Layout and Operation of granular fixed bed reactors

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Abstract Acid mining drainage (AMD) is often characterised by very low pH-values and high contents of dissolved metals. Thus major tasks in mining water treatment are neutralisation and metal removal. These requests are well known in drinking water treatment so that these established technologies can be adapted to the special needs for AMD. In the treatment of drinking water the usage of fixed bed reactors with back washing facilities is state of the art technology. A broad range of filter media enables very different applications. The choice between single or multi layer filtration systems allows an optimisation of the filtration selectivity, the effectiveness and the loading capacity.

Key Words water treatment, granular fixed bed reactors, multi layer filtration, catalytic manganese removal

Introduction

Mining waters are characterized by high acidity. They also contain high levels of dissolved metals such as iron, manganese or aluminia compounds (Wolfe *et al.* 2010). In some areas of Germany the aquifers, which are used for drinking water treatment, show similar types of contaminants. But the level of stress, especially in acidification, is often much less pronounced. Therefore the drinking water treatment methods are also applicable for AMD treatment. The higher level of contamination must be faced by adapting concepts.

This paper presents an overview on the state of the art of drinking water treatment in fixed bed reactors. A modified concept in drinking water preparation is described by a treatment plant dealing with high amounts of iron impurities.

Concept of fixed bed reactors

In drinking water treatment the filtration with granular filter media is the most common method for the removal of contaminants. The filter units can be installed as open or pressure vessels. Open systems, using gravity to pass the filter from top to bottom, enable velocities up to 15 m/h. In pressure filtration units the velocity can be doubled. Most filter units are equipped with back washing facilities for cleaning the filter bed. The back washing process is divided in several parts (table 1). To reach the fluidisation velocity of the used filter media is the key issue in the back washing procedure and mainly affects the efficiency of the cleaning process. Therefore the back washing velocity depends on the kind of filter media, the grain size and its bulk density. The amount of impurities in the water and the retention capacity of the filter bed define the frequency of back washing (Moll 1988).

Filtration selectivity and loading capacity are affected by the nature of the filter media and the grain size. A high surface and porosity of the filter media enable adsorption processes which are a prerequisite for the filtrative removal of organic impurities. Activated carbon filters used for the elimination of pesticides can be cited as an example. Grading influences the filtrate quality and the loading capacity. The finer the grain size the purer the filtrate, but loading capacity will drop down because of rising pressure loss in the filter bed. The impurities are retained mainly on the surface and block the filter bed. In contrast high loading capacity and running time are achieved when using a coarser grain size. In this case you must accept a worse filtrate quality because of penetra-

***Table 1** Back washing process in single layer filter (Rheinkalk Akdolit 2009)*

Back washing step	typical velocities (m/h)			Typical period (min)
	filter sand 0.7-1.25 mm	anthracite 1.4-2.5 mm	pumice 1.5-2.5 mm	
Lowering the water level above filter layer				
Air	60	60	60	3-5
Outgassing				2-5
Water	60	55	40	Till clear water drain

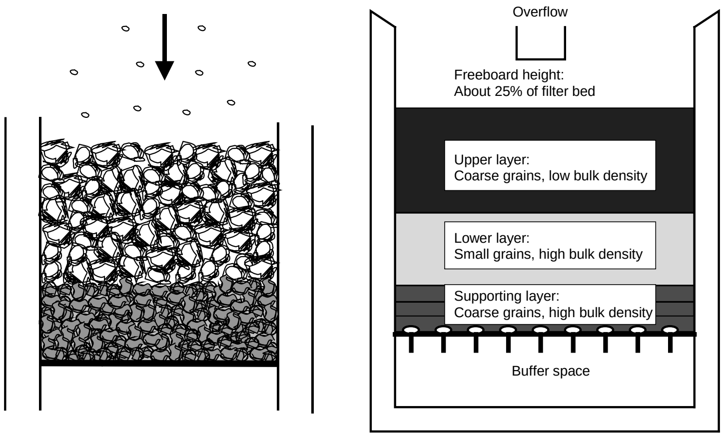

***Figure 1** Design of a multi layer filter unit.*

tion of the impurities in the filter bed (deep bed filtration) with the risk of breaking through.

Above described contradiction is solved in the design of a multi layer filter system. By layering coarse filter media with low bulk density on finer materials with higher specific gravity a combination of the advantages of deep bed and surface filtration is achieved (figure 1). Of course the different filter media must be coordinated very precisely in grain size and bulk density.

In the upper layer the deep bed filtration takes place that allows a high loading capacity and running period. The lower layer is responsible for a good filtrate quality. The loading of the lower layer leads to a sharp increase in pressure loss, which can be monitored well and used as an indication for the back washing of the filter. The risk of filter breakthrough is highly reduced, because the flush is triggered well in advance by the increase in pressure loss. Monitoring the pressure loss therefore allows the automation of the back washing process.

The back washing process must be performed in a way that a mixing of the different filter layers is prevented. Therefore grain sizes and densities have to be graded, so that the coarse upper layer gets the fluidisation point within a lower back washing velocity as the underneath layer. But the difference of fluidisation speed should also be as low as possible in order to minimise the total filter bed expansion. This is necessary to obtain a feasible freeboard height.

Compared to single layer filter units the loading capacity in multi layer filter can be doubled with values up to 2500 g/m³ filter media.

A broad range of different filter media is available and enables very different applications. Apart from lime and dolime products pumice and carbon-based material (natural anthracite, lignite coke or pet coke) are well known in water treatment. Depending on the kind of impurities special granulates with selective surfaces have been developed e.g. for the task of manganese removal. An overview of the recommended materials for multi layer filtration is given in the technical rule DVGW W 213, part 3. (DVGW 2005a)

Special granulate for manganese removal

In contrast to the removal of iron compounds which shows – in the known boundary conditions (DVGW 2005b) – good elimination rates within a few days, the start-up of manganese removal can take months (DVGW 2004). An acceleration of this treatment step is possible by the involvement of catalytic processes. Reaction kinetic is affected positively by a formation of incomplete oxidised hydrated oxides. The hydrated oxides contribute to catalyze the oxidation reaction (equation 1).

$$Mn^{2+} + (x\text{-}1) / 2\ O_2 + 2\ OH^- + zH_2O \rightarrow MnO_x \times zH_2O + H_2O \qquad 1$$

$1 < x \leq 2$

With complete oxidation (x = 2), manganese dioxide MnO_2 is generated, which has no catalytic properties, but can adsorb manganese (II) ions.

The granulate Akdolit® Mn FS represents a manganese dioxide enriched contact filter media which surface accelerates the manganese oxidation and allows short start-up periods even at pH-values in the neutral range. This filter material can be used either in single or multi layer filter units.

The oxidation products (manganese hydrate oxides) are deposited directly on the filter media grain and acts as an adsorbent for dissolved manganese compounds. Due to the high content of manganese dioxide Akdolit® Mn FS grain size 1 (0.4 – 1.25 mm) has a very high capacity of about 700 mg of manganese per liter demanganisation filter media. By filter back washing the precipitation will be finally removed from the filter bed. The back washing velocity should allow adequate bed expansion without a mechanical damage to the catalyst surface. For perfect effectiveness of the filter material a blocking of the catalyst surface by e.g. inert suspended solids or precipitated calcium carbonate has to be avoided. Therefore, the pH value of the calco carbonic equilibrium must not be exceeded.

First experiences with this innovative filter media indicate that the start-up period can be shortened up to less than one month (figure 2) (AWA Institut 2009). The results show high reactions rates combined with an excellent filtrate quality (Fischer *et al.* 2010).

Plant Dörenthe as an example of a modified drinking water treatment concept

The water supply company Tecklenburger Land has to deal with contaminated raw water that contains iron up to 11 mg/L and maximum 0.5 mg/L manganese. Therefore, the treatment line in the plant Dörenthe has to be adapted to face these problematic conditions. In the first step an aeration combined with physical degassing of aggressive carbon dioxide is installed. Afterwards milk of lime and flocculants ($FeCl_3$) are dosed which increase the pH-value and support the settling of the iron and manganese hydroxide in the reaction tank. Next the implementation of a Sepaflex™-plant – a kind of incilined plate settler – provides for continuous separation of iron and manganese hydroxide sludge. In the last step the final purification using single layer filtration systems is realised.

Drinking water test results confirm the properly functioning of the treatment plant. The flocculation process provides the elimination of huge amounts of iron and manganese impurities. Fine tuning requires an additional filtration step so that limits of the German drinking water regulation are met safely (table 2).

Conclusions

Granular fixed bed reactors with back washing facilities which are well known in drinking water treatment are a reasonable alternative in AMD technology. Due to a wide selection of filter media based on various products and grain sizes customized treatment design can be realised. Choosing between single layer and multi layer filtration is an additional design tool. Special granulates with selective surfaces as Akdolit® Mn FS used for manganese removal are able to improve effectiveness and reliability in treatment processes.

Table 2 *Water qualities during the treatment line (AWA Institut 1997)*

Treatment step	Carbon dioxide [mg/l]	Oxygen [mg/l]	Iron [mg/l]	Manganese [mg/l]	Turbidity [NTU]
Raw water (mix of different qualities)	43	2	7	0.3	71
Raw water after aeration	14	9	4	0.3	40
Raw water after flocculant dosage	20	9	19	0.4	92
Raw water after Sepaflex™-plant	14	9	0.8	0.3	1.4
Filtrate after single layer filter = drinking water	16	8	0.04	0.01	0.3
Limits according German drinking water regulation			**0.2**	**0.05**	**1**

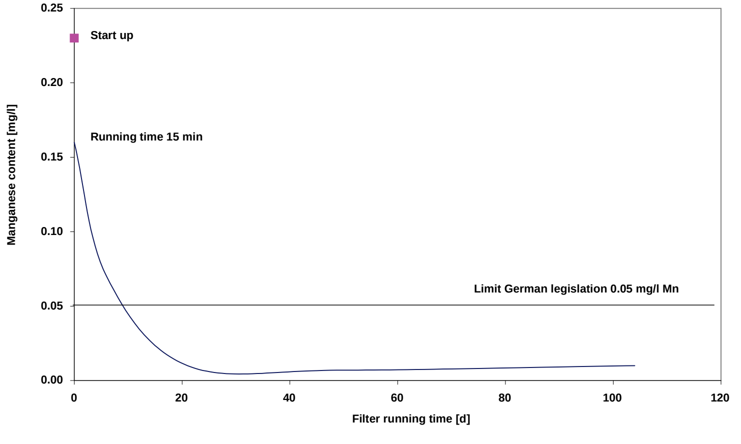

Figure 2 *Results of manganese removal with Akdolit® Mn FS, velocity 9 m/h, dumping height 1400 mm*

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