# Efficiency of glass balls in well construction

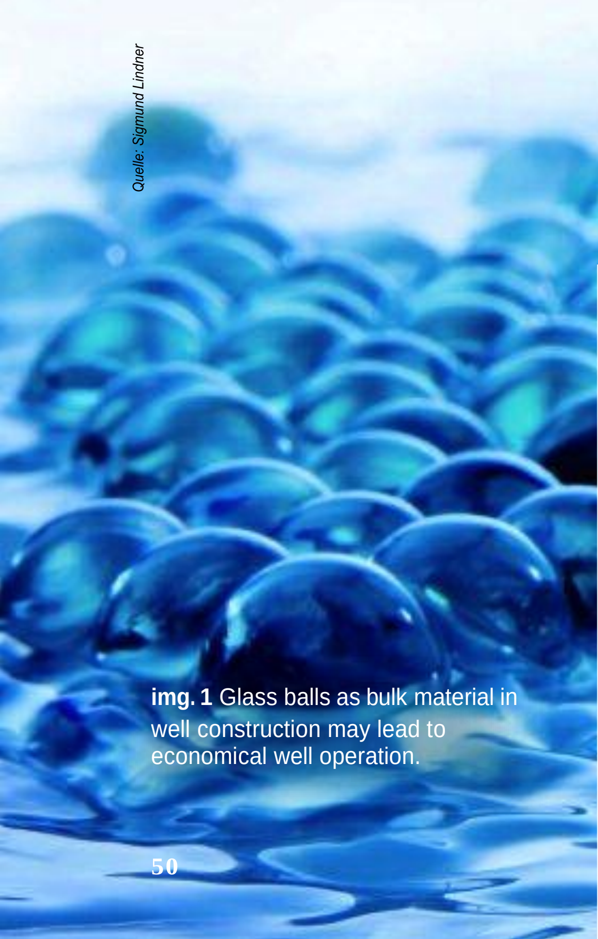
**Bulk material** Since the first application in late 2007, glass balls are increasingly replacing gravel as bulk material in drilled wells. Initiated through positive experience from application in wells tending to iron encrustation. A well is a long-term investment with usually more than a 40-year operating period and can be compared to commercial buildings.
In the Real Estate business, the influence of operating costs is known as an essential factor in efficiency. Following this approach, the investment and operating costs of drilled wells, with gravel and glass ball fills, have been compared based on 25 and 40 years in calculation.

Initial use of glass balls as bulk material was determinted by the quality of available natural sands and gravels. The utilized natural sands and gravels depict the following disadvantages as bulk materials:

- no ball shape
- significant low and top grain portions
- high dirt inclusions or abrasive materials
- no satisfactory strength
- clearing pumps and disinfection necessary
- cost-intensive developments necessary and
- possible colmation of filter slits [1].

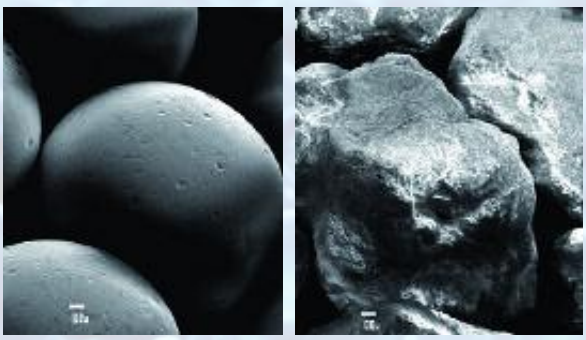
Basic insight on the influence of bulk materials and their effect on the function and life term of wells can be also found under [2 u. 3]. ‘low grain’ from filter gravel as well as fine particles from the ground water conduct are thus responsible for the clogging of pores in the drill hole surface and ring chamber. Furthermore the duration and costs of desanding and specific well performance are negatively influenced thereof [7].

Further factors of major technical and economic significance are the hydraulic and mechanic properties of the inner side. Included besides the caption behaviour towards performance-obstructing sediments, are particularly the hydraulic efficiency key figures for the ring chamber fill:
Mechanical stability, abrasion resistance, roundness of filling grains and



Quelle: Sigmund Lindner

**img. 1** Glass balls as bulk material in well construction may lead to economical well operation.



Quelle: C. Treskatis

**img. 2** REM-photograph of a glass ball as opposed to a filter gravel grain of equal size. The ‘smooth’ surface of the glass ball avoids the formation of tensile stress from load layup and minimizes the sediment of encrustations.


Quelle: Sigmund Lindner

img. 3 Glass balls poured in


Quelle: GCI

img. 4 Well filled with bulk glass balls and wound wire filter

chemical resistance (e.g. against regenerating agents) [7]. In 2009, DIN-filter gravels and glass balls by Fa. Sigmund Lindner **(img. 1)** were tested for the following key figures:

- roundness
- specific weight
- filling weight
- grain distribution
- break load on static excess loads
- break behaviour on static excess
- break behaviour on dynamic load
- abrasion resistance
- surface type
- surface profile
- Roughness height and
- specific surface.

Glass balls showed the best results of all tested parameters rather than DIN-Gravels [5] **(img. 2)**.
In parallel, the chemical likeliness to iron encrustation of filter gravel vs. glass balls were compared at the hydrology laboratory of the University of Bayreuth. Glass balls thus show a 40 % lower settlement of iron oxides than natural gravels [6].In summary, glass balls display advantages as opposed to mineral sands and gravels.
They offer a best possible effective pore chamber due to exactly the same grain size and ideal ball shape; the width of filter pipe slits can be adapted in an optimal way, since a single grain filling is possible, no clear pumps resp. cleaning of glass material is necessary nor is a disinfection prior to filling.
**(img. 3)**. Furthermore the iron and manganese sedimentation are delayed due to the smallest possible and smooth surface. Large pore chambers enable an optimal ability for regeneration, there are no late sedimentations and, due to low material abrasion, the fills with glass material is also possible in narrow ring chambers without bridging. Furthermore glass balls display a higher material density vs. Quartz gravel and camera inspections enable easy detection of iron encrustation in wound wire filter pipes or foreign bodies in the ring chamber (img.).

## Efficiency aspects

### General

Although the technical benefits of glass balls is acknowledged by experts, the higher purchase price of glass balls vs. natural mineral filter fills are often cited as disadvantage and obstacle for their utilization.
The material price alone is not a sufficient indicator for judging, the total efficiency of a well.
Wells are long-term investment goods with operating periods of usually more than 40 years.
Besides the investment costs, the operating costs also have to be considered in order to achieve the target of optimal total efficiency.
The great influence of operating costs is known as an essential factor in the efficiency of wells.
Due to high operating costs through a.o. high energy costs for drilling, frequently necessary regenerating etc.), it can be absolutely more efficient to replace a well which is otherwise intact [8]. ►

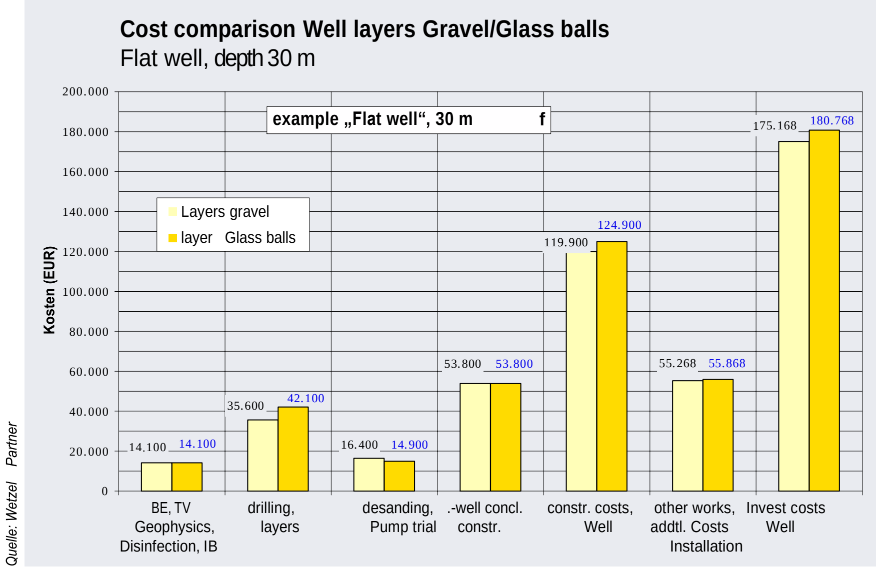
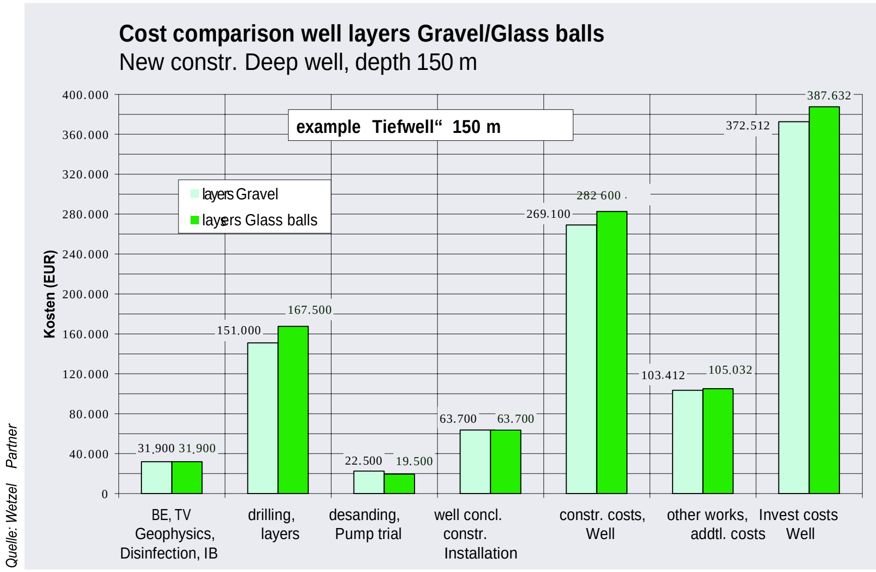



**Abb. 5** cost portions partial works ‘Flat well’




**img. 6** cost portions partial works ‘deep well’

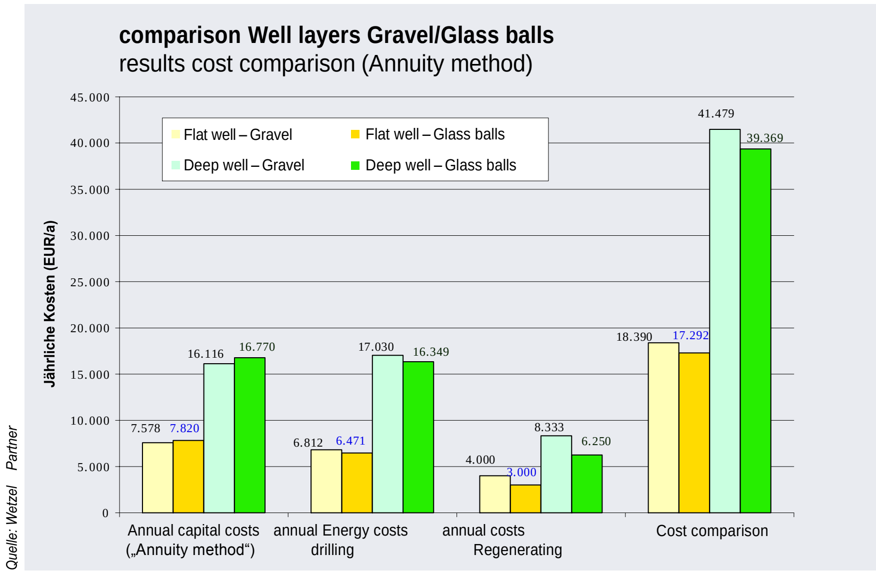



**Abb. 7** summary of annual costs (Annuity method)

For the following consideration, wells with common gravel fill as well as alternative use of glass balls have been tested for the investment and operating costs and regarding the resulting efficiency in comparison.
In order to reflect regionally different hydrogeology, two different wells were considered: a firm rock well of 150 m (deep well) and a relaxed rubble well of 30 m depth (‘flat well’).

The following cost aspects were taken into account for the comparing efficiency examination:

- Investment costs
- Energy costs of base water drilling and
- costs for regenerating.

The total efficiency was estimated by the annuity method and also by the KVR-guide lines (only ‘deep well’)

## Investment costs

For the construction of the example well, all directly and indirectly included cost aspects were considered in total:

- additional costs like site equipment TV inspection, geophysics, disinfection, opening
- drilling and inner lining
- desanding and trial pump
- well shaft with technical equipment, plunger power pump, pipe installation and fittings/gauges and
- other works and additional costs.

**Table 1** shows the investment costs for the example well. Cost basis is the medium market price 2010; the cost estimate for the example well also includes own assessments and own cost data **(img. 5, 6)**. Due to the higher material price, the investment costs for a well with a glass ball fill is higher. Lower costs for desanding cannot compensate the initially

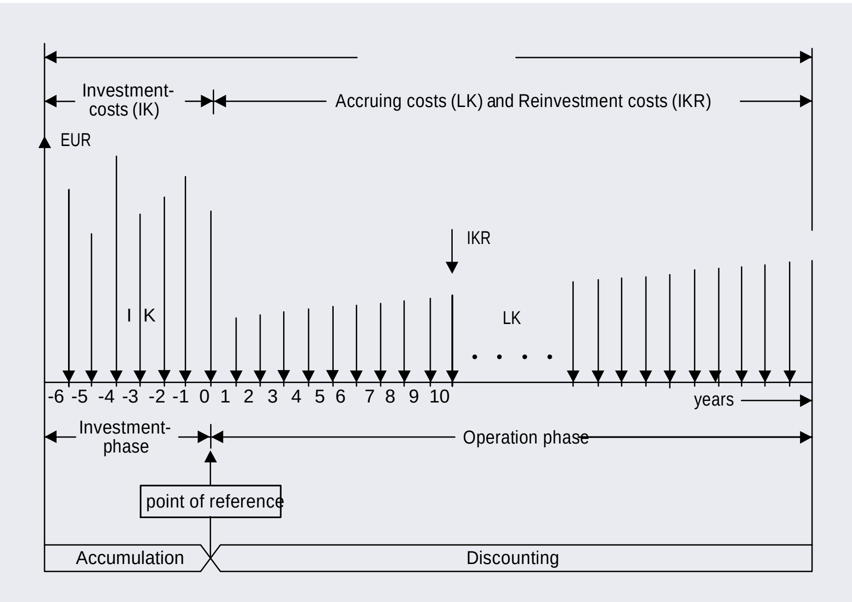
| | | Flat well 30 m | | deep well 150 m | |
|---|---|---|---|---|---|
| balls | | layers Gravel | layers Glass balls | layers Gravel | layer Glass |
| 1 | Site equipment | 7.700 | 7.700 | 23.200 | 23.200 |
| 2 | Drilling, layers | 35.600 | 42.100 | 151.000 | 167.500 |
| 3 | desanding and Pump trial | 16.400 | 14.900 | 22.500 | 19.500 |
| 4 | Well concluding wall | 26.400 | 26.400 | 27.200 | 27.200 |
| 5 | Installation | 27.400 | 27.400 | 36.500 | 36.500 |
| 6 | TV-geophysics (inspections) | 3.900 | 3.900 | 5.200 | 5.200 |
| 7 | Opening, other | 2.500 | 2.500 | 3.500 | 3.500 |
| | **subtotal 1 (only Well constr.)** | **119.900** | **124.900** | **269.100** | **282.600** |
| | **Other works** | **11.500** | **11.500** | **31.500** | **31.500** |
| | Pipe constr. | 3.500 | 3.500 | 3.500 | 3.500 |
| | Demoltion old well | 4.000 | 4.000 | 16.000 | 16.000 |
| | Opening drill | 4.000 | 4.000 | 12.000 | 12.000 |
| | **Electronics** | **25.000** | **25.000** | **32.000** | **32.000** |
| | **subtotal 2 (incl. Other works)** | **156.400** | **161.400** | **332.600** | **346.100** |
| | **Addtl. costs** | **18.768** | **19.368** | **39.912** | **41.532** |
| | **Investment costs** | **175.168** | **180.768** | **372.512** | **387.632** |
| | | **100,0%** | **103,2%** | **100,0%** | **104,1%** |
| **Excess** | | | **5.600** | | **15.120** |



Quelle: Wetzel Partner

**Table 1** cost listings for flat and deep well each with gravel and glass ball layer

**Cost column**




Quelle: Wetzel Partner

**img. 8** work parameter acc. to KVR-guidelines [10]

higher costs. The fill with glass balls can be limited to the filter sections with a certain excess and low fill. For the example 'flat well', the well equipped with a fictitious filter length of 15 m (well 1.300 /layer DN 600, total of 5 m excess or low fill) was assumed a fill of ca. 11.8 m³ (equals ca. 8 T glass balls at a material price of ca. 950 EUR/T). The specific costs for quartz gravel equal ca. 140 EUR/T.

For the deep well a use of ca. 20 T glass balls was assumed. This leads to excess costs of ca. 6.500 EUR for the 'flat well' and ca. 16.500 EUR for the 'deep well' (**Tab. 1**). Opposed are savings from desanding and well dev elopment, because glass ball layers contain no low grain and thus such expenses otherwise necessary are void. The examples state savings in amounts of ca. 1.500 EUR for 'flat well' and of ca. 3.000 EUR for 'deep well' Summarizing higher investment costs are defined; in the examples between 5.600 EUR/3.2 % (flat well) and 15.120 EUR/ 4.1% (deep well).

## Annual capital costs

By means of the annuity method a (single) investment depending on interest (following assumed average 3 % – constantly over the determined exploitation time) and the exploitation period (assumed 40 years) has been converted into annual capital costs. The annuity formula has been published in multiple, a.o.in [8], so this is not further explained here. The annual capital costs (**Tab. 2**) differ only by 242 EUR/a for the flat well and by 654 EUR/a for the deep well. These amounts stipulate the excess annual capital costs for the utilization of glass balls.

## Annual operating costs – Energy costs of base water drilling

Assumption: Hydraulic benefits of glass balls vs. quartz gravel resulting from higher effective porosity lead to a comparably less

sinking of operating water level owed to lower filter entry resistor and thus form a lower geodesic conveying height of the plunge power pump.
(mWS). **Table 3** calculates under assumption of fictitious but 'realistic' side conditions energy costs of drilling towards the required annual energy demand (see also [9]). For utilization of glass balls an average of ca. 1 m less well height of the 'flat well' (19 inst. 20 m) and a ca. 2 m less well height of the 'deep well' (48 inst. 50 m) with resp. to the total exploitation period of 40 years was taken into account. The fictitious consideration results in savings of ca 340 EUR/a for the 'flat well' (equals ca. 12,800 EUR in 40 years) and of ca. 690 EUR/a for the 'deep well' (equals ca. 27,600 EUR in 40 years). These savings are considered as being 'at the lowest limit'.

## Annual operating costs – expenses for well-regeneratings

For glass ball fills a 40% reduced sedimentation of iron oxides compared to gravel fills was determined in laboratory tests [6]. In the calculations this has been converted to a exploitation period of 40 years with a 25% less regenerating frequency for glass ball wells.
i.e. for gravel utilization:
Regeneration every three years; for glass ball use:
Regeneration every four years.

The costs for regenerating the 'flat well' were calculated with 12,000 EUR, those of the 'deep well' with 25,000 EUR. This contains pump tests init./after, a mechanical cleaning, regenerating by means of chemicals several TV-inspections and complete geophysical measurings intial and after regenerating (measure program a.o. Packer-FLOW: inflow behaviour, profile, permeability of filter slits and the direct fill; GG.D: Density measuring of the ring chamber fill a.o. for determining of 'relaxed storage' up to default spots; NN: Porosity of ring chamber fill in the sphere of the filter stretch; SGL: portion fine grain in the gravel-/glass ball fill etc.).

**Table 4** shows the results. As accruing operating costs the costs for regenerating were transformed to an average value p.a. without further interest add ons.

## Summary of annual costs

**Image 7** shows the results of efficiency considerations under the annuity method.
All in all, significant cost advantages result from the use of glass balls. Despite higher investment costs, the lower operating costs lead to cost savings overall.
For the 'flat well' the savings makes ca, 1,100 EUR p.a. (difference: 18.390 vs. 17.292), for the 'deep well' ca. 2,100 EUR/a (difference 41.479 vs. 39.369). The savings in the respective exploitation period of 40 years make ca. 44,000 EUR for the 'flat well' and ca. 84,000 EUR for the 'deep well'.

## Efficiency considerations under the KVR guidelines

The annuity method depending on the exploitation period of a well and the (estimated) average interest during the utilization time as well as the accruing operating costs supports only static expense ratio and expense analysis. In the framework of a 'dynamic cost comparison calculation', price and expense increase rates can be processed so that this method allows more exact results.
A cost comparison calculation under KVR guidelines should be preferred therefore vs. the annuity method with more complex facts. The individual work parameter of the dynamic cost comparison cannot be discussed in further detail here **(Abb. 8) it is referred to the** literature [10 – KVR-guidelines]. For the example 'deep well' an efficiency analysis was conducted under KVR-guidelines. The following side conditions were taken into account:

- Investment costs **(Tab. 1)**,
- Energy costs of base water drilling **(Tab. 3)** and
- Regenerating costs acc. to **table 4**.

In the framework of dynamic cost comparison the cash value (BW) is calculated from the investment (IK) and re-investment (IKR; calc. basis: DFAKE) at the time of

►

Interest factor: 3%

| | | | Flat well | | deep well | |
|---|---|---|---|---|---|---|
| | | | layer Gravel | layer Glass balls | layer Gravel | layer Glassb |
| 1 | **Investment and capital costs**<br>Investment costs | (EUR) | **175.168** | **180.768** | **372.512** | **387.632** |
| | **Debt service**<br>Exploitation time<br>Annuity factor<br>**Annual capital costs** | (a)<br>(-)<br>**(EUR/a)** | 40<br>0,0433<br>**7.578** | 40<br>0,0433<br>**7.820** | 40<br>0,0433<br>**16.116** | 40<br>0,0433<br>**16.770** |

**Table 2** annual capital costs of 'sample well' with gravel layer and glass ball layer (interest: 3 %)

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | **Energy costs water drilling**<br>Costs per Kilowatt/h i.M.<br>drilling p. M.<br>drilling p. M.<br>effectiveness plunge powerpumps (m) p.M.<br>drill output p. M. (Assumed)<br>**Sum energy costs drilling** | (EUR/KWh)<br>(m³/h)<br>(m³/a)<br>(%)<br>(mWS)<br>**(EUR/a)** | 0,15<br>80<br>**500.000**<br>60 %<br>**20**<br>**6.812** | 0,15<br>80<br>**500.000**<br>60 %<br>**19**<br>**6.471** | 0,15<br>80<br>**500.000**<br>60 %<br>**50**<br>**17.030** | 0,15<br>80<br>**500.000**<br>60 %<br>**48**<br>**16.349** |

**Table 3** annual energy costs of water drilling

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | **Regenerating**<br>Regenerating frequency (assumed)<br>Costs per regeneration<br>Annual costs regenerating | (a)<br>(EUR)<br>(EUR/a) | 3<br>**12.000**<br>**4.000** | 4<br>**12.000**<br>**3.000** | 3<br>**25.000**<br>**8.333** | 4<br>**25.000**<br>**6.250** |
| **Costs comparison** | | **(EUR/a)** | **18.390** | **17.292** | **41.479** | **39.369** |

Quelle: Wetzel Partner

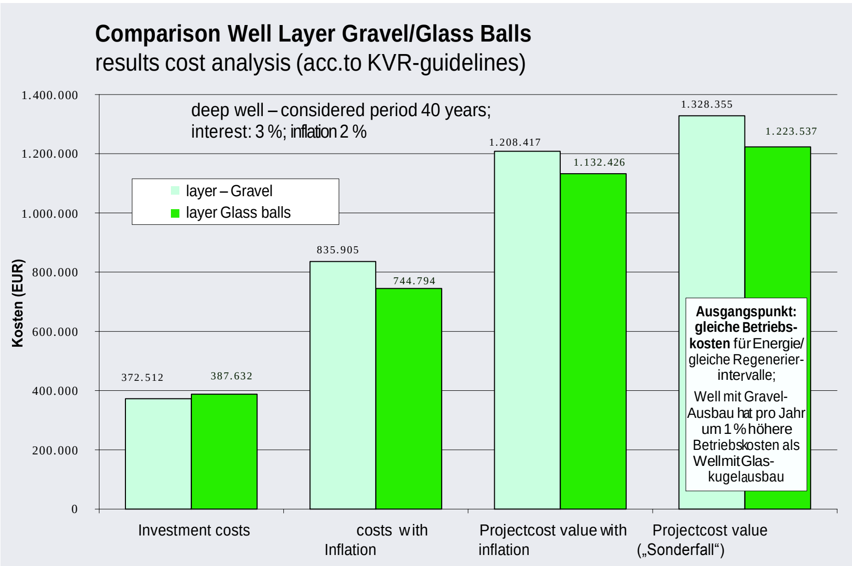
**Table 4** annual costs for regenerating

reference point (see img. 8). The cash value is also calculated for accruing costs (LK) at the reference point. Depending on cost parameter uniform or different inflation factors can be taken into account. (calc. Basis without inflation factor: discounting factor DEFAKR; calc. Basis with inflation factor: discounting factor DFAKRP). From the bottom line cash value for investment and re-investment and the cash value of accruing costs (with or without inflation factors) the resulting project cost cash value PKBW is determined.

The results of the dynamic cost comparison are shown in image 9. The layering with glass balls is estimated significantly more beneficiary in the consideration period of 40 years.
Over the analysed period, savings are determined under accounts of the stipulated side conditions as 'project cost cash value with inflation' in the amount of ca. 76,000 EUR (difference 1,208 Mio EUR vs. 1,132 Mio EUR).

A special case shall be pointed out: assumption of identical initial operating costs for a well with gravel layer and glass balls, i.e. identical energy costs of base water drilling and assumption of the same regenerating intervals – but with lump 1 % p.a. higher costs for the well with gravel layer. This special case shows savings as project cost cash value of ca. 104.000 EUR (difference: 1,328 Mio vs. 1,224 Mio).

**The assumed benefits for operating costs based on assumptions and 'theoretical models' require verification due to provable results from practical studies.**




Quelle: Wetzel Partner

**img. 9** summarized costs – 'deep well' (acc. to KVR-guidelines)

## Conclusion

As opposed to exactly determined construction costs, the regenerating demand could only be estimated based on laboratory results and our own long-term experience in well construction, due to lack of long-term operation experience with wells lined with glass balls. The figures are thus not suited to claim total repeatability in a strict scientific sense. They only provide a glance at an integral consideration of lifecycle costs of a well and show the savings potential of glass balls.

Despite some inpredictabilities it can still be concluded that wells with glass ball fills are more efficient than such operated with filter gravel. This is also owed to factors that are currently not quantifiable due to their well-specific distinction and non-linear nature, but nonetheless are cost effective like the constantly increasing drilling costs owed to the continuous sinking water level between two regeneration cycles. The same applies to the secondary sediment of filter gravels by breakage caused by hydromechanic regenerations, which leads to increased filter resistance and increased colmation, subsequently leading to higher drilling costs and decreasing life term of the well. In order to support the described assumptions, comparing measuring programs have been installed to existing wells in autumn 2010. In the near future, the quantifying aspects will be much better resolved.

Finally, the use of glass balls is also considered for several statewide planned projects in horizontal filter well construction.

Experiences from construction and operation soon to be reported.

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