Suitability of glass beads in the depth filtration of water

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Granular filter materials are used for particle separation in depth filters. The depth filtration describes a process in which particles are preferably not separated on the surface of the filter medium, but inside, i.e. in the depth of the filter bed. (DVGW 2005a)
Frequently used filter materials in the depth filtration of drinking water are quartz sands/gravels, pumice, basalt, expanded clays, expanded shale, various coals and diverse carbonate-rich rocks (DVGW 2005b). Besides using quartz sands, glass beads and glass granulates, so-called filter glass, some of which has been specially activated, are frequently used for particle separation in bathing water treatment (Markiel and Wistuba 2011).

The effectiveness of a depth filter operated as a rapid filter[1] is subject to a large number of influencing parameters. More than 20 variables, including characteristic features of the filter medium, the filter bed, the turbidity, as well as various process parameters have an effect on the filtration result (Gasper 2004). The mathematical compilation of all influencing variables into a generally valid and practically applicable correlation has not been achieved to date and shows the complexity of the processes in a depth filter during filtration (Wilhelm 2008; Stieß 1994).

As classical separation mechanisms of particles in the depth filter, Gimbel and Nahrstedt (2004) identify sedimentation, inertia, diffusion and the barrier effect. Hydrodynamic influences, such as hydrodynamic lateral forces and hydrodynamic inhibition also have an impact (Ives 1975; Leibnitz 2004). Other influencing factors are van der Waals forces and electro-kinetic forces, which can influence the deposition of particles on the surface of a filter grain (collector) (Leibnitz 2004). For example, there are electrostatic interactions between particles and the collector surface. Dirt particles suspended in liquids usually exhibit a negative surface charge (Kaulitzky 1999). If the collector surface also has a negative charge,
electrostatic potential barriers are created, which have a negative impact on the separation performance of the filter bed (Gimbel and Sontheimer 1980).

Due to the large number of different dirt particles in the raw water and the multitude of influencing variables, the dirt-holding capacity of a granular filter bed can only be estimated in relation to the specific application (Wilhelm 2008) or must be determined empirically in each individual case (DVGW 2005a).

According to Wilhelm (2008), particularly the density and water content of the dirt particles influence the separation of the dirt particles in the depth filter.

If largely spherical particles with low water content are filtered, structured collector surfaces have a favourable effect on particle deposition. In this context, superficial grain structures,

[1] Processes for particle removal in drinking water purification, in which the water flows through a filter medium of granular materials at filter flow speeds of several metres per hour (DGVW 2005c)

such as roughness or depressions on the collector, influence the separation performance (Gimbel and Nahrstedt 1980).

The specific surface area comprises the entire solid surface, i.e. on the one hand, outer surface structures, and internal, hence hydraulically inaccessible structures such as filter pores on the other hand.
In the case of filter materials with specific surfaces exceeding several square metres per gram, the specific surface is almost exclusively determined by the filter pores. Thus the specific surface area of such materials is not a meaningful parameter with regard to the particle separation capacity in the filter bed; the specific surface area is solely important with regard to adsorptive processes. If micro-scale quartz sands, i.e. model particles with low water content and high solid density, are suspended in the water and filtered through a deep-bed filter, they will be removed better by filter materials with a structured surface, such as pumice, anthracite and quartz sand than by glass beads filters, which have a smooth surface (Gimbel and Nahrstedt 1980; Gimbel 1982).

However, if agglomerates of water-containing turbidites, water-containing metal oxide flakes or microalgae, i.e. particles of low density with gelatinous properties or even fibrous substances are filtered, filter materials with a smooth surface and high roundness are clearly superior to filter materials with an irregular surface structure.

If the above-mentioned particles are filtered through a filter bed with filter media of non-uniform grain form, especially in the case of a high load input, caking and adhesion of the filter material and the support layer as well as a change in the effective particle size as a result of irreversible deposits (grain growth) may occur. Such deposits lead to formation of channels in the filter bed, which in turn cause inhomogeneous flow patterns through the filter during filtration operation. Disturbances of the plant and backwash operation, which occur due to insufficient filtration efficiency or uncontrolled filter bed fluidization, are the result. (Bäcker 2010)
On the opposite, using glass beads as filter material, the above-mentioned drawbacks are not to be expected. Glass beads in the filter bed show ideal settling behaviour in the filter bed after insertion and backwashing. The defined pore space shows an increased permeability and homogeneous flow during filter operation. Particles are separated evenly in the pore space, even into deep bed layers. Such separating mechanisms are assumingly contributed to hydrodynamic influences. The dirt holding capacity of a glass bead filter bed is thus significantly higher than that of a classic filter bed with materials of undefined grain shape (e.g. quartz sand, filter glass). The filter resistance over the glass bead filter bed increases with a delay, the filter runtimes between the backwash intervals increase. Covering layer formations or a low depth of penetration of the contaminants respectively, as occurs in the filter bed with non-uniform filter granulate, do not occur. Sticking, caking and grain growth as well as associated operation disturbances have not been observed in the glass bead filter bed to date.

Material losses and a reduction in grain size have a negative impact on the performance of a filter (Humby and Fitzpatrick 1996). Besides their advantageous shape and surface texture, glass beads show an increased abrasion resistance compared to quartz sand (cf. Treskatis et al. 2010; Markiel and Wistuba 2011); material losses during ongoing plant operation are negligible; the effective grain size is maintained in the long term.

In addition to transport and adhesion of particles to the collector surface, the particle detachment from the collector surface in the course of backwashing is also relevant for the process of separation of suspended turbid matter in the depth filter (Ives 1975). With a comparable particle size spectrum, a glass sphere filter bed can be backwashed much more efficiently than a quartz sand filter bed. Respectively, Rose (2019) demonstrated that the sufficient rinsing water velocity[2] of a quartz sand (0.71-1.25 mm) in the depth filter is 44 m/h at 19 % bed expansion; that of (functionalised) glass beads (0.75-1.25 mm) is only 33 m/h at 10% bed expansion. This results in savings in operating costs (electricity, clean water, waste water) and set-up costs (pump dimensioning). (Rose 2019)
Differential pressure losses in the glass bead filter bed during filtration and backwashing are also lower, which means that operating and set-up costs can be saved in equal measure (Rose 2019).

Another factor influencing the efficiency of the filtration process is the particle size distribution of the filter medium. From a process engineering point of view, the particle size distribution should be as narrow as possible. After backwashing, the filter bed should resettle to its original, homogeneous state. Due to the lower settling velocity of smaller grains, these accumulate in the upper of the filter layer in the case of inhomogeneous particle size distributions. This results in smaller pore widths at the bed surface, so that the depth effect of the filter can change into a surface effect, which leads to strongly increasing filter resistance (Gimbel and Nahrstedt 2004).

Due to a standardised manufacturing process, glass beads comply with highest and sustainable product and material qualities, whereas quartz sands often have irregular grain size distributions and unacceptably high undersize fractions (Herrmann and Stiegler 2008). Hence, the above described mechanisms can occur in the depth filter bed.

A constant filtrate quality during filtration and after backwashing is a prerequisite for trouble-free plant operation. With reference to the filtration of swimming pool water, Klaus et al. 2014 demonstrated that the filtrate quality of a glass ball filtration system is comparable to that of quartz sand filtration. The authors were able to show that glass beads in the depth filtration of swimming pool water are clearly superior to irregular shaped filter granulates such as quartz sand. In this context, they highlight the mechanical and hydraulic properties of the glass beads, which can be contributed to the advantageous shape and material characteristics and play an essential role in both operation and backwashing.

The advantages in the use of glass beads compared to unshaped granular filter media in the depth filter can be summarised as follows:

- Comparably effective separation of turbidity in the filtration of swimming and bathing pool water.
- No negative influence on filtration due to negative surface charge (here in comparison with especially activated glass granules).
- Increased dirt-holding capacity of the filter bed due to high penetration depth during filtration of low density gelatinous particles and fibres

[2] According to DVGW (2005b), an intermittent motion of all filter particles in the filter bed indicates sufficient rinsing water velocity

  - Extended backwash intervals
- Very high permeability of the filter bed due to defined particle shape and smooth surface
  - More even deposition of particles in the pore space of the filter bed down to high bed depths
- Negligible risk of caking and sticking in the filter bed, as well as of
- progressive grain growth
  - Long-lasting high process stability
- Very high abrasion resistance, i.e. material characteristics and effective grain size retained over the long term
  - Long-lasting high process stability, long service life cycle
- Consistently exact product and material quality due to standardised production results in stable stratification of the filter bed even after backwashing
  - Long-lasting high process stability
- Lower differential pressure losses due to defined grain shape and smooth surface
  - Savings in operating and set-up costs
- Sufficient backwashing of the filter bed at lower rinsing water velocities
  - Saving of water (pure water, waste water)

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