth surface

· less than 40 % incrustation of iron and manganese compared to gravel packs
· longer intervalls between well rehabilitations
· easy removal of iron and manganese coatings
· significantly less biofilms
· low acid solubility

6 Good visibility of filter pack in continous wire wrapped screen types

· best visual check capability

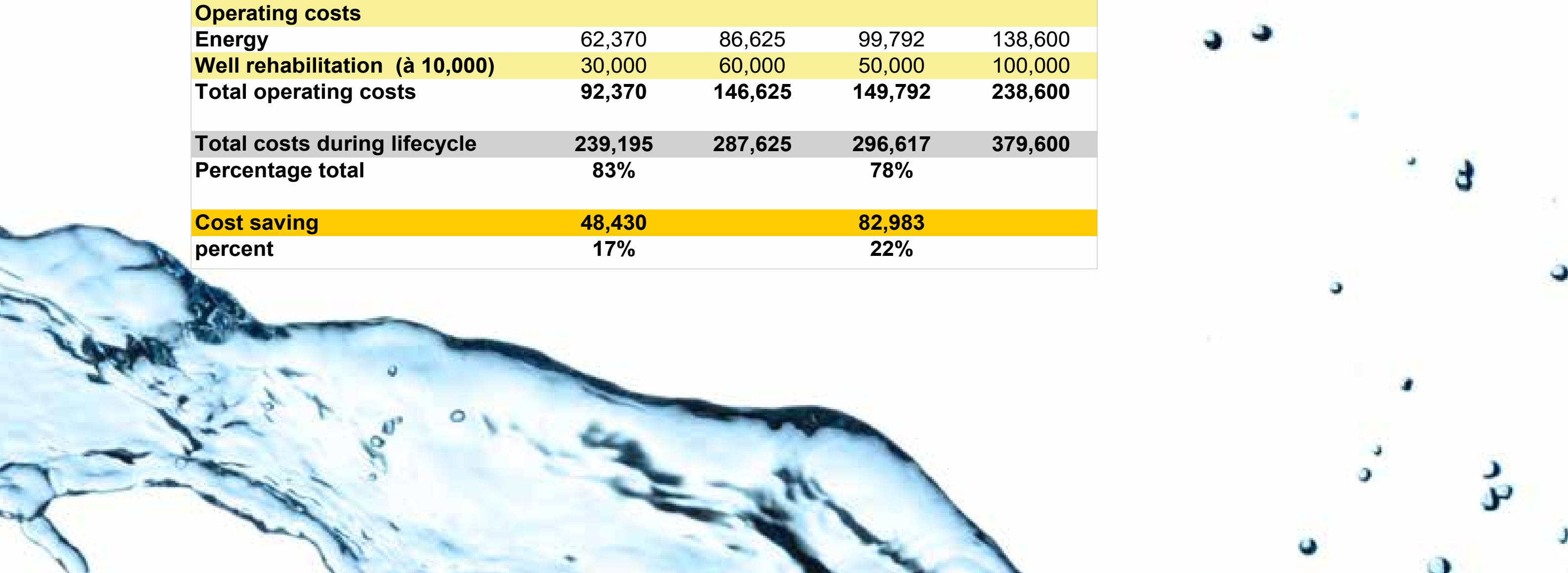
7 Longer lasting life cycle of well at lower costs for operation and maintenance

table on the back

Comperative Lifecycle Costs

Comparative Lifecycle Costs, water well, alluvial formation, depth 25 m (80 ft.) natural gravel vs. glass beads as filtermaterial				
		25 years		40 years
Capital expenditure	**glass beads**	**gravel**	**glass beads**	**gravel**
	EURO	**EURO**	**EURO**	**EURO**
construction site set up	15,000	15,000	15,000	15,000
well drilling	7,800	7,800	7,800	7,800
installations (well screens, etc.)	72,000	72,000	72,000	72,000
gravel	50	1,800	50	1,800
glass beads	6,000	0	6,000	0
pumping test	14,650	14,650	14,650	14,650
clean out pumping	400	2,400	400	2,400
sand removal pumping	150	600	150	600
Total capital expenditure	**116,050**	**114,250**	**116,050**	**114,250**
Differences	**1,800**		**1,800**	
Percentage total	**102%**		**102%**	
Operating costs				
Energy	44,794	59,725	71,670	95,560
Well rehabilitation (à 10,000)	25,000	50,000	50,000	100,000
Total operating costs	**69,794**	**109,725**	**121,670**	**195,560**
Total costs during lifecycle	**185,844**	**223,975**	**237,720**	**309,810**
Percentage total	**83%**		**77%**	
Cost saving	**38,131**		**72,090**	
percent	**17%**		**23%**	

Comparative Lifecycle Costs, water well, bed rock, depth 50 m (165 ft.) natural gravel vs. glass beads as filtermaterial				
		25 years		40 years
Capital expenditure	**glass beads**	**gravel**	**glass beads**	**gravel**
	EURO	**EURO**	**EURO**	**EURO**
construction site set up	20,000	20,000	20,000	20,000
well drilling	15,000	15,000	15,000	15,000
installations (well screens, etc.)	101,750	101,750	101,750	101,750
gravel	1,250	2,500	1,250	2,500
glass beads	8,000	0	8,000	0
sand removal pumping	600	1,300	600	1,300
clean out pumping	225	450	225	450
Total capital expenditure	**146,825**	**141,000**	**146,825**	**141,000**
Differences	**5,825**		**5,825**	
Percentage total	**104%**		**104%**	
Operating costs				
Energy	62,370	86,625	99,792	138,600
Well rehabilitation (à 10,000)	30,000	60,000	50,000	100,000
Total operating costs	**92,370**	**146,625**	**149,792**	**238,600**
Total costs during lifecycle	**239,195**	**287,625**	**296,617**	**379,600**
Percentage total	**83%**		**78%**	
Cost saving	**48,430**		**82,983**	
percent	**17%**		**22%**	



Product Data Sheet

SiLibeads – Glass beads for water wells / drinking water abstraction

First created on:	2017-09-26	Updated on:	2019-09-05	
Next inspection on:	2020-12-31	Printed on:	2019-09-05	Version: V26/2019

Product: **SiLibeads Glass beads**

Material:

Polished glass beads made of soda lime glass
Specific weight: 2.50 kg/l

Hydrolytic resistance:	(DIN ISO 720)	HGB 3	[< 9.0 mm]	/	HGB 3	[> 9.5 mm]
Acid resistance:	(DIN 12116)	S 1	[< 9.0 mm]	/	S 1	[> 9.5 mm]
Alkali resistance:	(DIN ISO 695)	A 1	[< 9.0 mm]	/	A 2	[> 9.5 mm]

Fields of application: Glass beads are used as back-up and borehole filter material

Major Advantages of SiLibeads Glass beads:

- Several times higher crushing strength than natural quartz gravel.
- Highest possible effective pore space due to uniform size and spherical shape.
- No flattened and broken sub grain hence wider well screen apertures possible
- No filter packs development necessary.
- No subsequent subsidence of filter pack
- Smooth surface delays iron and manganese incrustation.
- Faster and more efficient well development due to large and regular pore spaces.
- No bridging or jamming during fill-in process.
- Good visibility of filter pack through wire wrapped screens at video inspections

Technical Data:

Sizes:	see table of standard sizes
Deformation temperature:	600 °C
Softening point (Littleton point):	741 °C
Melting point:	1475 °C
Specific thermal Conductivity:	1.135 W/(m·K)
Hardness according to Mohs:	≥ 6

Chemical Analysis; Glass beads made of soda lime glass; CAS-Nr. 65997-17-3 / EINECS 266-046-0:

Name	Method	Weight (reference values)	CAS-No.	EINECS
Silicon dioxide SiO_2	DIN 51001	65.0 - 75.0 %	7631-86-9	231-545-4
Sodium oxide Na_2O	DIN 51001	12.0 - 17.0 %	1313-59-3	215-208-9
Calcium oxide CaO	DIN 51001	< 10.0 %	1305-78-8	215-138-9
Aluminium oxide Al_2O_3	DIN 51001	< 5.0 %	1344-28-1	215-691-6
Magnesium oxide MgO	DIN 51001	< 5.0 %	1309-48-4	215-171-9

The heavy metal content of the Glass beads keeps the permitted limits of EU directive 2011/65/EC (RoHS).			
Lead < 1000 ppm	Cadmium < 100 ppm	Chrome VI < 1000 ppm	Mercury < 1000 ppm

Assessment acc. to Food Legislation:

The tested Glass beads are a consumer good in the sense of §2 Abs. 6 No. 1 German Code for Food Stuff (LFGB), Commodities and Feeding Stuff. Therefore they have to comply with the legal requirements.
The Glass beads comply with the requirements § 31 of the German Food and Feed Code (LFGB) and of the European Food Regulation 1935/2004/EC, Article 3.

SiLibeads fulfill the micro biological requirements according to DIN EN ISO 14698-1 and VDI 6022.

Conformity to Water Well and Water Filtration Specifications

SiLibeads Glass beads meet **AWWA A 100** water well specification.
SiLibeads Glass beads meet **AWWA B 100** filtration specification.

Product Data Sheet

The German spirit of quality since 1854

SiLi® SIGMUND LINDNER

SiLibeads – Glass beads for water wells / drinking water abstraction

First created on:	2017-09-26	Updated on:	2019-09-05
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Version: V26/2019

Conformity to BS 6920:2000:

SiLibeads Glass beads have satisfied the criteria set out in BS 6920: Part 1: 2000 “Specification” and thus complies with the requirements of the “Water Regulations Advisory Scheme Tests of Effect on Water Quality”.

NSF-Certificate No. C0104873-01:

Sigmund Lindner is NSF International certified and complies with NSF/ANSI61 requirements.

NSF Certified to NSF/ANSI 61

Article	Diameter / mm	(approx.) **Mesh Sizes**	**Roundness** (nominal values)	**Compressive Resistance** (Reference values for middle diameter)	**Bulk density** kg/l	**Bulk density** lb/ ft.3
4501R	0.25 - 0.50	**60 – 35**	0.94	N/A	1.46	**91.14**
45015R	0.40 - 0.60	**40 – 30**	0.95	N/A	1.47	**91.77**
45021R	0.60 - 0.90	**30 – 19**	0.95	N/A	1.49	**93.02**
4503R	0.80 - 1.00	**22 – 18**	0.95	170 N	1.50	**93.64**
4504R	1.00 - 1.30	**18 – 15**	0.95	250 N	1.51	**94.27**
4505R	1.25 - 1.65	**16 – 12**	0.95	370 N	1.51	**94.27**
4506R	1.55 - 1.85	**13 – 11**	0.95	520 N	1.52	**94.89**
4507R	1.70 - 2.10	**12 – 9**	0.95	620 N	1.52	**94.90**
4508R	2.00 - 2.40	**10 – 8**	0.95	770 N	1.53	**95.51**
4510R	2.40 - 2.90	**8 – 7**	0.95	920 N	1.53	**95.52**
4511R	2.85 - 3.45	**7 – 6**	0.95	1,270 N	1.53	**95.53**
4512R	3.40 - 4.00	**6 – 5**	0.95	1,550 N	1.53	**95.54**
4513R	3.80 - 4.40	**5 1/2 - 4 1/2**	0.95	1,900 N	1.53	**95.55**
4514R	4.50 - 5.50	**4 1/2 - 3 1/2**	0.94	2,350 N	1.49	**93.02**
4515R	5.00 - 6.00	**3 3/4 - 3 1/4**	0.92	3,150 N	1.47	**91.77**

Other diameters and tolerances available upon request

Particle Size Conversion

Mesh	mm
80	0.177
70	0.210
60	0.250
50	0.297
45	0.354
40	0.420
35	0.500
30	0.595
25	0.707
20	0.841
18	1.00
16	1.19
14	1.41
12	1.68
10	2.00
8	2.38
7	2.83
6	3.36
5	4.00
4	4.76
3 1/2	5.66

Article	Diameter / mm	Inch Sizes	**Roundness** (nominal values)	**Compressive Resistance** (Reference values for middle diameter)	**Bulk density** kg/l	**Bulk density** lb/ ft.3
50165-B	9.40 - 10.60	**3/8" - 7/16"**	0.98	6,000 N	1.45	**90.52**
5017-B	10.50 - 11.50	**13/32" - 15/32"**	0.98	7,500 N	1.45	**90.52**
5018-B	11.50 - 12.50	**7/16" - 1/2"**	0.98	10,500 N	1.45	**90.52**
5021-B	13.30 - 14.70	**17/32" - 9/16"**	0.98	13,200 N	1.43	**89.27**
5023-B	15.30 - 16.70	**19/32" - 21/32"**	0.98	16,500 N	1.43	**89.27**

inches	mm
1/4	6.35
0.265	6.73
5/16	8.00
3/8	9.51
7/16	11.2
1/2	12.7
0.53	13.5
5/8	16.0
3/4	19.0
7/8	22.6
1.0	25.4

Glass Beads ≥ 10 mm can have a variance in size of approximately +/- 0.7 mm

Other diameters and tolerances available upon request

Roundness: simultaneous measurement of roundness through digital image processing (Retsch-Camsizer, value b/l3)

Product Data Sheet

SiLibeads – Glass beads for water wells / drinking water abstraction

First created on: 2017-09-26 Updated on: 2019-09-05
Next inspection on: 2020-12-31 Printed on: 2019-09-05 Version: V26/2019

Free of Silanes / Glycol / Epoxy:

We hereby confirm that Silanes, Glycol or Epoxy are not used during the production and packaging process.

HELPFUL INFORMATION:

Approximate Metric and Imperial Conversion Data

1 Cubic Feet = 1728 Cubic Inches = 28.32 liters
1 Cubic Yard = 27 Cubic Feet = 0.76 Cubic meters
1 US Liquid Gallon = 3.785 liters

1 kg = 2.2046 lbs. or 1 lb. = 0.454 kgs
1 liter = 0.035 Cubic Feet
1 Cubic Meter = 1,000 liters = 35.315 Cubic Feet

Calculating Annular Volume => $(R^2 - r^2) \times \pi \times h$

R^2 = Outer Cylinder Radius or Borehole Radius
r^2 = Inner Cylinder Radius or Casing
π = 3.14159265359
h = Height of Filling

Screen slot/ bead ratio

Maximum screen slot aperture recommended for all types of screens = 75% of the smallest bead diameter of the respective gradation.

Bead Sizing - Helpful Formula => $D = d_G \times F_G$

With: $U = d_{60} / d_{10}$

$F_G = 5 + U$ for $U < 5$ and $F_G = 10$ for $U > 5$

Derived from uniformity coefficient (U), characteristic grain size (d_G) and filter factor (F_G) based on reliable formation sieve analysis.

INSTALLATION:

Water Wells

SILibeads are used as filter pack media in the annulus of water wells. They are applied in the same way as natural gravel or sand. The bag is placed with its bottom end right above the feed hopper. The beads shall be placed by the use of a tremie pipe lowered to the bottom of the space to be packed and slowly raised as the beads fill the annular space. As the beads are being poured into the tremie pipe, water shall be poured in during the filling process to help in their placement

Filter Beds

SiLibeads replace natural sand and gravel in filter beds. They are applied in the same way as mineral filter media. They can be applied directly from the bag without any preparation of the filter bed

PREPARATION FOR USE & ROUTINE MONITORING:

If used properly, the product has no lifetime limits. The average cycle of use is several decades.
There is no need for special routine checks during use apart from the mandatory process or system checks.

Additional Information:

Storage:	Store containers (big bags) in a dry place, protected from direct sunlight.
Disposal:	Please consult national laws and local regulations in force for disposal or landfill.
Safety advice:	High risk of slipping due to spillage of the product
Product information:	Sample card SiLibeads … glass beads for technical applications Material safety data sheet SiLibeads; test reports

Certifications:

according to DIN EN ISO 9001:2015

according to HACCP-Standard for glass beads in contact with food stuffs

Manufacturer/Supplier:

Sigmund Lindner GmbH; Oberwarmensteinacher Str. 38; 95485 Warmensteinach / GERMANY
Phone: +49-9277-9940 Web: www.sili.eu
Fax: +49-9277-99499 E-Mail: sili@sigmund-lindner.com

All data are reference values – subject to change without prior notice

Certificates

Certificate

Standard: **ISO 9001:2015**

Certificate Registr. No.: **01 100 113653**

Certificate Holder:

Sigmund Lindner GmbH
Werk SiLibeads
Oberwarmensteinacher Str. 38
95485 Warmensteinach
Germany

including the location:

Werk SiLiglit
Bayreuther Straße 192
95485 Warmensteinach
Germany

Scope:

Development, production and sale of
• Technical Glass Beads
• Ceramic Beads
• Glitters made of Glass, Polyester and Aluminium

Proof has been furnished by means of an audit that the requirements of ISO 9001:2015 are met.

Validity:

The certificate is valid from 2018-05-17 until 2020-05-21.
First certification 2011

2019-06-19 (Change)

TÜV Rheinland Cert GmbH
Am Grauen Stein · 51105 Köln

www.tuv.com

TÜVRheinland®
Precisely Right.

CERTIFICAT ■ CERTIFICADO ■ СЕРТИФИКАТ ■ ZERTIFIKAT ■ CERTIFICATE ■ ZERTIFIKAT

Management Service

CERTIFICATE

The HACCP Management System
of

Sigmund Lindner GmbH
Oberwarmensteinacher Straße 38
95485 Warmensteinach
Germany

has been assessed and complies with the requirements of

TÜV MS Standard HACCP

Certification scheme for HACCP Management Systems which implements requirements of DIN EN 15593:2008 Packaging – management of hygiene in the production of packaging for foodstuffs and Codex Alimentarius: Hazard Analysis and Critical Control Point (HACCP) System and Guidelines for its implementation and General Principles of Food Hygiene (CAC/RCP 1-1969, Rev. 4 - 2003).

This certificate is applicable for:

Production of
glass beads with food contact.

This certificate is provided on the base of the TÜV MS Standard HACCP.
The certification system consists of a minimum annual audit of the HACCP management system and a minimum annual site inspection.

The certificate is valid from **2017-12-22** until **2020-12-21**.

Certificate Registration No.: **12 500 6581 TMS**.

Product Compliance Management
Munich, 2018-01-08

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, 2013
Certificate# C0504872 - 01

David Purkiss, General Manager
Water Distribution Systems

SiLibeads®

Press Releases

Development and scaling characteristics of glass bead and gravel packs – Findings for practical well design

Ever since their first introduction as filter pack medium in 2007, glass beads have been the subject of intensive investigation, but also of controversial discussions about their sense and necessity. In a series of comparative investigations conducted in the meantime basic findings were gained regarding the function of filter packs and their systemic interaction and influence factors.

Table 1 – Construction details of test wells 1 through 6 on the premises of the Construction Training Centre Rostrup (screen length: 4 m)

Well no.	Typ of ring space filling	Installed grain/ bead size[mm]	Filter pack length[m]
1	Glass beads (Gk)	1,7 bis 2,1	8,30
2	Filter sand (Fk)	1,0 bis 2,0	8,30
3	Glass beads (Gk)	2,0 bis 2,4	6,00
4	Glass beads(Gk)	2,4 bis 2,9	7,00
5	Glass beads(Gk)	2,85 bis 3,45	7,00
6	Filter gravel (Fk)	2,00 bis 3,15	8,00


Fig. 1

Picture: Teskatis

The use of new procedures or materials in well construction often triggers controversial discussion on the sense or the necessity of these measures. A positive effect of these discussions is that they do not only initiate product-related research, but that they also lead to the questioning of conventional and mostly empirically gained work basics and attitudes.

The physical properties of the two different filter pack materials were investigated in 2008 within the scope of an R&D project on a laboratory level.
It was found that there were measurable differences between the material types regarding roundness, breaking load, breaking characteristics, abrasion resistance and the cohesion behaviour to chemically induced iron hydroxides [1+2].

In 2011 laboratory and test rack tests were conducted at the Construction Training Centre at Rostrup.
The tests were intended to determine hydraulic characteristics to permit the general hydraulic characterisation of filter media in well constructions.
On a laboratory and technical level the various filter media were tested regarding the porosity for loose and dense bedding, their settling properties under unsaturated and saturated conditions, the permeability values and the through-flow rates as well as the system permeability of formation and filter pack [3+4].

The findings gathered from laboratory and technical tests during the years 2009 to 2011 were substantiated in the scope of a master's degree dissertation at the Jade University Oldenburg on real wells on the premises of the Bau ABC in Rostrup [5].

Investigation objective

In continuation of the laboratory and technical tests of the years 2011 in 2012 and 2013 more in-depth investigation was carried out on site of Bau ABC Rostrup.

The focus was mainly on the influence of filter materials on development and scaling properties and the (iron) clogging of glass beads in relation to filter gravels of similar grain sizes. The field investigations carried out to support the laboratory tests permitted first assessments regarding the sensitivity of different filter media of comparable ball and grain sizes, on specific capacity, as well asdevelopment and aging characteristics.

The objectives of the experimental investigations presented below were initially a confirmation of the laboratory results, and on the other hand an examination of the laboratory results in the well operations as well as the development of advantages and disadvantages in relation to the application area and the specific well technology and general conditions.
In parallel there were column tests with natural gravels and glass beads

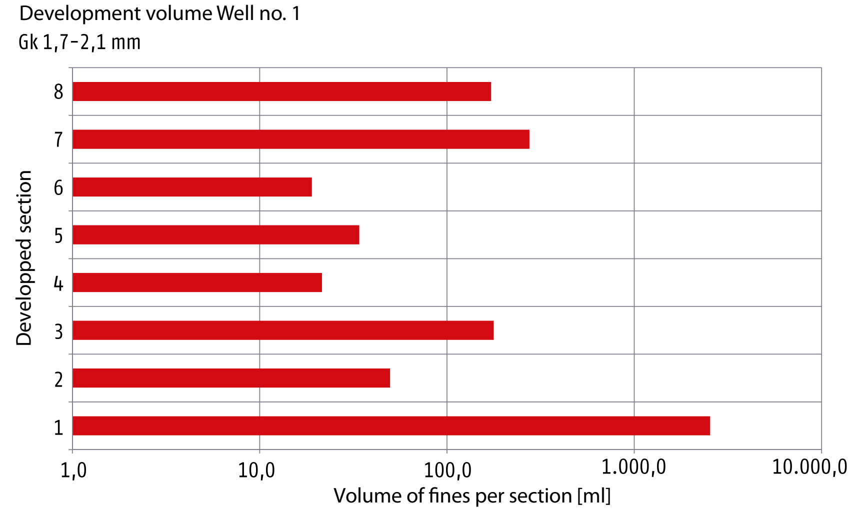

Image: L. Tholen

Fig. 2 – Gravel volume in the eight developped sections (L = 0.5 m) of the well B1 (construction with glass beads 1.7 to 2.1 mm); according to [5]

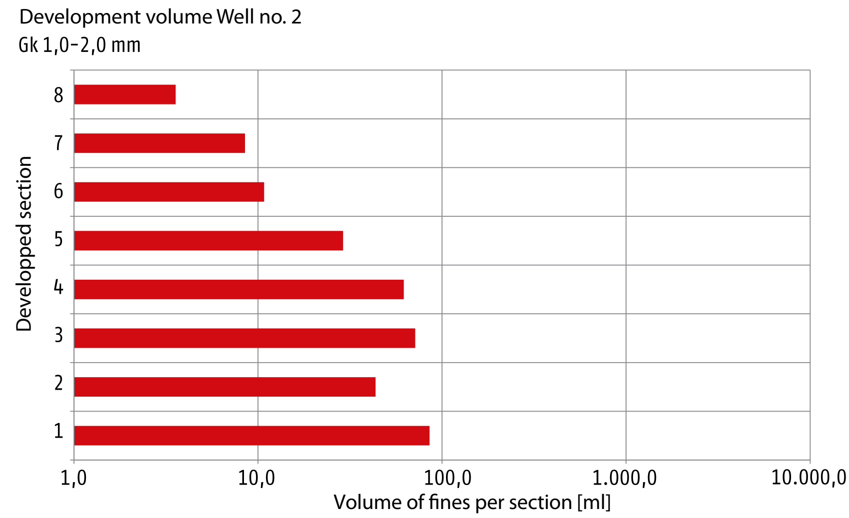

Image: L. Tholen

Fig. 3 – Gravel volume in the eight developped sections (L = 0.5 m) of the well B2 (construction with glass beads 1.0 to 2.0 mm); according to [5]

Table 2 – Volume of fines per section in wells B1 through B6 as well as the total finesvolumes when reaching a steady state value or the abortion criterion, according to [5

Fines volume[ml]						
Development section in the screened area	B1: Gk 1,7-2,1	B2: Fk 1,0-2,0	B3: Gk 2,0-2,4	B4: Gk 2,4-2,9	B5: Gk 2,85-3,45	B6: Fk 2,0-3,15
1	2.541,5	85,5	1.099,5	2.713,0	335,0	3.350,0
2	49,7	43,5	431,5	832,0	202,0	1.126,0
3	177,5	71,5	264,0	1.205,0	65,0	930,0
4	21,5	62,0	267,0	840,0	80,0	655,0
5	34,0	29,0	141,0	650,0	50,5	135,0
6	19,0	10,8	154,0	1.188,0	204,0	485,0
7	275,6	8,5	291,0	785,0	162,0	220,0
8	172,0	3,6	332,0	1.910,0	124,0	86,0
Total volume of the well	3.290,8	314,4	2.980,0	10.123,0	1.222,5	6.987,0

to investigate the use of glass beads as a replacement for gravel regarding the respective clogging behaviour. The results are described in detail in [5].

Development tests on actual wells

At the construction training centre in Rostrup six vertical wells were sunk into the quaternary fine and medium grain sands below the local aquiclude and equipped with PVC pipes (Fig. 1). The aquifer is confined and characterized by high iron and manganese content (7 to 12 mg/l Fe total and 1.2 to 1.8 mg/l Mn total). Rostrup was chosen as the location for test construction because the geologic conditions are fairly uniform so that different well designs can be tested in roughly the same hydrogeological conditions.

The lining of the bore holes with a diameter of 324 mm was created with PVC tubing material DN 125 as well as filter gravels or glass beads of various grain sizes. The grain or bead sizes were intentionally selected higher than the filter grain size listed in DVGW worksheet W 113 (Tab. 1). The sieve curves gained through extended sift sets amounted to filter grain sizes according to DVGW work sheet W 113 of ≤ 2 mm, for which a DIN filling of 1 to 2 mm was derived. The uniformity coefficient was below 2 throughout.

The wells were sunk in the year 2010 and only pumped clear at that time, geophysically surveyed and then left unproductive until the commencement of the test runs in autumn 2012. After a CCTV inspection, which showed soft coatings of varying thicknesses and mainly in the upper screen segment, a three-stage pump test run according to DVGW-AB W 111 was conducted. Subsequently, all wells were developed by means of a surge block (packer spacing 0.60 m). Then a further pump test with the extraction stages of 8, 12 and 16 m3/h was conducted. During the development work the following qualitative results were found in the six wells investigated:

- The silt volumes delivered at approx. 9 m3/h through the chamber in the gravel wells exhibited a trend below those from the glass bead wells (Tab. 2 and Fig. 2+3); the silt extraction increases with the bead or grain size of the respective filter material type as expected.

• In the gravel well no. 6 with the gradation of 2.0 to 3.15 mm a surprisingly high silt throughput was detected during the pumping development despite the conformity of the filler grain (determined with the standard sift set), probably caused by an erroneous determination of the characteristic grain (e.g. by using a sift set with an excessively wide test sift size) by errors in the soil sampling.

• Evenby moderate impulses of the "moving" piston (lift height 0.5 m) an increase of the silt delivery was detected regardless of the filler material type. A stable steady state of the silt delivery could not be achieved in all wells or all treatment stages along the 4 m filter length, which was caused by the technically intended "over-dimensioning" of the filter pack material in the wells no. 4 through 6.

• During the pump trials after development the wells no. 1 and 2 with fine grained packs (see Tab. 1) exhibited the previously defined threshold of < 0.1 g/m of sand and silt in all extraction stages 3, as expected. In well 3 a sand breach was only achieved at the highest extraction rate (16 m3/h), which was in excess of the production rate of 12 m3/h defined for this location.

• The wells no. 4 and 5 with coarser glass beadpacks could not be developed to a sand free state because, as expected, this gradations were, under production conditions, not stabile against finescoming from the aquifer.

• The well no. 6 with a gravel pack exhibited, at an extraction rateof 12 m3/h, a silt content of < 0.1 g/m3, and at 16 m3/h a silt breach, like well no. 3 with the glass bead filling.

From the trials on the six wells the following conclusions and evidence can be derived:

The specific capacity of the glass bead wells is, at given geologic conditions, approx. 15% higher than with the comparable grain sizes of the DIN filter gravels (Fig. 4). This ratio remains unchanged even after the development of the wells.

The system permeabilities of the wells are increased by development, as expected, with well no. 2 exhibiting the highest increase. However, the system permeabilities of the glass bead wells are higher than in the filter gravel wells by a power of ten.

The wells no. 1 and 2 correspond in their filter pack type with the local wells typical for Rostrup. This was proven by the sand free condition at the end of the development work by means of a pumptest according to DVGW-AB W 119.

The filter pack gradation of wells no. 4 through 6 must be rated as "over-dimensioned" for QOperation despite a filling of 2 to 3.5mm as specified according to DVGW-AB W 113.

The silt volume delivered increases with the bead or grain size and reaches in the treated sections of the filter stretches of 4m each various levels.

The particle sizes delivered during development were, for the "correctly" dimensioned filter gravel wells (well no. 2), up to 0.2mm (< 5% of the mass) and thereby below the grain size of 0.36mm as determined by W 113; in the glass bead well no. 1 there was a low delivery of particles measuring no more than 0.5mm (approx. 5% of the mass). The remaining wells all exhibited silt breaches with increasing particle shares of the characteristic grain size of 0.5mm (13 to 17% in wells no. 4 and 5). The size ofgrains put through increases with the fine grained soil (Cu < 2) as a function of the bead or grain size of the filter pack.

In the glass bead fillings "over-dimensioned" according to DVGW AB W 113 there were silt breaches with grain sizes larger than the characteristic grain size, which is not as significant as with the coarser gravel filling.

In glass bead fillings with a "correct" dimensioning of the bead size breach of particles with a size up to the characteristic grain size can be expected. This is substantiated by the development results of an ASR well in alluvial sands and gravels in Phoenix, Arizona. The well was only partially filled with glass beads for budget reasons; the remainder was filled with gravel with a grain size common at the location. The glass bead size corresponds with the gravel grading. While the section with the gravel filling delivers less particles in total and also coarser grains, probably originating from the filler material itself, the silt delivery from the glass bead section is limited by the characteristic grain size. The maximum diameter of the passing grain corresponds exactly with the pore channel size at dense bedding.

In filter gravels an ochring-induced pressure increase occurs earlier than in comparable glass bead packs.

This shows that glass beads can be brought in this bedding configuration without additional measures required (Fig. 5 + 6) [6].

Erroneous dimensioning and silt breaches can only be prevented by most precise sampling and sifting set grading in the finer grain sizes between 2.0 and 0.063 mm or more precise measuring procedures (e.g. by means of cam sizer measurements).

Filter gravels appear to exhibit a higher "tolerance" for erroneous sizing and procedural faults in well construction in respect of silt freedom andfilter stability. This higher "tolerance" of filter gravel for faulty craftsmanship is compensated by an increased risk of clogging and lower specific capacity of filter gravel in comparison with glass beads in comparable wells.

Laboratory tests to determine the pressure build-up due to chemical clogging The deposits of iron and manganese oxides in wells through oxidation in conjunction with microbiological influences are often an unavoidable side effect in the extraction of water. The consequence of this clogging, also called "ochring", is, regardless of the cause, a gradual increase of pressure losses in the permeable pores in filter packs with deposits and separation of iron and / or manganese oxides, as well as a reduction of specific capacity of the well.

At the construction training centre in Rostrup laboratory experiments were conducted to determine the pressure losses due to an artificially induced chemical ochring (through the induction of oxygen into the otherwise reduced, iron and manganese containing crude water from a well) in various filter packmaterial types and gradations. For this purpose different filter gravels and glass bead fractions were directly compared (Tab. 3). Microbiological aspects of ochring and the removal of the deposits by means of rehabilitation media available on the market were not investigated within the scope of these experiments [7]. With a similar objective and test setup and at almost the same time a team from various institutions conducted similar tests at the competence centre Wasser Berlin GmbH [8].

For the pressure loss determination in various materials a Darcy test setup was used to determine the permeability of filler materials of different thicknesses in the previous investigations [5]. The test cylinder was filled with the respective filler material to a height of approx. 50cm, but not compacted. The filter gravel was sifted dry so that the finer particles of the filter gravel could not clog up the fine sieve which provides stability to the column filling. The sieve mesh was adjusted to the filler size in each run to reduce pressure loss. The throughput water was taken from a well on the premises of the test centre, and in order to accelerate the ochring oxygen was artificially added. The pump was regulated at 2 bar in order to ensure the system safety [7].

The pressure curve in the filling was recorded at a constant throughput with data loggers and is shown for the investigated filter materials in Fig. 7. The pressure increase in the test body was at different times, according to the different filter materials. After reaching the pressure level of 2bar set in the test run the plateau phase was reached at different times. The time differences depend on material type and grain sizes. The period between the pressure build-up curves is almost constant after the turning point before the plateau phase resulting from the test setup.

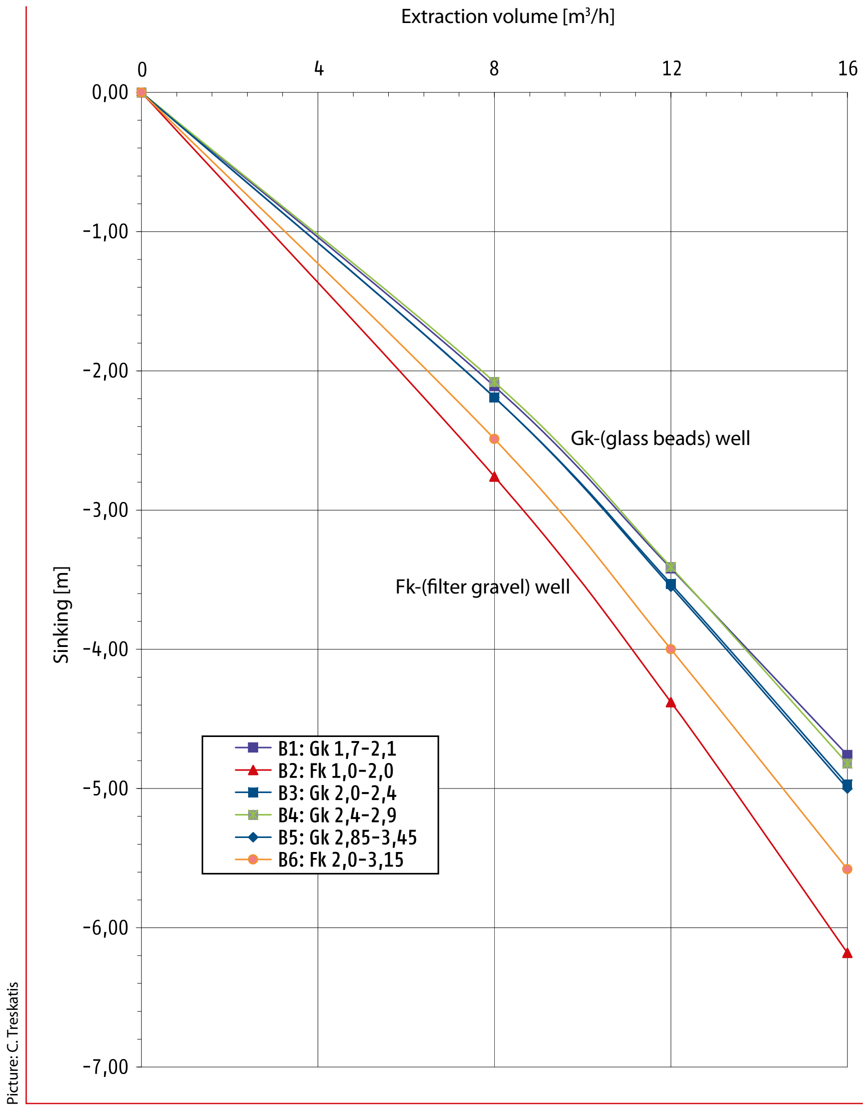

Fig. 4 – Yield curves of the wells no. 1 through 6 before development according to [5]

Test results

At the beginning of the test small pressure differences were noticed between the various material types, even without any chemical ochring; the glass beads exhibited the lowest start pressure.

Chemical ochring is very pronounced in all filter pack materials investigated and clearly visible. Caked agglomerates consisting of iron oxides and glass beads and filter gravel respectively could be detected in the middle of the test column.

Fig. 3 – Silt volume in the eight developped sections (L = 0.5 m) of the well B2 (construction with glass beads 1.0 to 2.0 mm); according to [5]

Gravel [mm]	Glas beads [mm]
0,70 – 1,25	0,75 – 1,00
1,00 – 2,00	1,70 – 2,10
2,00 – 3,15	2,40 – 2,90

Like filter gravel, glass beads were at first covered with a thin layer of man-
Like filter gravel, glass beads were at first covered with a thin layer of manganese oxide and embedded in an iron oxide matrix [7].

From the test runs conducted up to this point it may be derived that the rise in pressure due to scaling in filter gravel starts, in principle, at an earlier point than in the analogous glass bead fillings.

This conclusion applies to the direct comparison of fillings of equal volume. In glass bead fillings with comparable circumstances the pressure increase commences anytime between 40 and approx. 98 hours, in the comparable filter gravel fillings this occurs already after 24 to 70 hours. So the scaling of glass beads is delayed (in the laboratory) by a time factor of 2 to 2.5.

The pressure build up curves rise, after the test-related turning point has been reached (the plateau phase is due to the pressure limiter in the pump and cannot be compared to the actual well operations), to the test-related pressure limit of 2bar almost in parallel and with same gradient for all bead sizes.

The pressure build up curves in the initial phase up to the test-related turning point is, according to these test results, dependent on the material type and the grain size of the filling and its extent is influenced substantially by water quality.

The test setup has an influence on the pressure build up times, as was shown with a repetition of the test with glass bead size (diameter) 1.7 to 2.1mm. The first test run with 1.7 to 2.1mm glass beads resulted in a pressure increase after approx. 160 hours. The repeat test conducted at the end of the entire test series showed a pressure increase after only 80 hours. One of the possible causes for this time difference can be the increasing scale buildup of the feed lines and the dislodging and shifting of scale products in the filler cylinder, resulting in an earlier pressure increase than in the first test [6].

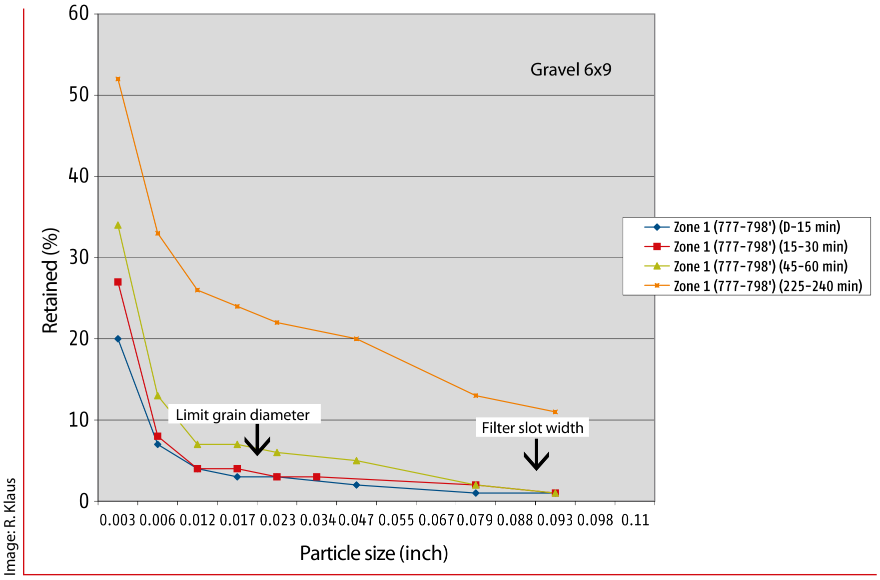

Fig. 5 – Grain distribution of the extract from the section with the gravel filling

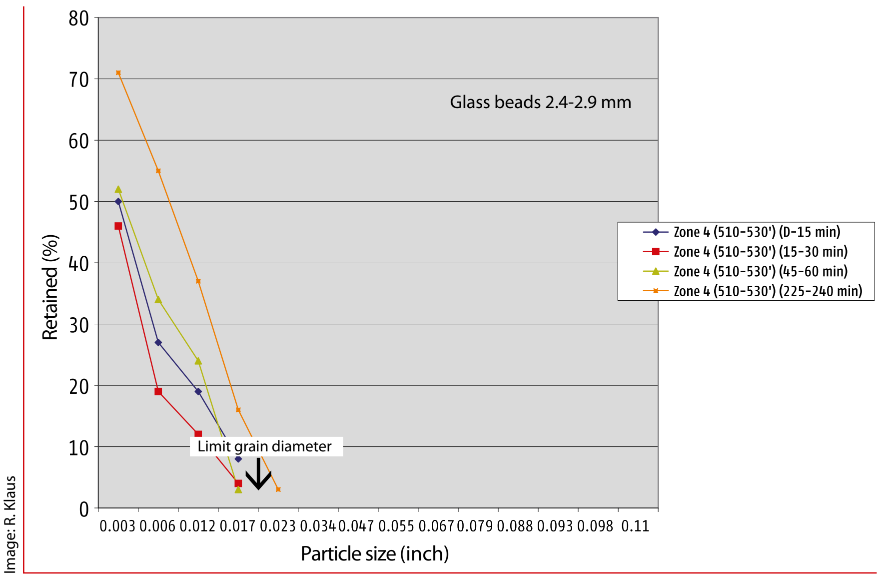

Fig. 6 – Grain distribution of the extract from the section with the glass beads filling

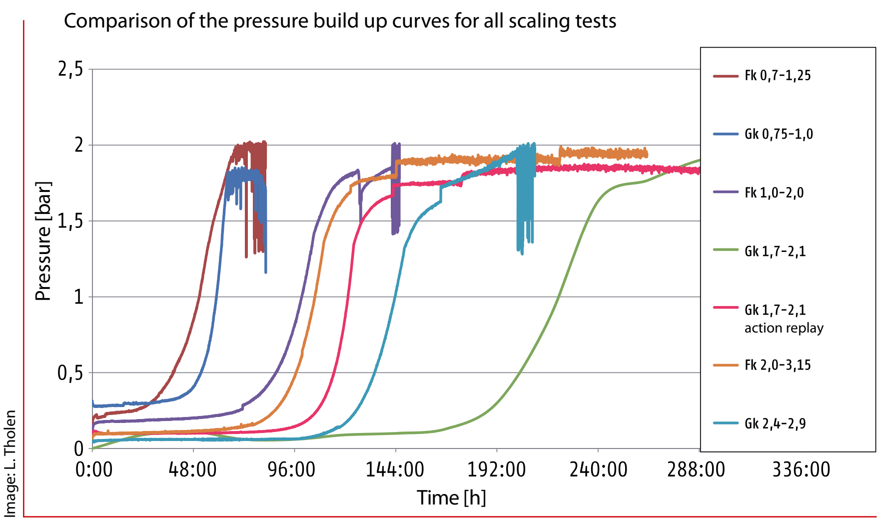

Fig. 5 – Pressure build up curves in the investigated filler materials with an induced chemical scaling, according to [5+7].

The results and conclusion from the investigations and tests in Berlin are different from those in Rostrup, mainly in respect of the comparison of the scaling reaction between glass beads and sand respectively gravel [8]. There are agreements in the results in respect of the hydraulic properties and characteristic values in the direct comparison of appropriately grained filter sands and glass beads. Here the respective grain sizes correspond with the investigated filler materials and they confirm the test results from Rostrup [1+2].

Regarding the accumulation ratios and the regeneration potential the glass beads in the Berlin study are fare worse than the filter sand and gravel fractions investigated there [8]. The grain of one of the filter gravels provided the best result. But it must be considered that the filler materials investigated in Berlin were of different size spectrums. By far the largest was a gravel with a grade of 5.6 to 8mm, while sand and glass beads were only investigated at a grade of 1.25 to 1.6 to 1.65mm respectively in the published comparative reports [8].

A direct comparison of the results is not possible due to the different test approaches and methods. As quoted by the authors of [8], because the hydraulic parameters are dependent on the material grain sizes, the materials must necessarily be tested within the same size class [7].

Summary

Experimental laboratory and field research shows that the sizing of a glass bead filter pack is unproblematic for sediments with a very low uniformity coeffiecient when investigated layer-specifically and an extended sift set is used for determining the characteristic grain size out of the sieve curve.
In order to prevent sand productionan exact bead size determination is required according to DVGW-W 113.
This applies also to gravel fillings, only in this case the sand production in case of an erroneous sizing is blurrred by embedding a relevant share of fines from the formation in the gravel pack.
In the case of glass bead packs this process is often directly visible.
When compared with mineral gravel packs, the scaling of glass bead packs with identical grain sizes in laboratory tests is delayed. The “scaling velocity” that can be derived from this is a measure for the increase in pressure over time in the test body and is reduced by

the smooth surface of glass beads and the more uniform pore geometry as compared with those of filter gravel.

The further pressure build-up curve characteristic of glass bead fillings is, in the laboratory, after the test-dependent turning point in parallel to the pressure build-up of filter gravels. The pressure increase in the laboratory experiments was limited by a frequency control of the pump with a constant extraction flow rate for safety reasons, which is not the case in real wells. In real wells the differential pressure increases in the filling, contrary to the laboratory experiments, and continues to rise even when the extraction volume is decreased.

Glass beads do not prevent any scaling of the well, but they delay the process. The findings from the experiments confirm that the initially different material properties of the investigated filter pack types are very heavily overlaid by individual aging processes in the well.

Acknowledgement

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New construction of water wells with glass beads

Productivities and savings potentials

Since late 2007, glass beads were used as a replacement for gravel as filter pack material. The initial point was the poor quality of the available natural sands and gravels which causes a lot of disadvantages in relation to glass beads in terms of form, stability and other criteria [1]. The inferior breaking resistance of gravel resulted in irreversible clogging of the annuluswhich can only be compensated by complete renovations. The life cycle of a well is thereby considerably reduced. The quality and state of the other components would have allowed flawless operation for an additional 10 to 20 years.

In 2009, DIN filter gravels and glass beads were tested for their mechanical properties. Glass beads proved to be superior in all parameters tested [5]. In 2011, there were comprehensive comparative studies on the hydrologic and hydrodynamic characteristics together with the performance in the development process. Also here the glass beads turned out to be superior to than filter gravel [6]. Table 1 shows a brief contrast of the materials „glass beads and sand“.

Though the long-term performance records of wells finished with glass beads currently don't exist, the benefits of glass beads can be expected due to material and hydraulic properties. While the technical advantages of glass beads are unanimously accepted among experts, higher procurement prices of glass beads compared to filter packs from mineral materials are frequently cited as a disadvantage and an obstacle to their application. The material price alone is by far not sufficient to assess the total cost-effectiveness of a well.

Wells are investment assets with a long service life of more than 40 years. In addition to the investment costs, the operation and maintenance costs have to be analysed in order to get a general idea of cost-effectiveness.

The major effect of the operating costs has long been known to be a major factor in the cost-effectiveness of wells. For a comparative cost effectiveness study,at least the following cost aspects must be taken into account:

- Investment costs,
- Energy costs of groundwater con veyance,
- Costs for maintenance and service (here: Costs of rehabilitation measures).

Recently the aspects of „investment costs“ or added costs for the use of glass beads compared to gravel and „energy costs of groundwater conveyance“ have been studied for newly constructed wells.

In 2009/2010, three new wells were constructed at a well field replacing existing wells in close distance. The wells were equipped with continuous wire wraped screens and glass beads as filter pack. Two of these wells, wells „A“ and „B“, are included in the following assessments. Other comparative data are available from a water well of a steel millt in Southern Germany.

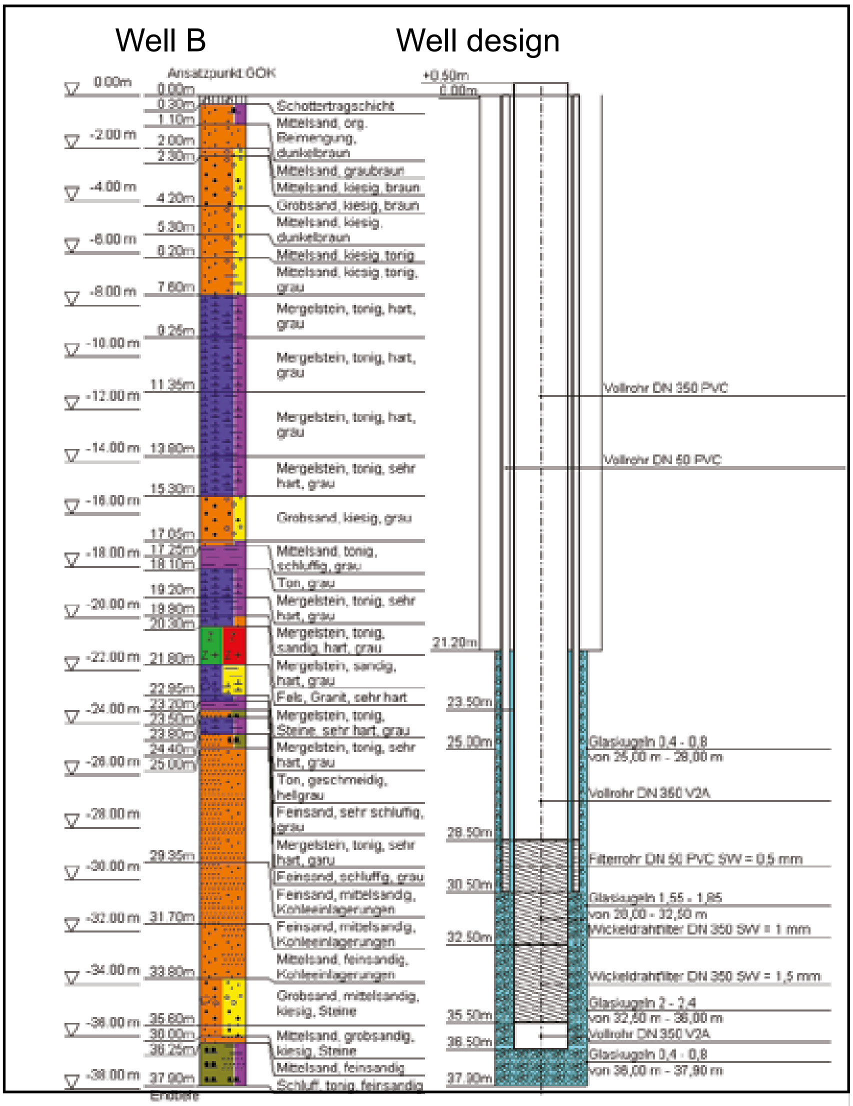

Figure. 1: Geology and instuction drawing of well "B" with glass beads

Table 1: Comparable contrast gravel/glass bearings in well construction

	Glass beads	Sand / Gravel
Percentage of undersize of material	+	-
Hydraulic properies	+	-
Mechanic properies	+	-
Bedding properies	+	-
Chemical resistance	+	-/+
Rehabilitation capability	+	-/+
Costs of material	-	+
Subsequent costs for development	+	-

In that well,in the original borehole the corroded copper screens and blanks were replaced with stainless steel continuous wire wrapped screens and stainless steel blanks. The annulus was refilled with glass beads. This well is listed as well „C" in the assessment. The constructional drawings for wells „B" and „C" are shown in Figure 1 and 2 (Figure 3).

For these wells new data is available from pumping tests. Assessments of discharge flow and drawdown as well as specific capacities are shown in Table 2 (with: Q = discharge; s = drawdown; E = specific capacity). Significant boosts in capacity can be achieved in all wells (Figure 4).

In Table 3 savings of energy costs for conveyance resulted in the wells studied. The annual conveyance quantities were estimated in the calculations. The annual discharge quantities were estimated in the calculations.

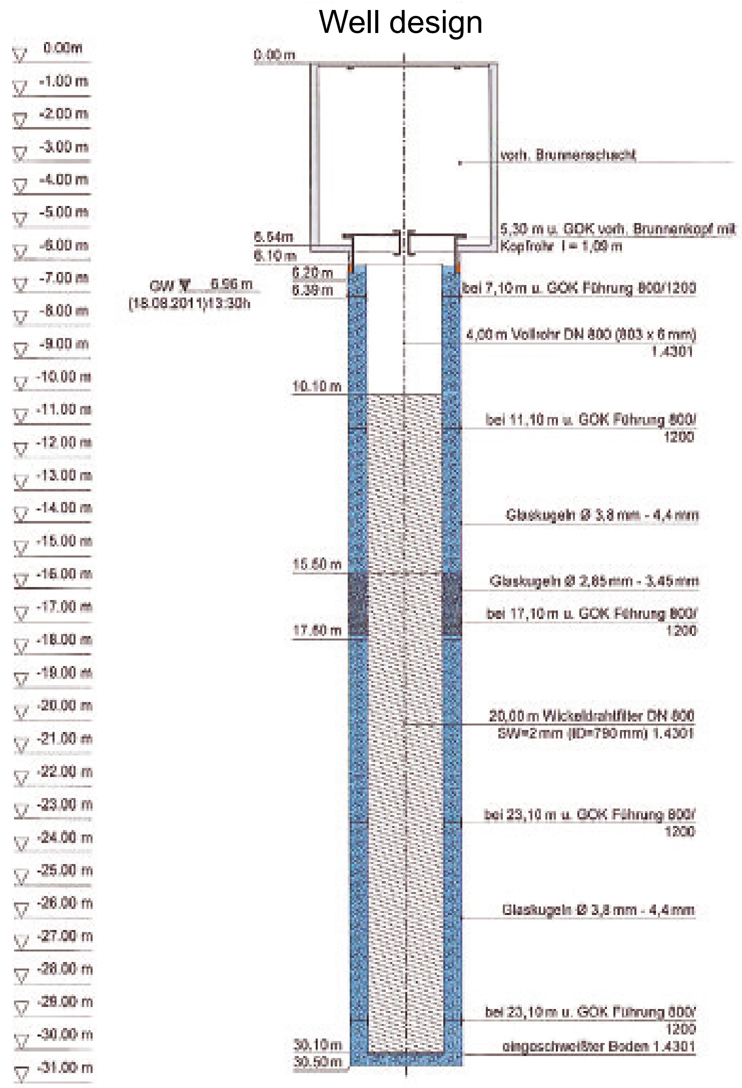

Figure. 1: Geology and construction drawings of well „B" with glass beads

Table 2: Conveyance quantities and yields achieved

	Well expansion	Q1	s1	E1	Q2	s2	E2	Q3	s3	E3	E average	Performance increase by
		(m³/h)	(m)	(m³/h/m)	(m³/h)	(m)	(m³/h/m)	(m³/h)	(m)	(m³/h/m)	(m³/h/m)	
Well A	Stone mat/ gravel	15,60	3,13	4,98	33,80	6,98	4,84	61,70	9,90	6,23	5,4	
Well A new	Tinted glass	20,16	2,02	9,98	39,60	3,91	10,13	60,48	5,71	10,59	10,2	91,2%
Well B	Stpne mat/ gravel	11,84	1,11	10,67	28,10	3,77	7,45	42,48	5,63	7,55	8,6	
Well B new	Tinted glass	19,80	1,76	11,25	39,96	3,72	10,74	59,76	5,61	10,65	10,9	27,2%
Well C	Copper gauze	259,00	2,80	92,50	92,5							
Well C new	Copper gauze	288,00	070	411,43							411,4	344,8%

Table 3: Contrast of well capacities old/new and gravel / glass beads

Energy costs raw water conveyance							
				glass beads			
		Well A old	Well A new	Well B old	Well B new	Well C old	Well C new
Costs per kilowatt hour on average	(Euor/ KWh)	0,15	0,15	0,15	0,15	0,15	0,15
Discharge on average	(M≥/h)	60	60	60	60	200	200
Discharge (collection)	(M≥a)	500.000	500.000	500.000	500.000	1.800.000	1.800.000
Level of effectiveness (μ) on average	(%)	60%	60%	60%	60%	60%	60%
Special yield on average (according to available data)	(M≥h/m/)	**5,4**	**10,2**	**8,6**	**10,9**	**92,5**	**411,4**
Relative conveyance depths (only referring to strict reduction s)	(mWS)	11,2	5,9	7,0	5,5	2,2	0,5
Total of energy costs pumping	**(EUR/a)**	**3.818**	**1.997**	**2.389**	**1.878**	**2.651**	**596**
Savings	**(EUR/a)**		**1.821**		**511**		**2.055**

Cost comparisons for the use of gravel or glass beads were provided by the operators forwells „A“ and „C“. A cost contrast is shown in Table 4 and 5. The sole differences in annual costs from „saving energy costs“ and added costs „debt service“ for the selection of glass beads equals EUR 1,821 - 273 = EUR 1,548/a (savings potential well „A“) and 2,055-718= EUR 1,337/a (savings potential well „C“).

The extrapolation over an operating time of 40 years - presuming conditions remain the same - the resulting savings potential for well „A“ is approx. EUR 62,000 and for well „C“ approx EUR 53,000. Additional savings can be expected for glass bead filter packs due to minimized iron clogging tendencies and resulting bigger intervals of well rehabilitation. Observations of an old well approx. four years old with glass bead filter pack in the Central Franconian sandstone Keuper have shown:

- Considerably less iron deposits in the annulus compared to wells with gravel pack,
- Minimal increase of filter resistance despite iron clogging,
- Easier removal of the deposits from the filter pack.

Table 4: Overview of total costs well “A”and “C’

	Well „A“		Well „C“	
“Partial trade	Filter pack with gravel	Filter pack with glass beads	Filter pack with gravel	Filter pack with glass beads
1. Construction site set-up	EUR	EUR	EUR	EUR
2. Drill	15,419	15,419	Individual costs not known	Individual costs not known
3. Casing	13,581	13,581	Individual costs not known	Individual costs not known
4. De-sanding and pump test	19,638	255,950	3,200	21,600
5. Well completion work	8,632	8,632	3,300	1,485
6. Inspections	31,502	31,502	Individual costs not known	Individual costs not known
Interim total 1 (Only well construction)	2,563	2,563	Individual costs not known	Individual costs not known
Interim total 1 (only well construction)	91,335	97,647	136,915	153,500
	100,0%	106,0%	100,0%	112,1%
Added costs		6,312		16,585

Table 5: Overrview of capital costs wells “A” and “C”

		Cost situation well “A”		Cost situation well “C”	
		Filter pack “Gravel”	Filter pack “Glass beads”	Filter pack “Gravel”	Filter pack “Glass beads”
Investment and capital costs					
Investment costs	(EUR)	91,355	97,647	136,915	153,500
Operation time	(a)	40	40	40	40
Annual capital costs	(EUR/a)	3.951	4.224	5.923	6.641
Added costs “capiitalised”	(EUR/a)		273		

Of importance here is the continuous monitoring of well productivities and the amount and costs of rehabilitation measures in order to update the well performance in a technical and financial sense. Finally, it should be noted that new wells equipped with a natural gravel pack can also show increases in performance when they will be properly constructed and developed. This was not a subject of the study. Due to the inferior stability of gravel compared to glass beads (a initially mentioned) - over the entire life cycle of a well - the authors see considerable technical benefits for the use of glass beads, particularly in terms of performance in addition to the financial benefits presented.

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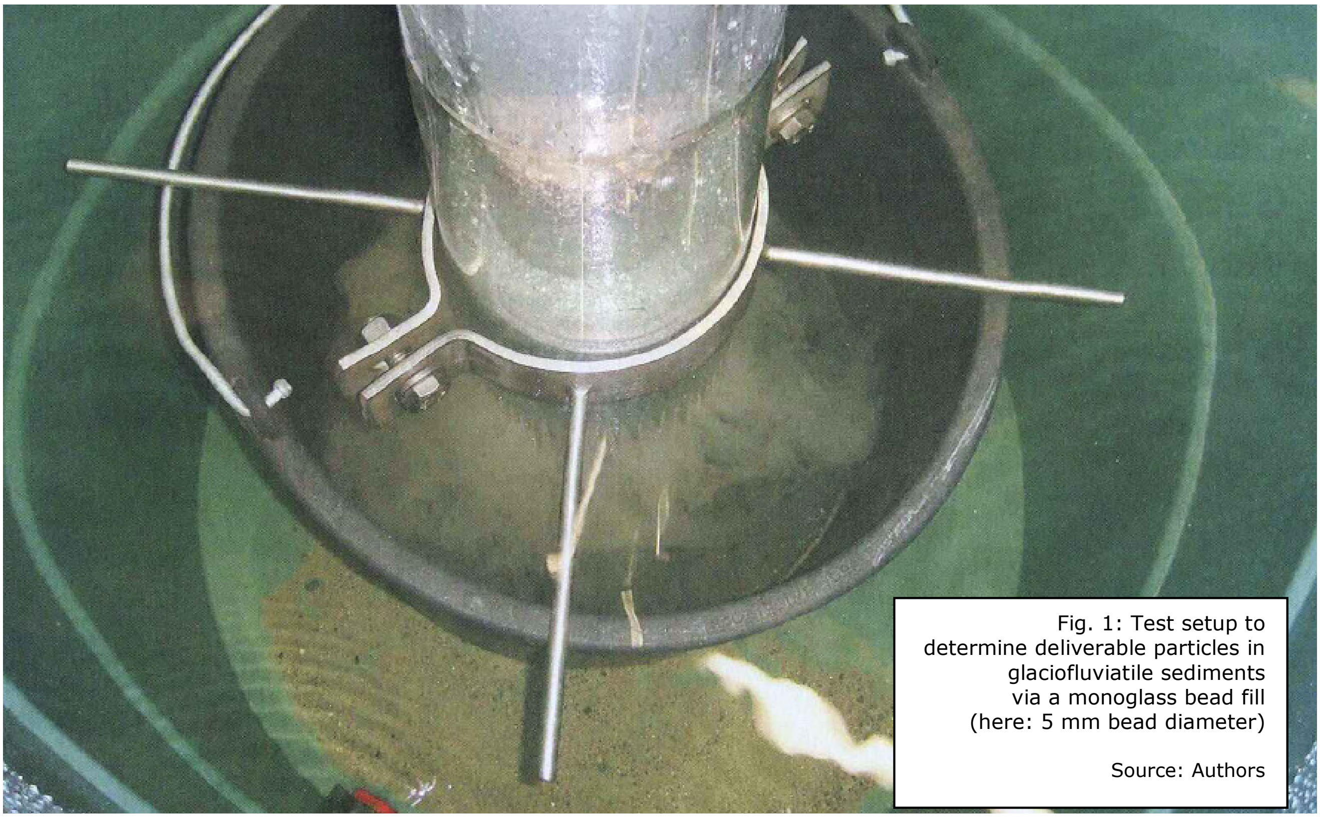


Fig. 1: Test setup to determine deliverable particles in glaciofluviatile sediments via a monoglass bead fill (here: 5 mm bead diameter)

Source: Authors

Comparison of selected material characteristics of glass beads and filter gravel for use in drinking water wells

Selected material characteristics of glass beads and filter gravel that are specific to well construction were determined within the scope of a R&D project currently underway, funded by the Federal Ministry of Economics and Technology. Initial results of these laboratory tests that are currently being performed by the project leaders are presented below.

Glass beads made of acid-proof soda-lime glass have been used as bulk materials for the "silicification" of well filters since 2007. Initial experience with glass beads as filter fills was gathered during the construction of bedrock wells in Franconia and made available to professional circles by Stiegler & Herrmann (2008). The use of glass beads in wells was first triggered as the result of knowledge gained in the development and regeneration of wells that were severely susceptible to iron clogging, as well as the autochthonous discharge of large amounts of fine grain and fine particles with the DIN filter gravels from a variety of natural mineral deposits. These fine grain components, along with the fine particles from the aquifer, were made responsible for the clogging of wells caused by undersize particles (DeZwart 2007, Treskatis 2007). At the same time, it was found that the "rough" surface and primary minerals on the gravel grains promote the agglomeration of incrustations. The first quantitative findings on the agglomeration behaviour of iron minerals to glass beads as compared with DIN filter gravels were published by Treskatis et al. (2009). These investigations provided confirmation for the practical experiences in well construction that, when glass beads are used in the well ring area, not only can the formation of fine grain pieces and fragment pieces, which are contingent on mechanical factors, be avoided, but also can a significantly lower tendency towards incrustation be expected.

Aside from the agglomeration behaviour towards incrustations, mechanical stability, wear resistance, roundness of the fill grains, and chemical resistance (e.g. against regenerants according to DVGW worksheet W 130) are important parameters in well construction, especially for a well's hydraulic productivity.

Object of study and methodology

Materials examined for testing purposes were four commercially available filter gravels used in well construction, in grain size fractions according to DIN 4924 (1 to 2 mm up to 8 to 12 mm) and glass beads (acid-polished and matt) in granulation spectra 1.25 to 1.65 mm and up to a maximum size of 12 mm. The following physical properties were examined in bench scale tests:

- roundness,
- specific weight,
- fill weight,
- grading,
- 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.

The methods and boundary conditions used to determine these material properties are summarised in table 1. As of now, initial results are available from comparative measurements of these physical parameters for the following gravel and glass bead fractions:

- Filter gravel: 1 to 2 mm and 1.4 to 2.2 mm as the main products used in comparison, as well as 2.0 to 3.15 mm, 5.6 to 8.0 mm, and 8.0 to 12.0 mm for selected tests
- Glass beads: 1.25 to 1.65 mm as products used in comparison with the filter gravels listed above, and 1.50 mm, 2.85 to 3.45 mm, 3.00 mm, 5.00 to 6.00 mm, and 12 mm for selected tests.

Parameters no. 5 to 7 affect the clogging properties of the fill body and, together with parameter no. 4, the amount of the undersize grains from the aquifer or from the bulk material itself that can be desanded or that promotes clogging. The formation of undersize grain particles within the bulk material was one of the reasons for looking for alternatives for fragment-forming filter gravels that are conducive to clogging.

Parameters no. 9 to 12 affect the microbiological and chemical incrustation properties of a fill inside a well.

Parameter no. 12 is also of importance in selecting the fill goods in drinking water wells. According to Houben & Treskatis (2003), small inner surfaces on the fill goods reduce primary agglomeration of the incrustation products, thereby delaying the "iron clogging" of wells. Furthermore, this parameter affects the results obtained with the regenerant and its sustainability regarding the dissolving process and repeated iron clogging.

Results

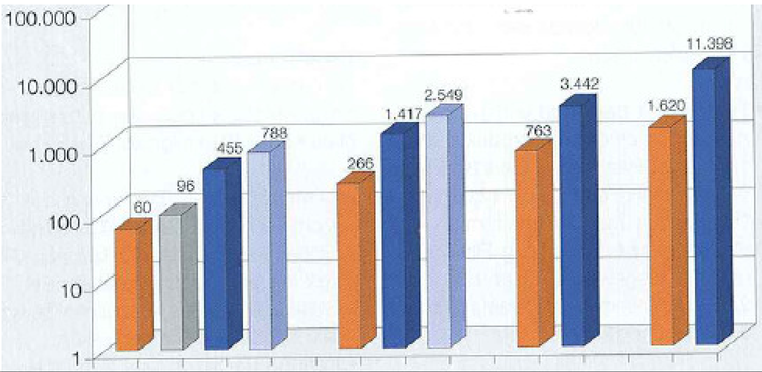
The laboratory tests comparing the two types of materials and various grain sizes yielded the following results:

- Parameter no. 1: The specific weight of the commercially available quartz filter gravel is between 2.615 and 2.655 kg/dm^3, depending on quartz content. Specific weights of 2.503 kg/dm^3 are measured for glass beads.
- Parameter no. 2: The fill weight for grade 2 mm quartz filter gravel is 1.599 to 1.615 kg/dm^3 and 1.585 kg/dm^3 for a glass bead of comparable size.
- Parameter no. 3: The roundness of glass beads was determined to be 0.97 according to the formula listed in table 1. The quotient b/(l x 3) comes to 0.73 to 0.78 for quartz gravel in the optimal case.
- Parameter no. 4: Grading was determined for several glaciofluviatile sediments from the Lake Constance area by means of digital image analysis, in order to determine the grain size that can pass through the fill mass, when filter gravel and glass beads are most densely stacked. This ➢

allows the fitting of grain sizes in the embankment and the well's desanding capability to be improved, and makes it possible to directly determine the grain from the aquifer that is able to pass. Additional experiments are currently being done regarding this in bench scale tests. Figure 1 shows a test set-up to quantitatively determine the grain that is able to pass through from the sediment via a glass bead fill with a defined ball diameter.

Average breaking load depending on filter type

Average
breaking load [N]



A B C D E F G H I J K

A = Filter gravel no. 1 (1.4-2.2 mm); B = filter gravel no. 2 (1-2 mm); C = glass bead type S (1.25-1.65 mm) part no.: 4505 #923033; D = glass bead type S (1.50+-0.2) part no.: 4505-A #820029-1; E = filter gravel no. 3 (2.0-3.15 mm); F = glass bead type S (2.85-3.45 mm) part no.: 4511 #920032; G = glass bead type S (3.00+-0.3) part no.: 4511-A #820022); H = filter gravel no. 4 (5.6-8 mm); I = glass bead type S (5-6 mm); J = filter gravel no. 5 (8-12 mm); K = glass bead type M (12 mm) part no.: 5018-99-24 #855057-20

Filter type

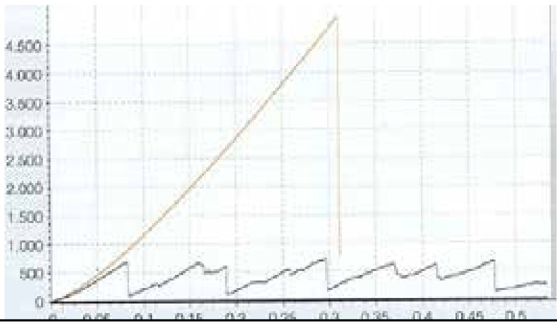
Inspection lot n=20;
Machine type inspect table 20kN (Hege-Hegewald & Peschke)
Test velocity: from 0 ≤ 50 mm/min

Breaking load determination: at 90 % -> Fmax.
Tester: Michael Danhof

Fig. 2: Magnitudes of breaking load of filter gravel and glass beads at different granulation and bead sizes and mixtures at static load handling.
Source: Authors

Comparison of breaking characteristics filter gravel no. 4 (5.6-8 mm) glass bead 4515R (5-6 mm)

Force [N]



Path [mm]

___ Filter gravel no. 4 (5.6-8 mm) Glass bead 4515R #953059 (5-6 mm)

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

- Parameter no. 5: The breaking load at static load for the filter gravels showed an increase in load handling of ca. 60 N up to 1.620 N maximum, in parallel with the increase in grain size (Fig. 2). Glass beads showed an analogous increase in load handling with sphere size. The breaking load here rose from 455 N to > 11,000 N.
- Parameter no. 6: the breaking characteristics of filter gravel and glass beads differ significantly. Filter gravel breaks into smaller fractions at lower loads which then continue to break into even smaller pieces during further loading. The 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 test stamp (= deformation length) are shown in Fig. 3. The curve for filter gravel shows load handling up to ca. 700 N. The grain breaks and the load is distributed out to several grains which themselves also break once the break threshold has been exceeded. This results in a saw tooth curve of the load handling-deformation length ratio. The load curve of a glass bead, however, displays the properties of an amorphous object (Fig. 4) which takes the load only up to the break threshold (here: ca. 4,800 N) and then split into minute particles that are unable to accept any further load.
- Parameter no. 7: The dynamic breaking characteristics are currently still being determined. Results will be available in late 2009.
- Parameter no. 8: Abrasion resistance was determined in a mill with accelerator. The abrasion of the glass beads and filter gravel grains < 0.2 mm was rinsed out of the mill after 9 hours. This mass was then compared to the mass of the test objects. Glass beads suffered a

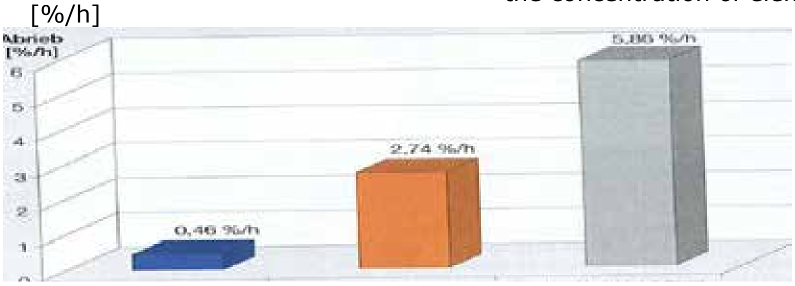
loss due to abrasion (mass loss) of ca. 0.5 percent per hour of grinding, the filter gravel by up to ca. 6 percent per hour (Fig. 5). Overall, the mass loss for glass beads was lower by a factor of about 13 for the entire testing period than for filter gravel (up to 53 percent mass loss).

- Parameters no. 9 and 10: The surface relief and the surface profile of glass beads and filter gravel were determined by means of scanning electron microscopy (Fig. 4). The surface differs significantly as expected. The gravel grain surface displays a distinctly irregular structure with high points and depressions that can be found only here and there on the surface of glass beads. The surface profile of a glass bead 1.5 mm +/- 0.2 mm and of a grain from the 1-2 mm fraction is shown in Figure 6.
- Parameter no. 11: The peak-to-valley heights, determined as the height difference between the highest and the lowest point along a scanning track 0.5 mm in length, are up to 1.21 µm for quartz gravel, for the glass beads, however, up to 0.58 µm.
- Parameter no. 12: The specific surface of a glass bead 1.25 mm and 1.5 mm in size (+/- 0.2 mm) has a mass of less than 0.01 m^2/g. Compared to this, filter gravel reaches a specific surface of up to 0.95 m^2/g mass (with a granulation of 1.4 to 2.2 mm).
- Parameter no. 13: The chemical resistance of the glass beads and the filter gravel to pH-controlled regenerants was confirmed in principle by means of the testing solutions used in conventional amounts. However, material-dependent differences were found when dissolving elements out of the bulk materials at different acid concentrations. Figure 7 shows an example of the concentration of elements in a 15-hour treatment using a synthetic hydrochloric acid that is free of elements (diluted 1:5).

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

Abrasion [%/h]

Abrasion [%/h]



Glass bead type S (1.25-1.65 mm)	Filter gravel no. 2 (1-2 mm)	Filter type no. 1 (1.4-2.2 mm)
		Testing particles

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

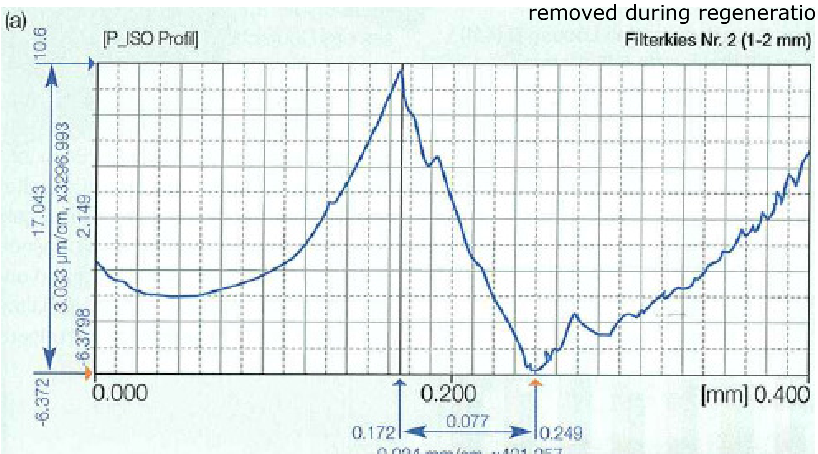
Discussion

As expected, glass beads differ from filter gravel in all parameters examined in the material tests performed thus far. These differences are controlled on the one hand by the differences in solidness of amorphous (glass) and crystalline (gravel grain) structures, and on the other hand by the presence of surface tensions and anisotropies in the structure of the material. In addition, the material properties play a role, as expected, in exposing the materials to chemicals. The following physical and chemical characteristics were determined in particular.

- Parameter no. 3 (roundness): Glass beads very nearly approach the ideal spherical shape due to the manufacturing process, while quartz filter gravel are usually oval in shape due to the manner in which they are formed.
- Parameter no. 4 (grain distribution): The nearly ideal roundness of glass beads allows the densest packing of spheres to be formed whose tetra-hedron-shaped hollows allow a defined characteristic grain out of the aquifer to pass through. This characteristic grain of the first order results from the multiplication of the reversal point in a conventional sieve analysis according to DVGW worksheet W 113, multiplied by the irregularity factor. However, it can also be determined by the grain spectrum at a greater discriminatory power by means of digital image analysis, e.g. at grain sizes of tenths of a millimetre, and the mass of the respective fraction can be quantified. The choice of the grain that is able to pass and that is to be removed can, however, also be determined by dividing a glass bead diameter, which had previously been selected according to W 113, by a factor of 6.7. When comparing this calculation

with the very finely adjustable grain spectrum of a digital image analysis of unconsolidated sediment, the proportion by weight of the removable grain at the time of desanding can be determined, thereby allowing suffusion of the soil into the well and the permanent presence of sand in the well to be prevented (Fig. 1).

- Parameter no. 5 (breaking load, static): the larger the grain size of the fill material, the larger the load bearing capacity of the two materials. However, the difference in breaking loads rises exponentially between glass beads and gravel grains of the same size. The larger the glass bead, the larger is the load bearing capacity compared to the same size gravel grain fraction (Fig. 2).
- Parameter no. 6 (breaking property, static): Compared to filter gravel, glass beads can accept very large static loads > 4 kN up to their breaking threshold before breaking into fine particles. Acid-polished glass beads can accept higher static loads compared to matte beads since the solidness of an amorphous solid material is controlled by the anisotropies at the surface. These usually minor anisotropies generate tension at the surface of the sphere and are largely removed on polished beads (Fig. 4.1 and 4.2) allowing tensile forces at the surface of the sphere to be avoided. This type of glass beads is useful for installation situations with particularly high loads. Filter gravel, however, forms numerous broken pieces at low strains of ca. 0.5 to 0.7 kN already; these push themselves into the pore volume of the fill material, thereby even making it possible for the grain lattice to accept more strain. In a loading case, mixtures made up of varying grain sizes develop above the grains' breaking threshold.



Filterkies Nr. 2 = filter gravel no. 2

(b) 09-14043 sample no 2: glass bead type S (1.50 mm +/- 0.2) part no. 4505-A 1820029-1
Profile = P_ISO range = [1]

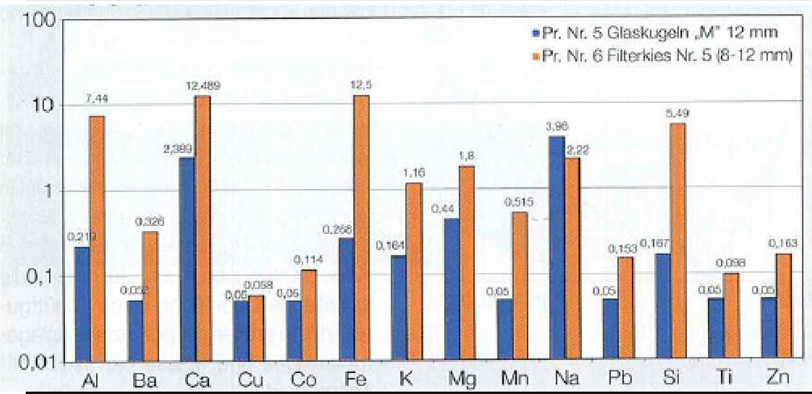
Fig. 6: Surface profile of a grain from the 1-2 mm fraction (a) and a glass bead 1.5 mm +/- 0.2 mm (b)

- Parameter no. 8 (abrasion): The loss of mass in grinding filter gravel simulates the process of pouring into a well by means of pipes. In this process, the individual filter gravel grain can lose up to half of its mass, thereby forming additional autochthonous subsize grain particles in the fill.
- Parameters no. 9 to 11 (surface relief, surface profile, peak-to-valley heights): Glass beads have a surface that is only very slightly profiled, a fact that is confirmed by the results on agglomeration properties raised by Treskatis et al. (2009). In contrast, agglomerations located in the depressions located in the surface of quartz grains, which are in part several micrometers in size, can adhere permanently an increase in layer thickness (Fig. 6.1 and 6.2: up to 17.04 µm of total height difference in the surface profile of the gravel grain measured, compared to 3.03 µm for the glass bead; profile length measured: 0.4 mm). As a result, these agglomerations can only be insufficiently removed during regeneration and mineralize in the course of time.
- Parameter no. 12 (specific surface): The difference in the specific surface of a glass bead of less than 0.01 m^2/g compared to filter gravel (up to 0.95 m^2/g) explains the reduced sustainability of well regenerations for gravel fill wells which are frequently encountered in the field. The larger the specific surface of a bulk material, the larger the potential agglomeration surface and mass of the incrustation products.
- Parameter no. 13 (resistance to pH-controlled regenerants): The dissolved amount and the type of elements depends primarily on the primary mineral content of the bulk material. For glass beads made of soda-lime glass, the elements of Ca, Na and Si are dissolved (e.g. up to 12 mg/kg Na, see Fig. 7), while Al, Ca and Si dominate for gravel. Add to this heavy metal impurities in gravel, such as e.g. Ba, Cu and Pb, which result from the

additional impurities of the filter gravel and the iron sulphide sediments, such as e.g. pyrite. All in all, the concentration of elements in the test solutions generated by means of pH-controlled regenerants is greater and more varied for filter gravel than it is for glass beads.

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 [mg/kg] — [blue] Pr. no. 5 glass beads "M" 12 mm; [orange] Pr. no. 6 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

filter gravels from a variety of deposits were compared. Significant differences were found in mechanical strength, morphology of the grain/sphere surface and roundness that are responsible for the agglomeration properties of incrustations. For glass beads, with their almost ideal roundness, a very minor specific, internal surface was found, with minor roughness and peak-to-valley heights. Filter gravels, however, have genetically determined distinctly structured rough surfaces that provide great potential for agglomerations. We deduce from this that regeneration frequency and sustainability of regeneration are affected by this.

The preliminary material tests show that the minerally amorphous glass beads have hydraulic advantages and favour a reduction of agglomeration of incrustations, which are limited for genetic reasons in the DIN filter gravels examined. This indicates that the discriminatory power of the DIN sieve analysis, which is relatively imprecise in determining the characteristic grain, due to an inaccurate determination of fill bead size, can quickly lead to the wrong well dimensions for fine-grained sediments consisting of similar grains. Further tests are currently being performed in this regard in bench-scale tests within the framework of the R&D project.

Summary
The physical properties of glass beads and filter gravel of a variety of grain spectra and provenance were systematically examined in laboratory tests using technical aspects of application used in well construction. Glass beads and commercially available filter gravels from a variety of deposits were compared. Significant differences were found in mechanical strength, morphology of the grain/sphere surface and roundness that are responsible for the agglomeration properties of incrustations. For glass beads, with their almost ideal roundness, a very minor specific, internal surface was found, with minor roughness and peak-to-valley heights. Filter gravels, however, have genetically determined distinctly structured rough surfaces that provide great potential for agglomerations. We deduce from this that regeneration frequency and sustainability of regeneration are affected by this.

Of particular importance for the productiveness and the clogging properties are the breaking loads and breaking characteristics. For filter gravel, a low breaking load of less than 0.7 N compared to more than 4 N for glass beads can be expected. Under the installation conditions used in well construction, glass bead breaks and splinter formations are not expected. The abrasion of a glass bead is lower by a factor of 13 than for the same size filter gravel. Thus, glass beads do not contribute to the formation of subsize particles or clogging particles.

With the aid of digital image analysis, we were able to determine the grain distribution of natural sediments as a model with high resolution of grain grades. This will allow us to adjust the size of the sphere more accurately to the mobilisable (sub-size) grain from the aquifer in the course of further testing. The objective is to achieve an improvement in the desanding and regeneration capability of the well.

Due to their genetic history, filter sands and filter gravels are contaminated with a variety of primary minerals and do not consist of pure SiO_2 alone. Therefore, when these fill materials are exposed to acids, Al, Ba, Cu, Fe, Mn and Pb are dissolved out in particular, in addition to the quartz indicator Si as a main element. No element concentrations that are alarming from a toxicological point of view can be found for glass beads since it is primarily Ca, Na and minor amounts of Si, Mg and K that are dissolved out.

Glass beads have mechanical and physical advantages compared to natural filter gravels and can make an important contribution to avoid clogging and to reduce incrustations when used in suitable unconsolidated sediments and bedrock, and thereby to an overall reduction in desanding and regeneration expenses.

Acknowledgements
This R&D project is funded by the Federal Ministry of Economics and Technology based on a resolution by the German Bundestag (sponsorship ID no.: KU2027701BN8: "Shoring of drill holes for water production - glass beads as a filling, supporting and filter material for modern well construction; examination of the sand retention properties (filter effect) of glass beads compared to gravel, tendency towards iron clogging of glass beads in wells and under laboratory conditions, installation properties of glass beads in drilled wells" dated 12/03/2009).

Table 1: Methods and boundary conditions of material tests on glass beads and filter gravel of various grain sizes					
No.	**Parameter**	**Measuring method**	**Boundary condition**	**Number of tests per granulation/material**	**Equipment used**
1	Specific weight	Displacement method		n = 20	Pycnometer
2	Fill weight	Volume-related weight determination of fill	A 1-dm^3 measuring beaker is filled with the fill material and the increase in weight is determined.	n = 20	1-dm^3 measuring beaker
3	Roundness	Comparing width b to length l	Roundness quotient = b/(l x 3): a quotient of 1 indicates an ideal sphere		digital image analysis by means of Camsizer®
4	Grain distribution	digital image analyses and sieve analyses of real inliner drill probes from glaciofluviatile sediments in South Germany	Unconsolidated rocks selected up to 10 mm grain size; glass beads up to 12 mm bead size; test quantity: 100 g	n = 1	digital image analysis by means of Camsizer®
5	Breaking load with static stress	Determining the average breaking load depending on the material and the granulation/grain diameter	Determining the average breaking load at 90 % drop in force; testing velocity 50 mm/min	n = 20	Inspect table 20 kN according to Hegewald & Heschke
6	Breaking property with static stress	Comparing the breaking properties of filter gravel and glass beads of various diameters	Determining the breaking load as a function of path length and deformation	n = 1	Inspect table 20 kN according to Hegewald & Heschke
7	Breaking properties with dynamic stress	Bombarding a steel plate to simulate the impact of the grains/spheres on the well installation piping and on glass beads as well as on filter gravel (under conditions found at the edge of drill holes)	Velocities of 66.2 km/h (free fall) for filter gravel (12 mm) and 64.3 km/h for glass beads (12 mm)	Tests currently underway	
8	Abrasion resistance	Simulation of the loss of mass by abrasion during mechanical regeneration, e.g. in the impulse method according to DVGW W 130	Determination of the loss of mass by abrasion of grains/spheres; testing quantity 330 ml	n = 1	Willy A. Bachofen "WAB Multilab"
9	Surface texture	digital surface images with SEM		n = 1	Scanning electron microscopy (SEM)
10	Surface profile	Determination of the surface profile across a defined scanning distance; scanning the surface of gravel grains and glass beads to determine the external relief		n = 1	Surface profiler
11	Roughness	Determining the peak-to-valley height as the height difference on a scanning distance of 0.5 mm		n = 1	Pertometer
12	specific surface	Determining the overall surface (outer surface + surface of the pores opened to the outside) of the spheres and gravel grains by means of gas adsorption		n = 1	BET
13	chemical resistance	Analysis of elements dissolved from the glass beads and gravel grains after inserting them in a variety of pH-controlled regenerant test solutions	Synthetic test solutions were prepared from commercially available products (acids) since these contained trace element impurities. All in all, 15 h of treatment time; spheres and grains were completely submerged at T = 20°C	n = 1	ICP

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Glass Bead Filter Media: Higher Efficiency and Reduced Operation and Maintenance Costs

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Sigmund Lindner, Germany

ABSTRACT

The declining quality of natural sand and gravel filter pack media for water supply wells is a challenge for the well industry worldwide. Insufficient values for crushing strength, abrasion resistivity, roundness, gradation and chemical resistivity lead to insufficient hydraulics, increased well clogging and scaling, higher electrical energy demand, reduced lifetime and increased operations and maintenance costs. Deeper wells also suffer from bridging and jamming of gravel during installation which results in incomplete annular filling, improper bedding and sudden subsidence leading to severe well damage.

High performance wells, like ASR, mine dewatering and in-situ leaching wells with huge water volumes transported, created further needs to raise the standards for filter pack media. Otherwise they are impaired by irreversible clogging due to disintegration and compaction of gravel packs which means significantly reduced well performance and lifetime.

In late 2007, high quality soda lime glass beads were first used as an alternative for gravel in the filter pack of a 400 ft. well in Germany with severe scaling problems. Extensive comparative field and laboratory studies with several universities and discussions whether glass beads are a better choice also fostered the fundamental analysis and understanding of the role of filter packs and the influence of media properties on well performance. Bench tests proved how underrated features like sphericity and gradation so far were for well development capacity and efficiency.

Experience with app.180 wells in Europe and the USA, among them two 1.500 m deep mine dewatering wells in Colorado, with glass bead filter packs show properly packed isotropic annular fillings, higher increased specific well capacity (25 % - 300 %) . The savings in pumping costs add up to several thousand dollars per year. Together with reduced well cleaning, the total cost savings over well lifetime reach high two-digit percent figures compared to wells with standard gravel packs.

INTRODUCTION

Until late 2007 gravel and sand were exclusively used as filter pack media in water wells. Gravel and sand are natural minerals of finite accessibility, consequently their availability and quality is rapidly declining in recent years. This phenomenon is global. Apart from that, even material in accordance with industry norms causes many problems in well construction and functionality. For instance the German industry norm DIN 4924, which determines the specifications of mineral sands and gravel for filter packs in water wells, accepts 1% of unclarified particles, 10% of undersized, and 15% of oversized particles.

The amount of undersized particles grows during transport of the material to the construction site due to disintegration because of insufficient crushing strength. A summary of negative effects on well construction and performance caused by natural filter pack media is given by Hermann & Stiegler, 2008. Among others the main problems are:

- Jamming and bridging because of angular and edged grain
- High percentage of undersized particles and fines
- Cost intensive development work with limited effects
- Reduced porosity and permeability of the filter pack
- Clogged filter packs and well screens with gravel debris

Figure 1 shows a clogged continuous wire wrapped screen after development.

Figure1: Clogged well screen with gravel debris after development pumping

In 2010 laboratory tests were conducted (Paul, 2010) in order to qualify and quantify the effects physical properties of natural gravel have on the hydrologic performance of filter packs. For instance a 10% share of undersized particles reduces the permeability of a filter pack to 55 – 75% compared to a pack free of undersized grain. (Table1.)

Table 1 Permeability of a gravel pack in relation to share of undersized particles

Gravel (mm)	Share of undersized grain (%)	Kf (%)
5.6 – 8	0	100
5.6 – 8	10	75-55

As the equation in the figure below shows, the inferior sphericity of natural gravel causes 36% higher head loss resp. reduced permeability compared to perfect rounded glass beads

$$\frac{k_{glass}}{k_{sand}} = \frac{\frac{1}{3^2}}{\frac{1}{3{,}5^2}} = 1{,}36 = \frac{\Delta p_{sand}}{\Delta p_{glass}}$$

The difference is caused by the so called form factor for the sphericity index of the media which is 3 for glass beads and 3.5 for sand.

Examinations in the Netherlands first proved fines in gravel packs are a major source for irreversible well clogging and enhanced microbiological scaling with iron and manganese (Van Beek & Kooper, 1980; Van Beek, 1995; DeZwart, 2007). Further indications on promoting factors of pack media for well clogging and scaling are given by Treskatis & Houben, 2003. They specifically discuss grain shape, inner surface (coarseness), size, geometry and volume of pore channels and fines (from formation and filter pack).

With average operation times of more than 40 years, operation and maintenance costs for frequent well rehabilitation to restore capacity loss by scaling are a major financial burden in total lifetime costs of a well. In addition there are high investments for the substitution of irreversible damaged wells.

High performance wells, like ASR wells with their bidirectional water flow, huge water volumes transported, and higher amount of fines due to the nature of the source water for infiltration created further needs to raise the standards for filter pack media. Otherwise they are impaired by irreversible clogging, due to disintegration and compaction of gravel packs which means significantly reduced well performance and lifetime.

Alternative filter pack media which will avoid these problems were in high demand. First quality demands were named by Treskatis, Hein, Peiffer & Hermann, 2009.

Table 2 Quality characteristics for filter pack media (Treskatis et al., 2009)

Characteristics of the material	Quality goals
Washed and free from "undersized particles"	Low material losses, free from "undersized particles" and compaction when developing the well; reduction of development time
Well- rounded gravel grain	Increasing the porosity and hydraulic permeability; reduction of head losses; improvement of development ability and yield
High quartz share	Avoidance of volume changes through swellable or broken minerals
Smooth surface	Minimizing deposits
Low irregular form	Little segregation during filling; avoidance of head loss by clogging

With regard to these demands, glass beads seemed to be a natural choice for a test.

ALTERNATIVE FILTER PACK MEDIA

In late 2007 soda lime glass beads from Sigmund Lindner were first applied in a 150 m deep well in the Frankonian Keupersandstone near Nuremberg. Wells in that formation have to cope with severe well scaling by iron and manganese encrustations. Gravel filter packs in former wells were irreversibly destroyed after some rehab cycles with high impact hydro mechanical cleaning techniques. Promising results from handling and well performance gave way to a series of comparative R & D projects.

PHYSICAL PROPERTIES

A major R & D project, funded by the German Federal Ministry of Economics and Technology was conducted from 2008 – 2009. The authors (Treskatis, Danhof, Dressler & Herrmann, 2010) performed comparative laboratory tests with several gradations and sources of natural gravel and glass beads for the parameters:

Table 3 Tested parameters

Roundness	peak-to-valley heights
specific weight	surface relief
bulk density	surface profile
grading	specific surface
breaking load during static stress	abrasion resistivity
breaking properties during static stress	chemical resistance to rehabilitation
breaking properties during dynamic stress	solvents
	abrasion resistance

With the result: “Glass beads have mechanical, physical and chemical advantages compared to natural filter gravels and can make an important contribution to avoid clogging and to reduce incrustations when used in suitable unconsolidated sediments and bedrock, and thereby to an overall reduction in development and rehabilitation expenses” (Treskatis, Danhof, Dressler & Herrmann, 2010).

Figures 2 and 3 of this publication give a clear indication about the amount of differences in relevant properties between gravel and glass beads.

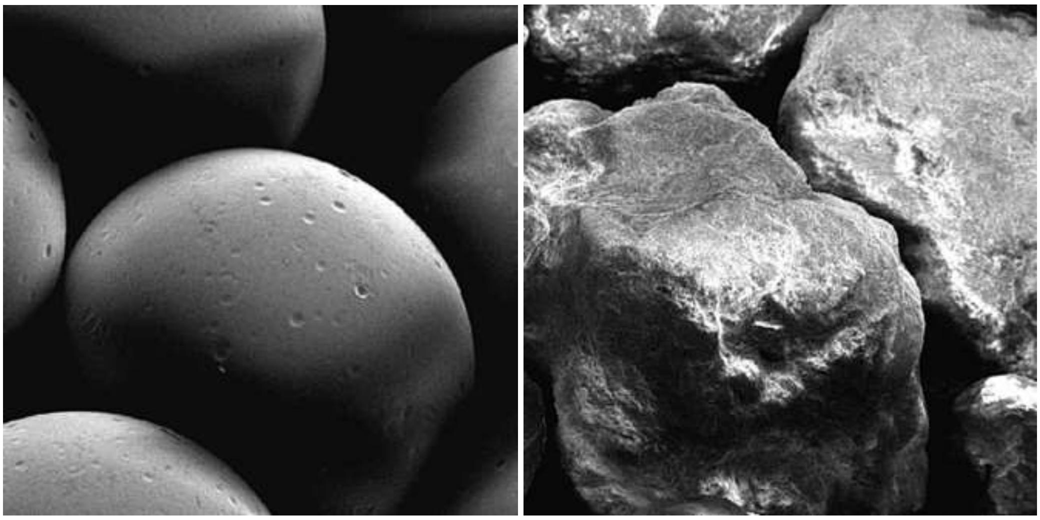
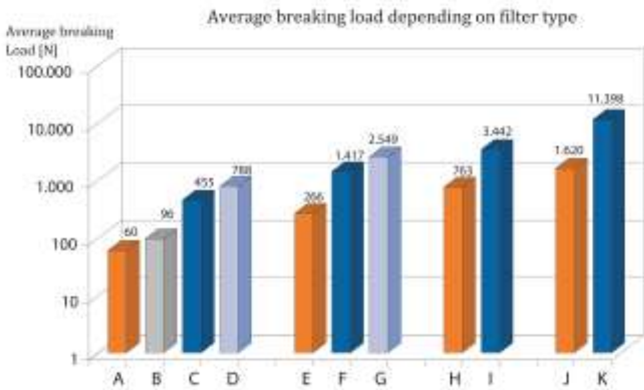


Figure 2 REM image of a glass bead compared to a filter gravel grain of the same grain size. The “smooth” surface of the glass bead prevents the formation of tensile stress when load is applied and reduces the agglomeration of incrustations (Treskatis et al., 2010)



A = Filter gravel no.1 (1.4-2.2 mm)
B = filter gravel no.2 (1-2 mm)
C = glass bead type S (1.25-1.65 mm)
part no.: 4505 #923033
D = glass bead type S (1.50+-0.2)
part no.: 4505-A #820029-1
E = filter gravel no.3 (2.0-3.15 mm);
F = glass bead type S (2.85-3.45 mm)
part no.: 4511 #920032
G = glass bead type S (3.00+-0.3)
part no.: 4511-A #820022)
H = filter gravel no. 4 (5.6-8 mm)
I = glass bead type S (5-6 mm)
J = filter gravel no. 5 (8-12 mm)
K = glass bead type M (12 mm)
part no.: 5018-99-24 #855057-20

Figure 3 Magnitudes of breaking loads in Newton [N] for filter gravel and glass beads at different gradations at static load handling (Treskatis et al., 2010)

HYDRAULIC AND HYDRODYNAMIC PROPERTIES

Comparative tests in the laboratory of the Bau ABC (Federal Academy for Construction) in Rostrup, Germany also showed better values of glass beads for bedding properties, porosity, and permeability, as well as better capabilities for sand discharge in the well development process at significantly higher efficiency. Glass beads generate a faster and more efficient sand removal, while the limit of sand breakthrough, especially in uniform soils is already at a low leakage size. Soil based grain is effortlessly mobilized through glass bead packs. Thus a comparatively rapid development is possible. On the other hand, glass bead packs have a higher sensitivity toward sand breakthrough compared to gravel when oversized. (Treskatis, Tholen & Klaus 2011, 2012; Klaus 2013).

The table below shows an overview of development time and efficiency for several wells from New England, USA, constructed in 2013 and 2014. In every case, the actual time for well development was significantly lower than estimated, based on local experience with mineral gravel packs. The range goes from 25 to 50%. Nevertheless, well efficiency was close to 100% whereas it is between 50 to 63% for comparable wells with mineral gravel packs in this area.

Table 4 Well development time and **efficiency** for glass bead packed wells

Town/ City	State	Customer	Well Dimension	Well Depth (ft)	Screen Length	Screen Opening	SiLi Bead Size (MM)	Well Yield (GPM)	Dev. Hours	Budgeted Dev. Hours	Well Efficiency
Seekonk	MA	Seekonk Water	24" x 18"	56	10	0,300	18,0	750	30	80	95
Bourne	MA	Bourne Water	22" x 16"	227	20	0,035	1.25 - 1.65	824	20	80	93
Bridgewater	MA	Bridgewater Water	18" x 12"	53,5	10	0,280	12,0	300	29	40	100
Harrisville	RI	Harrisville Water	24" x 18"	31	5	0,140	5.0 - 6.0	305	16	40	92

WELL SCALING

First column tests with gravel and glass beads in 2008 showed that in natural gravel packs, approx. 40% more iron mass was embedded than in glass beads. Thus a lower incrustation tendency could be expected in actual wells when using glass beads as filter pack media (Treskatis, Hein, Peiffer & Hermann, 2009). Recent tests by the author with actual wells in a test field and an extended laboratory set up with highly ferrous and manganiferous groundwater proved that scaling of glass beads is delayed by factor 2 – 3 compared to natural gravel. See Klaus, Treskatis & Tholen, 2013.

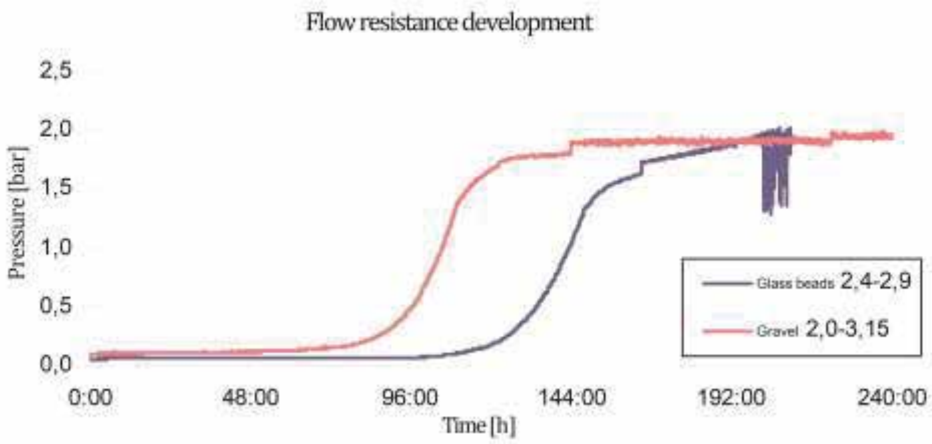


Figure 4 Pressure development in gravel packs 2.0 – 3.15 mm grading and glass beads packs grading 2.4 – 2.9 mm under continuous perfusion with iron and manganese containing groundwater

Figure 4 shows pressure development in gravel and glass bead filled columns which were streamed with groundwater containing dissolved Fe >15 mg/l. The default was set to stop pumping at a back pressure of 2.5 bar The tests were run with different gradations of both media. All showed a delayed pressure build-up in the glass bead fillings by factor 2 – 3 as a means of pore channel clogging with iron scale.

FIELD

RESULTS

To date more than 6,000 metric tons of glass beads were used in more than 180 water wells in Germany, Italy and the USA, covering the whole hydrogeological spectrum from alluvial to bed rock and multiple groundwater chemistry, proving the laboratory results described above.

Further observations from contractors, technical consultants and well owners are:

- Easy application, no bridging or jamming during filling process
- No dust during the filling process therefore no health and safety issues
- Consolidated bedding after filling, no subsidence compared to gravel
- Time and volume for development is down to 50% compared to gravel
- Higher specific capacity
- Lower tendency of scaling in filter packs
- Intervals between rehabilitation can be stretched, which means lower expenses for O and M (The first water well equipped with glass beads in the town of Rosstal, near Nuremberg,

still has not to be rehabilitated. The predecessor well in the same geologic setting had to be rehabilitated between every two years to once a year)

In 2013 two dewatering wells for mines in Colorado, app 1.400 m deep, were equipped with glass bead packs. Even under these demanding conditions the positive experience with handling, filling and yield could be proved. Figure 5 shows a comparative overview of specific capacities for several water supply wells in Eastern Germany for three production rates after rehabilitation with glass bead filter packs.

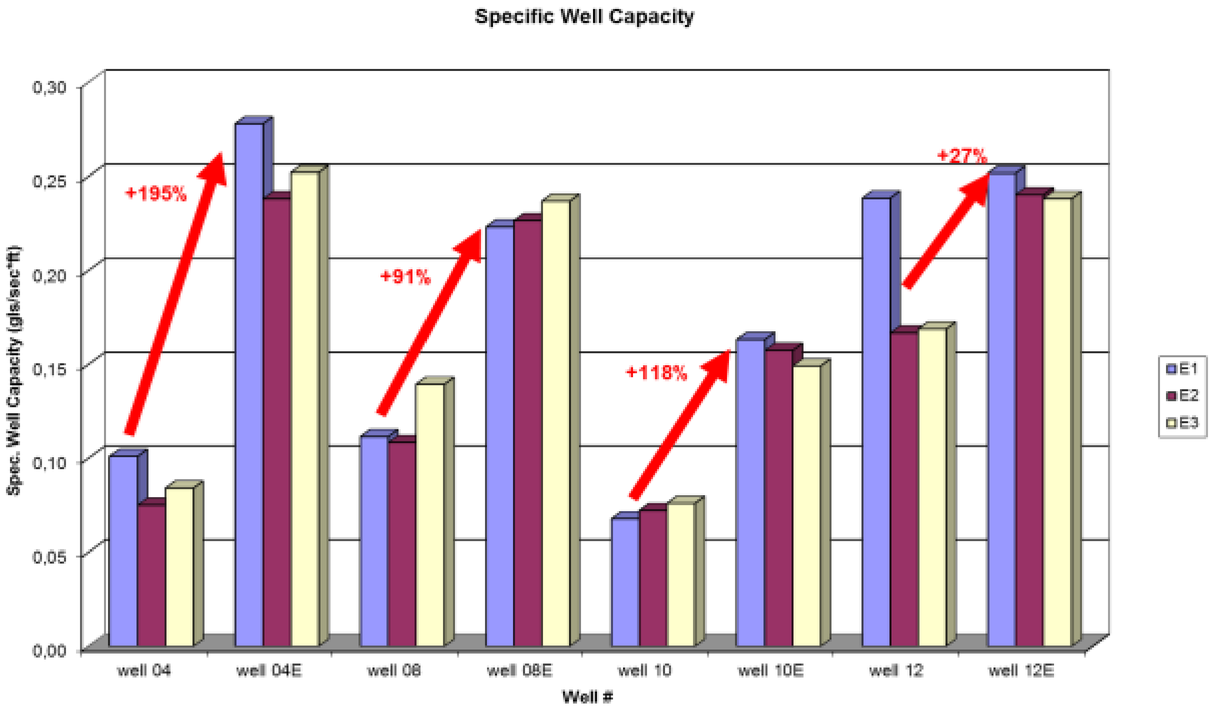


Figure 5 Specific capacities of former wells with standard gravel packs and replacement well (E) with glass bead filter packs

ECONOMIC ASPECTS

Based on local conditions, the capital investment costs for glass beads are between 2 and 5 times higher than for gravel. Regarding total costs of wells the surplus is between <0.5% and 5% depending on depth, diameter, screened area, etc. But material price alone is no indicator for the efficiency of a well. Wells are long term investments with lifetime cycles far beyond 40 years. Operating costs, primarily for electrical energy and rehabilitation after iron and manganese scaling, are the essential factor. Due to higher specific capacity and delayed scaling, glass bead wells imply cost saving potential for O and M which will more than compensate the initial higher capital investment.

Klaus & Walter, 2011 did a first cost benefit analysis based on the then known facts. Even this first tentative approach on the base of 1% savings for electric energy and 25% for rehabilitation costs produced a total benefit of 8% after 40 years considering interest and inflation.

Actual wells showed an increase in performance between 20% and 300% with corresponding savings for pumping energy. An updated calculation by Klaus and Walter (2012) brought savings for pumping costs between 50 and 80% per year, which means a ROI in 3.5/8 years just on the base of cost savings for water pumping, see table below. A first extrapolation of the potential savings for rehabilitation based on the results of the recent scaling tests brings total lifetime savings up to more than 20%.

Table 5 Cost savings for pumping of remodeled extraction wells with glass bead packs compared to former layout with gravel filter packs

Energy costs raw water conveyance							
				glass beads			
		Well A old	Well A new	Well B old	Well B new	Well C old	Well C new
Costs per kilowatt hour on average	(Euro/ KWh)	0,15	0,15	0,15	0,15	0,15	0,15
Discharge on average	(M≥/h)	60	60	60	60	200	200
Discharge (collection)	(M≥a)	500.000	500.000	500.000	500.000	1.800.000	1.800.000
Level of effectiveness (µ) on average	(%)	60%	60%	60%	60%	60%	60%
Special yield on average (according to available data)	(M≥h/m/)	**5,4**	**10,2**	**8,6**	**10,9**	**92,5**	**411,4**
Relative conveyance depths (only referring to strict reduction s)	(mWS)	11,2	5,9	7,0	5,5	2,2	0,5
Total of energy costs pumping	**(EUR/a)**	**3.818**	**1.997**	**2.389**	**1.878**	**2.651**	**596**
Savings	**(EUR/a)**		**1.821**		**511**		**2.055**

CONCLUSIONS

Glass beads as a substitute for mineral gravel in filter packs of water wells have been successfully applied since 2007. They are easy to handle. They can be sized and processed with the same methods and techniques as gravel.

The field and laboratory results show that this application is an advance in well construction and shifts the state of the art to a higher level.

For the first time, physical, hydrological and chemical properties of a filter pack can remain consistent for the entire well lifetime cycle. Savings of electrical energy and O and M costs for rehabilitation are a major step towards real sustainability.

Promising results and positive feedback are also coming from the wastewater and water treatment sector.

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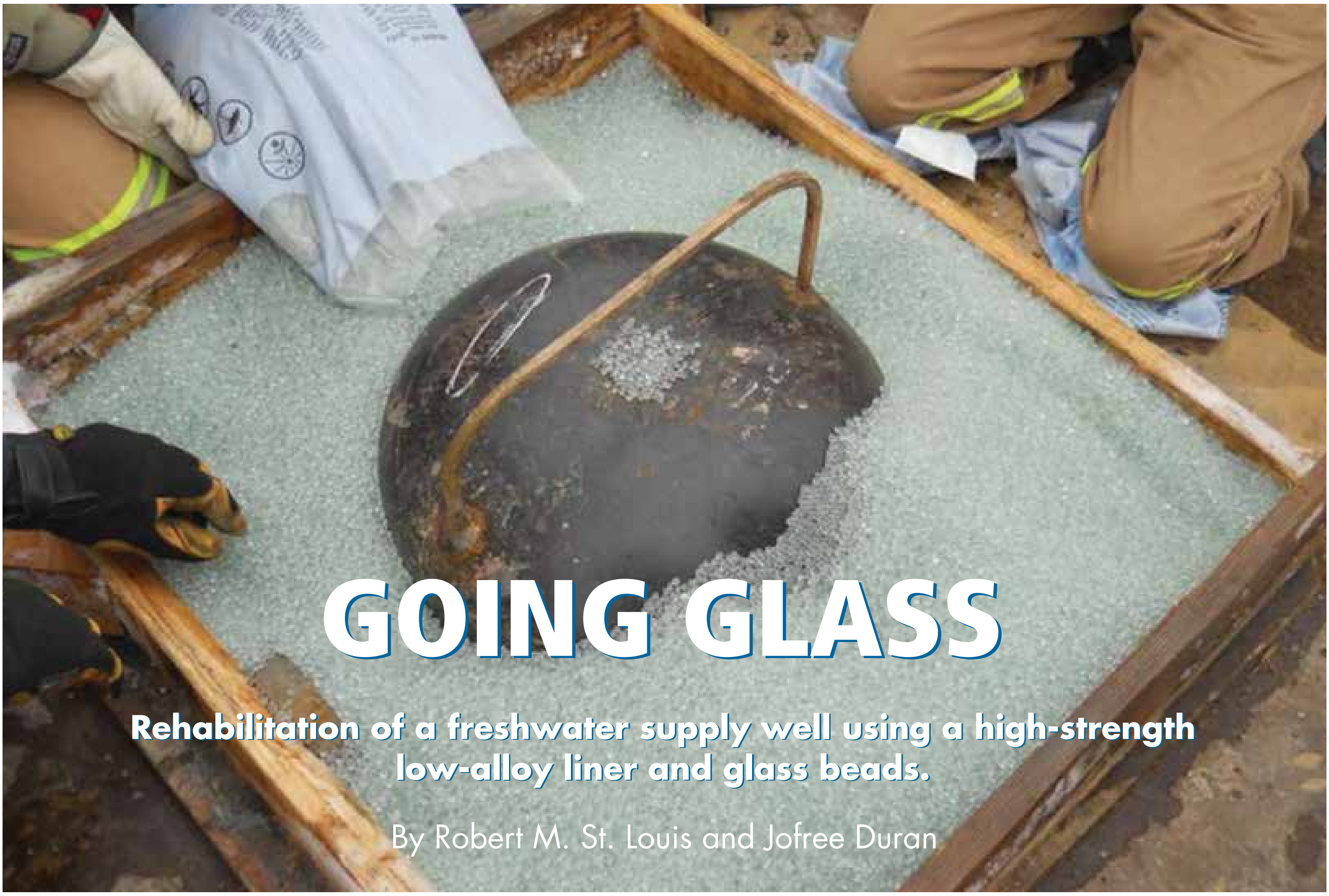

GOING GLASS

Rehabilitation of a freshwater supply well using a high-strength low-alloy liner and glass beads.

By Robert M. St. Louis and Jofree Duran

While not a favorite topic of those who supply water to communities, businesses, and homes, the fact is sometimes mistakes made in the design of a well can and often do result in rapid deterioration of the well.

Such situations can cause much frustration, but they also can be the catalyst for the introduction of new technology as part of the solution. While none of this is rocket science, careful attention to detail during well design and construction can minimize problems in the future.

This article will present a brief case history of a poorly designed well and the rehabilitation program used to restore the well to service.

The Well

A freshwater well named PW-4 was originally constructed in 2006 in an alluvial (sand, gravel, silt and clay) aquifer known to contain chloride-impacted groundwater resulting from operations by a previous owner of the property. Geometric mean chloride concentration was 224 mg/L (essentially 224 parts per million), and total dissolved solids were 799 mg/L.

PW-4 was constructed using 20-inch outside diameter, 5/16-inch wall mild steel (ASTM A53 Grade B) casing in a 28-inch borehole. The louver screen, with 0.125-inch slot, extended from 175 to 415 feet below ground surface (bgs). Static water level was 122 feet bgs, and when pumped at 2000 gallons per minute, the well had a specific capacity of 44.

Glass beads being installed between existing casing and liner. Note the 18-inch bullnose on top of the liner and the wooden frame constructed to contain the glass beads.

The vertical turbine line shaft pump (14-inch diameter) failed after just seven years. A video survey showed extensive corrosion of the casing (Figures 1 and 2), including complete loss of the casing in the deepest portions of the well due to corrosion, and in addition, no filter pack could be seen in the well.

The damage to the casing was extensive enough to cause concern about the integrity of the casing, and the lack of filter pack virtually guaranteed the well would be likely to pump significant amounts of sand.

In fact, the pump had failed because of sand production. The decision was made not to pump the well until an analysis of options was made. The main criteria in the analysis were cost, specific capacity, and the pump. (It was preferred the well would continue to use a vertical turbine line shaft pump, rather than a submersible unit.)

The Rehab

Both replacement and rehabilitation of the well were considered. Ultimately rehabilitation was selected, primarily due

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Figure 1. Corrosion damage at 263.3 feet bgs. Cobbles from the alluvial native ground are clearly visible in the center of the photograph. Louvers are approximately 3 inches wide.

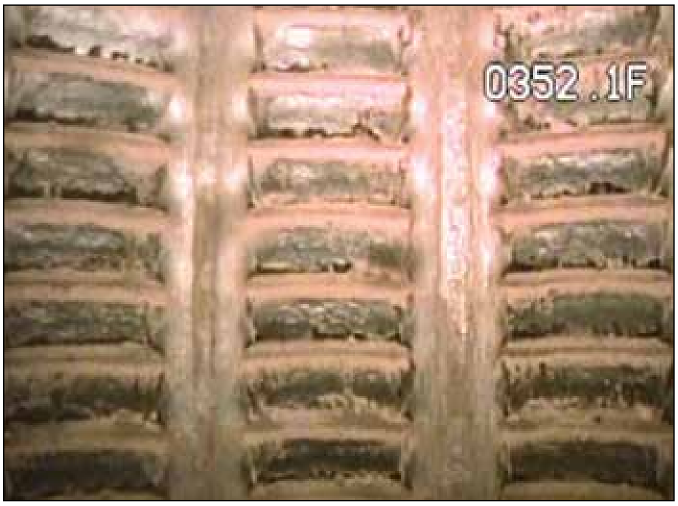

Figure 2. Corrosion damage at 352.1 feet bgs. Louvers are noticeably corroded, and no filter pack is visible.

GOING GLASS from page 25

to the substantially lower cost compared with abandoning the well and drilling a replacement.

The relatively large diameter of the pump required the liner be 16 to 18 inches in diameter, with 18 inches preferred. Prior to ordering liner material, a casing dummy (18 inches outside diameter, 50 feet long) was lowered to the bottom of the well on a cable to ensure an 18-inch liner could be installed. Using a cable to run the casing dummy allows for direct observation of deviation or deformation that might prevent installation of a liner of a diameter equal to that of the casing dummy.

After successful completion of the dummy test, the liner was ordered. High-strength low-alloy steel (HSLA, ASTM 139 A 606 Type 4) was selected for the liner material. This alloy is nine times more corrosion resistant than mild steel and is significantly less expensive than stainless steel. In light of the loss of original filter pack, a blank section 20 feet long was planned for installation from 300 to 320 feet bgs for the pump intake position to minimize pumping of sand.

The annulus between the 18-inch liner and the inside diameter of the existing casing was only 0.625 inch, so there was no room for weld couplings or louvers on the liner. This resulted in the selection of double-row mill-slot, slot opening 0.125 inch, with machine beveled ends on each joint of liner to aid in welding.

The small annulus between the casing and liner precluded the installation of a tremie pipe for placement of filter pack, and free-falling natural gravel pack from surface would likely cause bridging of the gravel pack, resulting in an incomplete filter pack.

Therefore, 5 mm (0.196 inch) diameter glass beads were chosen for the filter medium, as they were about 150% larger than the slot size of the liner.

Glass beads are chemically inert and highly resistant to breakage. Of even greater importance to this well rehabilitation is the fact glass beads are nearly perfect spheres of the specified diameter, which allows them to flow freely with little likelihood of bridging during installation and minimize well loss during operation.

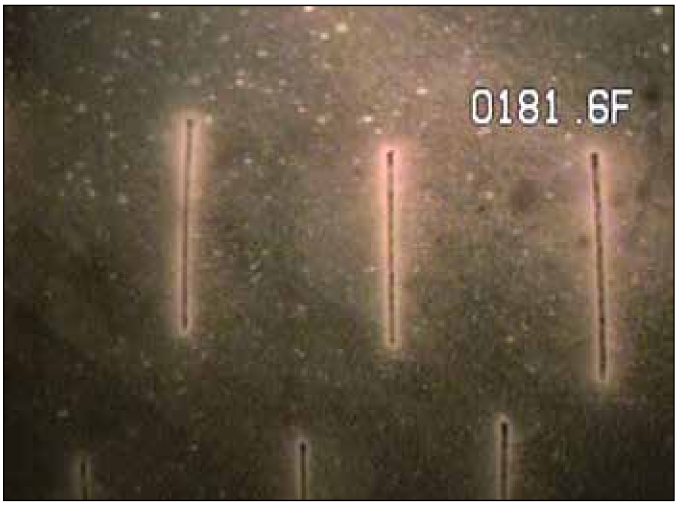

Figure 3. Screen capture from video survey conducted after development. Note the uniform distribution of glass beads visible through the mill slots.

After landing the liner, a wooden frame was constructed around the top of the well. An 18-inch bullnose was placed over the top of the liner, and the glass beads (packaged in 20 kg [44 pound] bags) were poured down the annulus. A total of 3 metric tons of beads were installed in 45 minutes with no difficulty as shown in the lead photo. It was not necessary to wash the beads down the annulus with water, as they flowed freely.

Well development was accomplished using a double surge block (swab) while airlifting. Total development required after installation of the liner and glass beads was 25 hours. Figure 3 is a screen capture from the video survey conducted after development. The glass beads are clearly visible through the mill slots, and exhibit a uniform distribution.

Figure 4 shows the original well construction and the rehabilitated well. The original well had a specific capacity of 44 (pumping 2000 gpm with 46 feet of drawdown). After rehabilitation, the specific capacity is 79 (pumping 1500 gpm with 19 feet of drawdown). Clearly, the rehabilitation effort was successful.

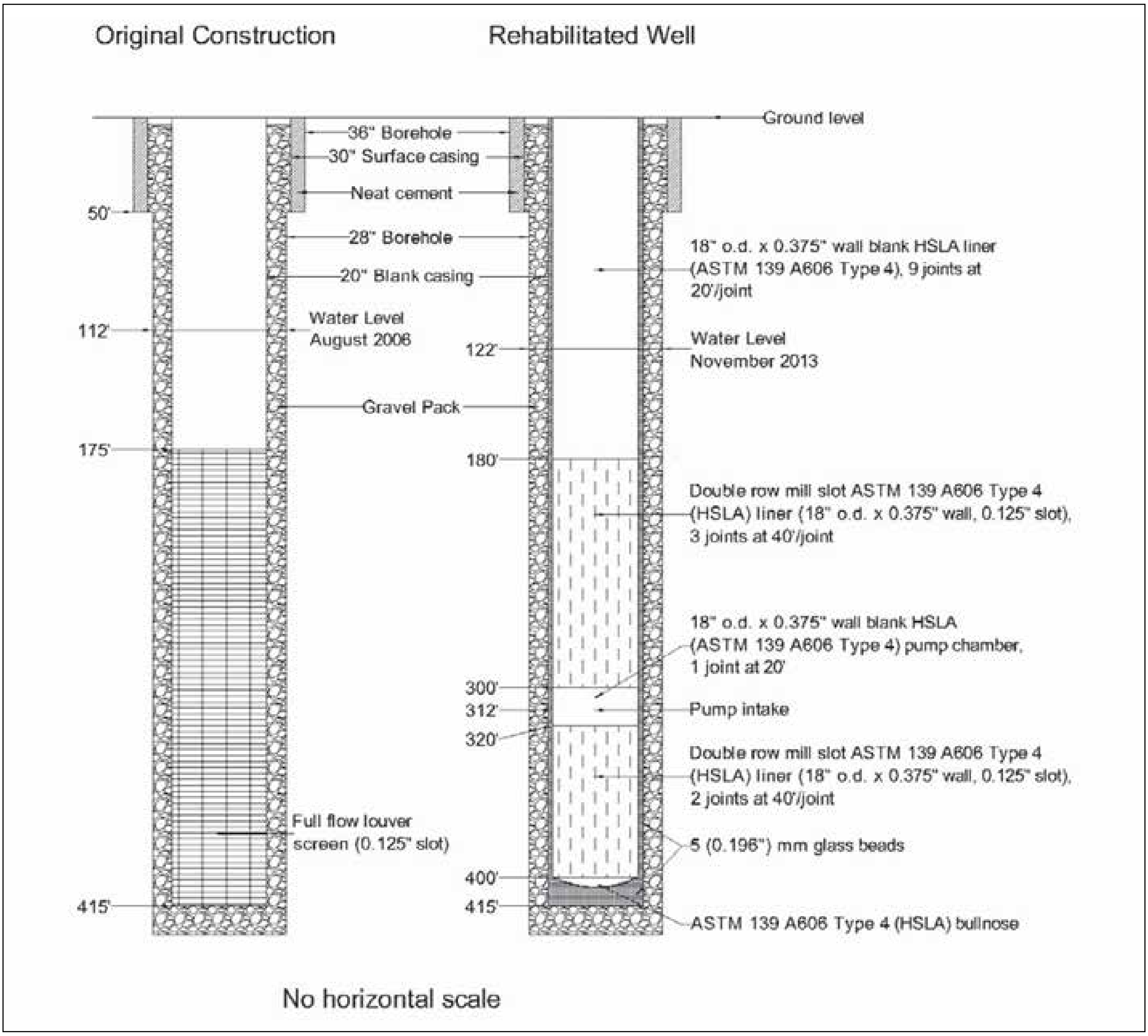

Figure 4. As-built diagrams of the well as originally constructed and after rehabilitation.

Conclusions

This well rehabilitation effort resulted from a failure to take the groundwater chemistry into account when the original well was designed. Because of this oversight, a well that should have seen more than 20 years of service had to be either replaced or rehabilitated after only seven years of use due to corrosion.

The use of glass beads as a filter medium is not yet widespread in the United States, but the combination of rapid installation, reduced development time, and the high specific capacity of the rehabilitated well are solid confirmation the proper product was selected. Total costs for this rehabilitation were about 20% of the cost of a new well, representing a savings of several thousand dollars. WWJ

DACUM Codes

To help meet your professional needs, this article covers skills and competencies found in DACUM charts for drillers and pump installers. DO refers to the drilling chart. The letter and number immediately following is the skill on the chart covered by the article. This article covers:

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Fathoming of a foot cementation of a drinking water well in Massachusetts

Advantages in the construction and operation of high-performance wells due to modern filter media

The persistent drought in the southwest of the USA and the consequential respective shortage of surface water has resulted in a sharp increase in groundwater use. An essential element for the sustainable management of groundwater resources are combined pumping and injection wells, into which water from different sources is injected for underground storage and later extraction during peak periods of low precipitation. The constantly changing water chemistry and the high hydraulic load place high demands on well construction and induce strong siltation and precipitation processes. Measurements over a period of two years, on a well partly backfilled with glass balls, demonstrated that this filter medium can achieve significantly longer service lives and a sustained higher specific performance of the well, which leads to significant savings in operating and maintenance costs.

Combined pumping and injection wells (ASR wells) have been known and used in the USA for decades. The purpose is derived from their name: ASR is the abbreviation for "Aquifer Storage and Recovery". Experts estimated the number of all ASR wells in the USA in 2015 at 500 to 700, with depths ranging from 35 to 1,000 m, mainly used for public drinking water supply [1]. Although up to 80 % of the country's groundwater is extracted for economic purposes, ASR wells are not quite common in this sector. The main reason for this is probably the high costs per unit of pumped water.

The increasing intensity of droughts and heavy rainfall in recent years has pushed the traditional surface-water based drinking-water supply to its limits, especially in the southwest of the USA. Bans and restrictions on the use of water by private households have therefore been the rule in California for years. As a consequence, there has been an increased focus on groundwater use. In this context, there has been a boom in ASR-based supply concepts for more than ten years. Well fields with more than 20 wells are not unusual. The author Reinhard Klaus (RKP Consulting) is currently involved in a program of this size in Arizona via a supplier of innovative well filter and bulk filler materials.

Especially in the arid climate zones of the American southwest, ASR-supported groundwater management reduces the discrepancy between peak demand and natural supply, also known from near-surface, spring water-supported supply areas. In addition, ASR wells make it possible to secure and store the above-ground water discharge in spring and autumn when the supply exceeds the demand, and which would otherwise be lost through the outfall of local use.

As tempting as this method may sound, it cannot be the panacea for solving water shortages in arid climate zones. The most important prerequisite certainly is sufficient available water of suitable quality. Adequate treatment before the injection is the rule. The aquifer must have a corresponding useful porosity to facilitate storage, yet porosity must not be too high, as otherwise too much water will run off. Due to the natural groundwater gradient, water losses are unavoidable and the availability of the stored water is therefore a function of time.

Although ASR systems cannot increase the total water supply, by linking hydrology and hydrogeology they increase the usable supply considerably with the indirect collection and storage of the discontinuous runoff from heavy rainfall and other meteorological events via the respective water receiving dry well while at the same time avoiding the overuse of groundwater resources. ASR systems are therefore integrated into the entire water supply system.


City of Phoenix

Fig. 1 - pump impeller destroyed by sand ingress

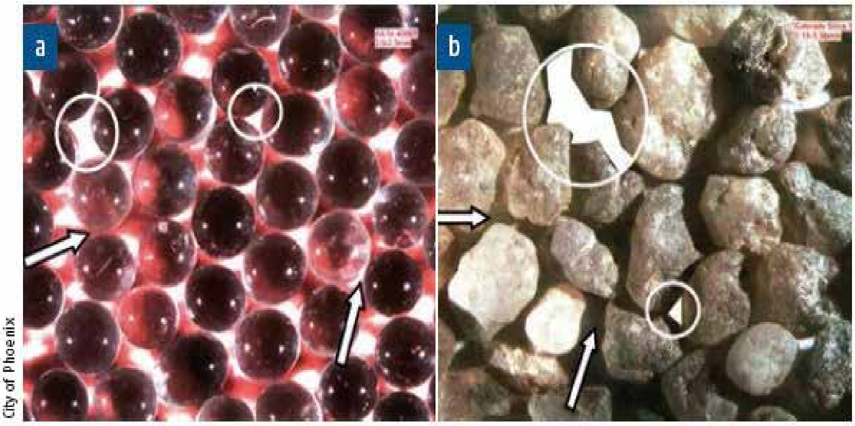

Fig. 2 - comparison of the physical and hydraulic properties of a) SiLibeads glass beads and b) quartz gravel: roundness: a) 2.4 to 2.9 mm: 0.95 to 0.98, b) 2.2 to 3.4 mm: 0.77; hydraulic permeability: a) kf vert. = kf hor., b) kf vert. < kf hor.; storage and roundness are decisive here for the hydraulic permeability.

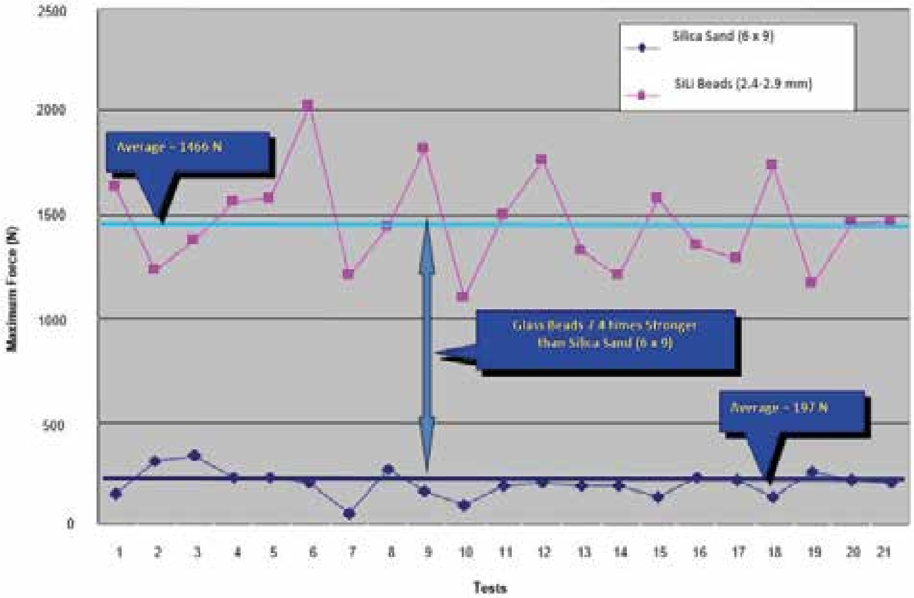

Fig. 3 - Breaking strength tests of glass beads and filter gravel test

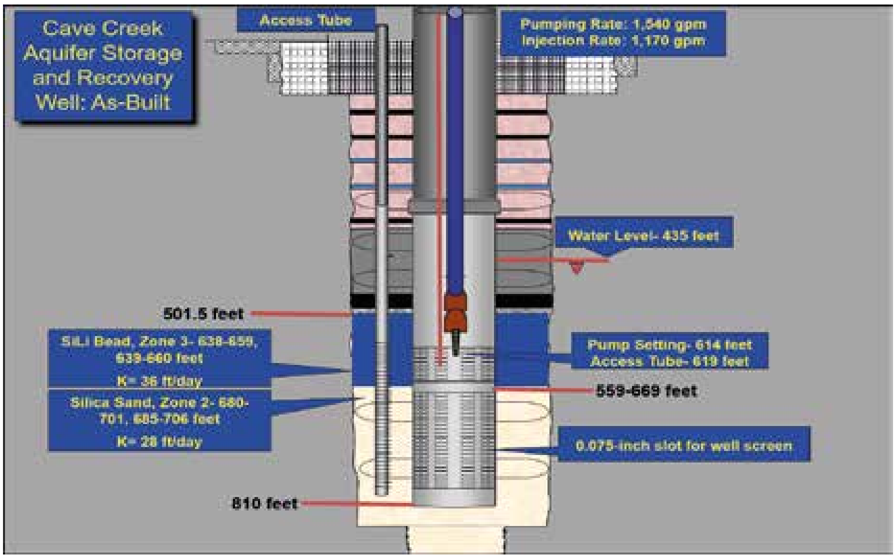

Fig. 4 - Expansion plan of the ASR well in Cave Creek with illustration of the investigation areas

David Pyne and Peter Scott, two pioneers of this technology, also point out the following advantages [1]:

- Avoidance of significant evaporation and transpiration losses due to underground storage compared to surface reservoirs.
- ASRA systems are easy to adapt or expand. As demand increases, an additional well can be added instead of a substantial initial investment in an overall plant designed to meet a predicted peak demand.
- Withdrawals from ASR wells are privileged under water law over withdrawals from groundwater users in the same aquifer.

According to [1], 28 different forms of application are currently known; the four main ones are:

- seasonal storage,
- long-term storage,
- emergency storage,
- ensuring security of supply.

Also worth mentioning is the importance of ASR systems as a hydraulic barrier against the intrusion of salt water along California's coastline. Most ASR plants rely on combined pumping and injection wells. However, these are only part of a complex infrastructure with sophisticated control technology. Due to the bimodal operation and the complex, varying hydro-chemical conditions, the design and maintenance requirements for the wells themselves are also significantly higher than for conventional pumping and injection wells. ASR wells in loose sediments siltate very quickly due to fine particles and mineral precipitates. Regular regeneration and de-sanding measures at short intervals are therefore indispensable and represent the largest operating cost factor.

The following explanations are based on the last part of the complete three-part, English-language internet blog by co-author Gary M. Gin, Managing Director of Leonard Rice Engineers in Phoenix, Arizona [2]. In the genealogy of ASR experts, he belongs to the next generation, the *"Junge Wilde"*, who with innovative ideas on this decades-old technology provide important impulses for the improvement of profitability, efficiency and operational safety.

The water flows preferentially through the glass bead filling, which leads to a correspondingly higher volume flow rate in this area.

The aim of Gin's three-part blog series was to show the advances in ASR well technology and to demonstrate how these advances can improve the efficiency of ASR well systems. In the introduction to the blog, the author discussed the development of ASR well technologies and the methods used in the industry for injecting water with their advantages and disadvantages. Part 1 described the alternative injection method "Reverse Siphon", where the hydraulic controls for prevention of air entrapment and initiation of injection are located at the surface of the wellhead rather than being connected to the pump assembly at the bottom of the well. The second part of the blog describes the use of an epoxy coating to prevent iron oxide particles from clogging the interface between filter tube and filter bed. In the last part, the use of glass beads as a filter medium to optimize injection performance and productivity is discussed. This discussion is recorded and reproduced below.

Use of filter dumps

First, the purpose of a filter medium installed between the borehole wall and the filter pipe has to be investigated. According to [3], a filter bed is installed in order to retain most of the coarser-grained formation material behind the filter tube, to reduce the amount of fine particles that can enter the well (sand pumping), and to improve the well hydraulics.

The filter material should be rounded and well sorted to ensure good porosity and high hydraulic conductivity (improved flow to the well) in the vicinity of the filter tube [3]. Conventional bulk materials usually consist of quartz and feldspar grains, which are rounded off by water-weathering processes caused by wind and water. The grains should not consist of rock fragments and/or calcium carbonate. There are frequent reports of wells pumping large quantities of sand, destroying the impellers and pumping stages of the pumps (Fig. 1).

In general, pumping sand occurs due to one or several factors: poor installation of the filter bed; incorrect dimensioning of the bulk solids and filter slot widths; or poor selection of filter media. In his blog post, Gin assumes that the well lining has been correctly designed and that the filter fill has been installed in a qualified manner. The key question is, whether there is a filter bed that provides better hydraulics and reduces the potential pumping of sand particles into the well.

The choice of filter fill is particularly critical for ASR wells as they clog more frequently, resulting in decreasing injection and delivery rates over time. To answer the above question, a series of tests were performed to measure the degree of roundness (sphericity), sorting and breaking strength of glass beads (2.4 to 2.9 mm) and quartz gravel (2.2 to 3.4 mm) (Figs. 2 & 3).

At 0.95 to 0.98, the roundness of glass beads is almost at the theoretical optimum of 1, while that of filter gravel of the highest quality at 0.77 is significantly lower. A significant difference also exists in the discriminate directional permeability of the bulk solids made of the respective materials. While bulk packs of mineral gravel have a significantly worse vertical than horizontal permeability coefficient (kf), glass bead packs are completely isotropic. The breaking strength of glass beads is 7.4 times higher than that of the used natural quartz gravel, which means that the glass beads can withstand more abrasion and maintain constant pore space diameters over time. It was also found that the degree of roundness and sorting was better for glass beads than for quartz gravel (Fig. 2). The greater breaking strength and roundness of the glass beads in combination with their better sorting establishes higher porosity with regular pore structure [4, 5]. It was then examined whether these initial findings were valid and measurable.

Testing of the hydraulic properties of glass beads compared to quartz gravel

To test the performance difference between these filter media in practice, an ASR well was constructed in Cave Creek, a suburb of Phoenix in Arizona. The well was backfilled partly with glass beads (2.4 to 2.9 mm) and partly with naturally occurring quartz gravel (2.2 to 3.4 mm). For the comparative measurements of the hydraulic properties during operation, approx. 7 m thick intervals (zones) of glass beads and quartz gravel with comparable hydraulic conductivity (kf) were selected. In the glass sphere package the hydraulic conductivity was 1.2 * 10E4 m/s, in the gravel package 9.9 * 10E5 m/s (Fig. 4).

The use of stainless steel as fountain construction material, glass beads as filter medium, and an automatic well control system makes the maintenance of the well less costly and more trouble-free.

The hydraulic conductivity of the aquifer was determined by multiple slug tests. The aim of the comparative measurements was to determine whether glass beads have better hydraulic properties than natural quartz gravel. For this purpose, several Packer flowmeter measurements were conducted in the filter areas of the above-mentioned differently backfilled zones over a period of one year during pumping and injection operation. In addition to determining and quantifying the inflow zones, it was also possible to determine the differences in the specific yield for pumping and injection operation in the individual zones for the respective bulk materials. In other words: How much water flows out of and into the glass beads and quartz gravel? Figures 5 and 6 show the results for the specific yield (gpm/feet) in pumping and injection mode and the changes over the measurement period.

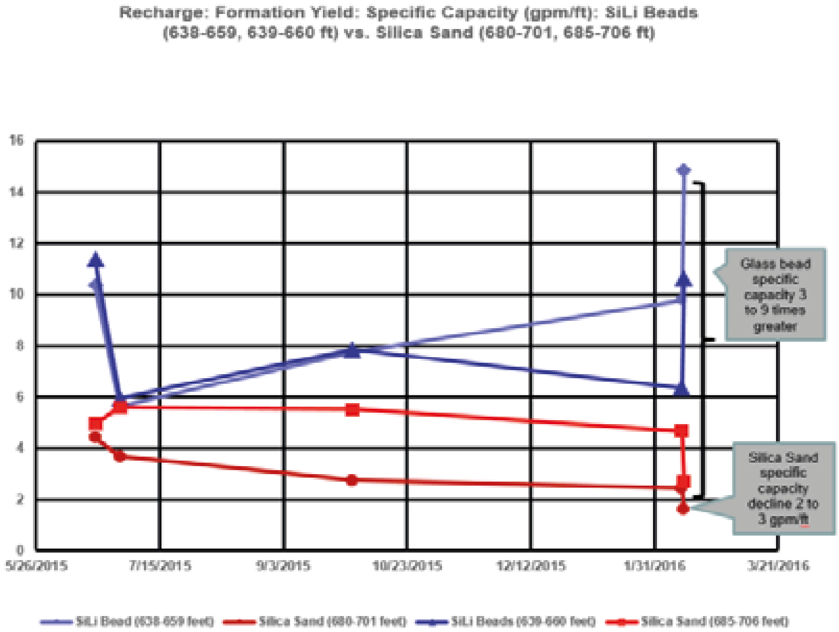

Abb. 5 – Entwicklung der spezifischen Kapazität/Ergiebigkeit im Schluck-/Injektionsbetrieb in der Glas kugel- und Kiesschüttung

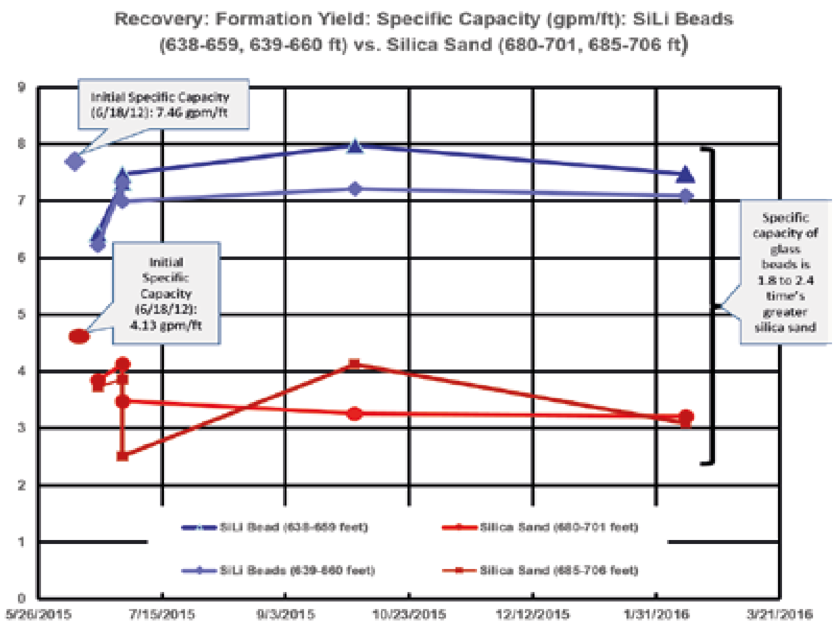

Fig. 6 - Development of specific capacity/yield in pumping/feed operation in glass bead and gravel fills

Serious differences were also found in the regeneration capacity of the well in Cave Creek compared to classical gravel wells. Figure 7 shows the typical decrease in specific yield for gravel wells over time. The losses are irreversible and inevitably lead to the shut-down of the well before the end of the calculated operating life for economic reasons, since extraction and regeneration costs are too high. The well 299, shown in Figure 7, had lost 50% of its specific yield after four years.

The well in Cave Creek with 50% glass beads backfilling shows a completely different course. Even after almost two years of operation of the new construction, its specific yield can achieve effortlessly the increased output power measured at commissioning. After fine adjustment of the pump and extraction cycles, the special yield even increases further. Repeated shock-flushing with the operating pump during de-sanding/development are sufficient (Fig. 8) for complete recovery of the genuine output power.

Conclusions

The following conclusions could be drawn from the one-year ASR well performance test: In injection mode, the specific yield of the glass bead zone was 3 to 9 times higher than that of the quartz gravel section. This means that the water flows preferentially through the glass bead bed, which leads to a correspondingly higher volume flow in this area (Fig. 5).

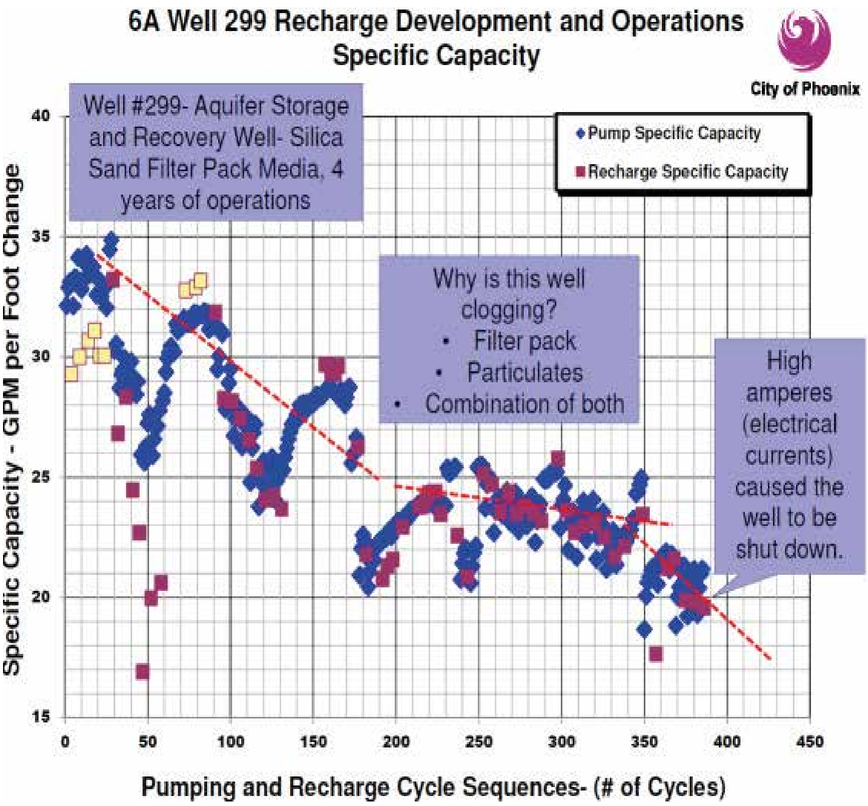

Fig. 7 - ASR well 299 with complete gravel backfilling - Development of specific capacity/yield over four years in continuous pumping and injection operation

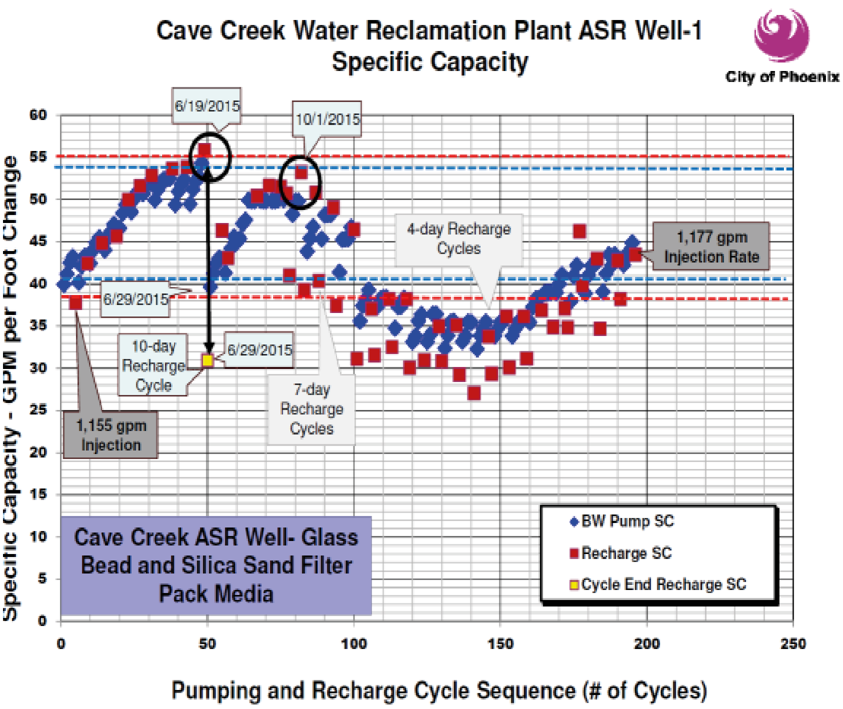

Fig. 8 - ASR wells with glass bead and gravel filling in Cave Creek: Development of the specific capacity/yield over two years in continuous pumping and injection mode

The specific yield of the quartz gravel section slowly deteriorated from 1.12 to 0.44 l/s*m, suggesting that the pore spaces are either clogged or are losing diameter due to abrasion. The glass beads maintain their initial specific capacity of 1.9 l/s*m or even improve after development pumping (Fig. 5).

During pumping, the specific yield of the glass bead zone was 0.34 to 0.46 l/s*m higher than that of the quartz gravel section (Fig. 6). This means that significantly more water from the aquifer was pumped through the glass sphere zone. The higher specific capacity leads to flatter operating water levels, which extends the life of the pumping equipment and reduces pumping and maintenance costs over time.

During both injection and pumping, the glass bead sections showed no loss of performance during the test period after backwashing (sand removal), indicating longevity and consistent well performance.

By evaluating and scaling these results, an adapted injection cycle (duration of injection cycles and frequency of backwashing) could be developed, which makes the performance comparable between an ASR well with glass beads and a quartz gravel ASR well. The hydraulic efficiency of the glass beads was determined to be 45 to 55 % higher than that of quartz gravel.

The results of these tests show for the first time measurable advantages in operation and maintenance costs as well as capital costs in real life well operation. The use of stainless steel as well lining material, glass beads as filter medium and an automatic well control system has made the maintenance of this well more cost-effective and less costly for the operator.

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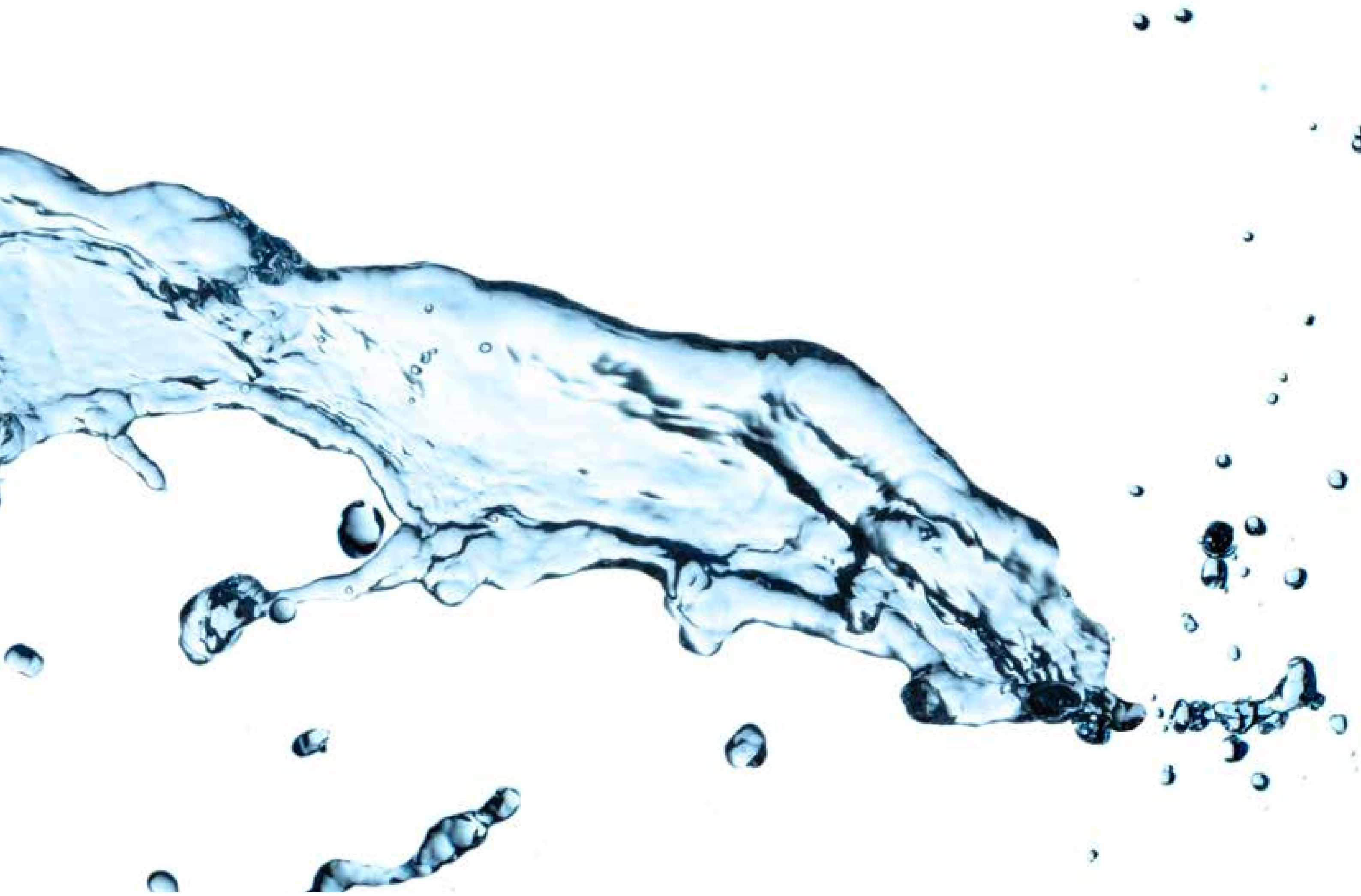

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