Biological denitrification of ground water – 8 years full scale experiences with the BIODEN-process

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Abstract In order to offer optimum solutions for each individual case VA TECH WABAG developed a biological as well as a physical process for the nitrate removal from drinking water sources. The BIODEN-process applies heterotrophic denitrification and the ENR-process uses electrodialysis for the selective nitrate separation. Both processes are meanwhile in full-scale application for nearly one decade. The main advantages of the BIODEN-process are the degradation of the pollutant and the high water recovery. The strong points of the ENR-process are the additional hardness removal and the quick availability, so that the plant can be started and stopped on demand. Furthermore the ENR-process shows high nitrate selectivity compared to other physical processes.

Keywords Nitrate removal, drinking water, biological denitrification, biological filtration, dual media filtration, electrodialysis

Introduction

Nitrate as a drinking water pollutant became a problem in the last quarter of the 20th century for many water works especially in western and central Europe (Packham 1991; Packer et al. 1995). Beside sanitation programs and blending strategies, suitable nitrate removal technologies were necessary. In principle there are desalination processes, such as reverse osmosis, ion exchange and electrodialysis as well as biological denitrification processes applicable (Rohmann and Sontheimer 1985). Furthermore the catalytically nitrate degradation should be also mentioned in this respect (Tacke and Vorlop 1991).

Degrading processes, such as autotrophic respectively heterotrophic biological denitrification and catalytic nitrate reduction solve the problem by nitrate destruction (Gimbel at al. 2004). The physical processes separate the nitrate from drinking water. Hence a suitable discharge possibility for the brine stream is required. In the case of ion exchange, excepting the CARIX-process (Hagen 1991), an additional salt load results from the regenerating chemicals.

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The BIODEN-process

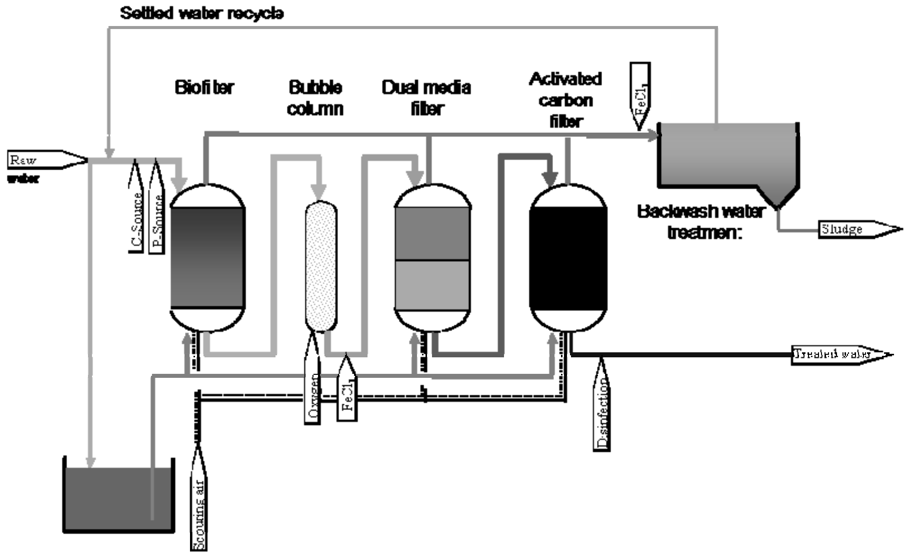

Figure 1 Principal scheme of the BIODEN-process

The BIODEN-process is based on the natural biological denitrification, which takes place in soil and ground water. However, in the BIODEN-process the denitrification is enhanced under controlled conditions in a fixed bed biofilter. In order to meet drinking water requirements, the denitrification process needs an aerobic post-treatment. So the BIODEN-process consists of the following main process steps:

- Substrate dosing
- Denitrifying biofilter
- Aeration
- Flock-filtration
- Polishing filter
- Safety disinfection
- Backwash system and backwash water recycling

As substrate a carbon and phosphate source are dosed into the raw water. Normally all other nutrients are normally sufficiently present in the raw water.

The nitrate degradation is based on the heterotrophic biological denitrification. This process takes place in a pressurised fixed bed biofilter. The choice of granulation of the biofilter material observes the optimum between biomass retention and built-up of filter headloss.

In the aeration, the denitrified water is saturated with oxygen. Thus aerobic activities in the flock-filters and polishing filters are supported and the final drinking water has sufficient oxygen content.

In the flock-filtration the low turbidity, caused by a minor biomass washout is removed by flocculation and dual media filtration.

Any accidentally occurring residual substrate is aerobically degraded in the dual media filters and / or subsequent polishing filters.

The last stage of the treatment train is a safety disinfection. However, long term experiences of the full scale plant showed, that the treated water already fulfilled drinking water standards only after the polishing filters.

Biofilters, dual media filters and polishing filters are regenerated by means of backwashing. The used backwash water is collected and recycled after clarification. Excessive biomass and particles from flock-filtration are removed as a concentrated liquid or even dewatered sludge.

The BIODEN-process has several strong points. As a main point the degradation of the pollutant shall be mentioned. The fixed bed biofilter has an excellent retention for the denitrifying biomass. Hence the loading of the subsequent aerobic post-treatment is low. The backwash water of the filters is clarified by simple sedimentation. As the clarified water contains only the denitrifying biocenosis it is directly recycled to the plant inlet. Thus a water recovery of practically 100% is accomplished. The technology is based on standard filtration processes and does not need any special equipment. Compared to other nitrate removal technologies, the BIODEN-process is very cost effective.

The only probable disadvantage is the necessity of continuous operation in order to maintain the biological activity. However, performance increase needs only short time, as long as the biological activity is maintained at a minimum level.

The BIODEN-process was developed and tested in a two year pilot test trail (Lahnsteiner and Hell 1993).

Results

The BIODEN-Plant Obersiebenbrunn

The first full scale plant with a capacity of 180 m^3/h was started up in Austria in 1997. This plant is now running for 8 years with excellent results. The plant consists of two parallel lines. Each line is equipped with substrate dosing, biofilter, bubble column for aeration, flock-filtration and polishing filters. Ethanol is dosed as carbon source and diluted phosphoric acid is added as phosphate source. The plant is operated continuously at nominal capacity. The treated water is blended with untreated water from other wells of the same well field. When the drinking water demand is low, the treated water is infiltrated into the catchment area of the un-treated wells. The substrate dosing is controlled in order to reach an average nitrate value of 5 mg/l in the denitrified water. In the case, that slightly elevated concentrations of nitrite and / or organic matter could be detected in the effluent of the biofilter, these substances were always safely degraded in the dual media filter. The colony count in the effluent of the biofilter already falls below 1000 cfu/ml. After dual media filters and polishing filters, the colony count is fare below 100 cfu/ml, in the most cases below 10 cfu/ml.

The backwash water from all filters is collected and clarified in two parallel settling basins. The clear water is recycled to the plant inlet. The concentrated sludge is discharged into the local sewage treatment plant. The sludge discharge lies below the guaranteed value of 25 m³/d. Hence the water recovery is greater than 99 %.

During start-up of the plant special attention was drawn to the optimisation of the flock filtration. As turbidity is rather low, the iron concentration was utilised for assessment of the filter ripening. Figure 2 shows an iron peak after backwash of a dual media filter.

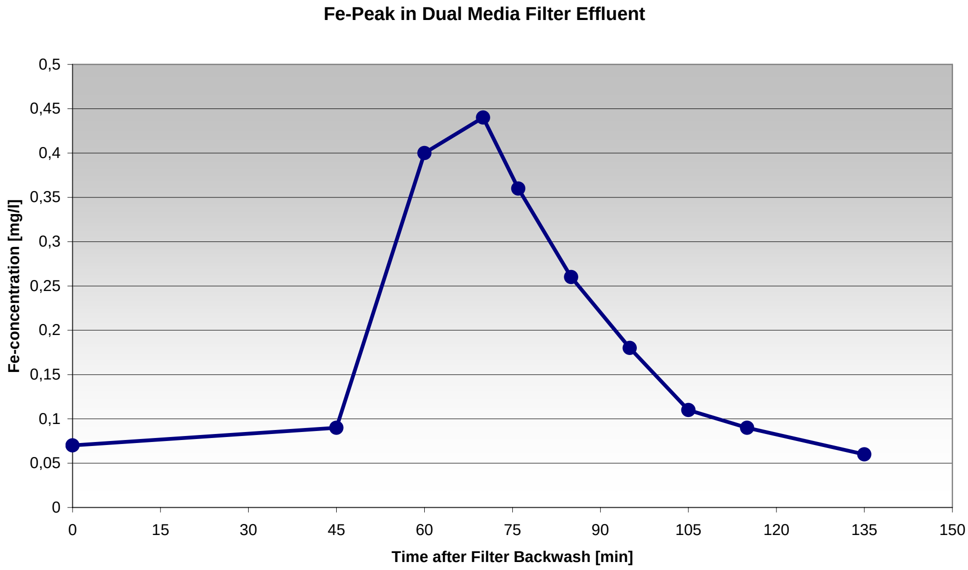

Figure 2 Iron peak after backwash of dual media filter

The maximum iron concentration appears more than one hour after filter restart. For that reason product discharge after filter restart was not applied. However, that iron peak was markedly buffered by the subsequent polishing filter and the iron peak maxima decreased in the following month of operation.

The average annual production rate during the last four years was 1 381 000 m³/a. Based on annual costs the following specific expenditures were calculated.

- Chemicals 0.026 €/m³
- Electric power 0.015 €/m³
- Wastewater disposal 0.013 €/m³
- Spare parts 0.005 €/m³
- Service costs 0.005 €/m³

Hence the operating costs except manpower amounts to 0.064 €/m³. The expenditure of time
is about 22 to 25 hours per week.

Other BIODEN-references

Two treatment plants in Italy are also based on the BIODEN-process. One demonstration plant with a capacity of 50 m³/h was also started up in 1997 and one 540 m³/h plant was started up in 2004. These two plants are operated with acetic acid as carbon source.

Deviating from the BIODEN-process these plants are not equipped with activated carbon filters and backwash water is not recycled. The 540 m³/h plant consists of three lines. The lines were started up one by one. For the first line full nitrate degradation was accomplished approximately 1 week after start-up. The raw water nitrate concentration was 80 mg/l. The design concentration was 100 mg/l. The treated water nitrate concentration is adjusted to 5 mg/l. After optimisation of substrate dosing and backwash procedure, the plant is running satisfyingly at full capacity.

A 500 m³/h BIODEN-plant is started up in January 2006 in Czestochowa (Poland). This plant consists of 3 lines of biofilters, bubble columns, flock-filtration, polishing filters and backwash- and sludge-treatment. The capacity of each line is 50% of the nominal plant capacity. Hence the effective capacity would be 750 m³/h. As there is no sewer connection available, the special requirement of the Czestochowa plant was 100% water recovery. For that reason the plant is also equipped with a sludge dewatering unit.

The ENR-process

Description of the ENR-process

The principle of electrodialysis involves the removal of ionic components from aqueous solutions through ion exchange membranes using the driving force of an electric field. The water to be treated is pumped through a membrane stack, which consists of alternately placed anionic and cationic selective membranes. Separated by gasket frames and spacers, the membranes are fixed between two end plates, which contain the electrodes producing the electric field. In order to transfer the electric current and to remove gases produced by the electrode reactions, the electrode chambers are rinsed with an electrolyte solution. In the compartments of the membrane stack, the ion content is diluted or concentrated according to the ion penetration through the membranes (see Figure 3). Identical compartments are connected by a distributing and collecting system. Thus the raw water is separated into a diluate and a brine stream. Both streams flow at the same velocity through the membrane stack. As a rule the water to be diluted passes the membrane stack once whereas the brine stream is recycled. The brine concentration is adjusted by means of dilution with raw water. Thus the brine stream is operated in a feed and bleed mode.

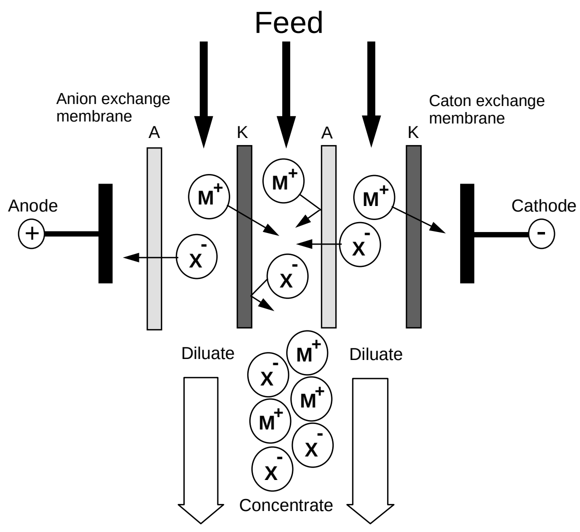

Figure 3

The electrodialysis principle

The degree of desalination is determined by the ion content of the raw water, the applied stack voltage, the type of membranes, the geometry of the membrane stack and the cross-flow velocity.

The application of monovalent selective anion exchange membranes results in an excellent nitrate selectivity (Mizutani 1990). Thus the brine quality and water recovery is much better compared to reverse osmosis (Rautenbach et al. 1986).

The ENR-plant Kleylehof

The ENR-plant Kleylehof is designed for a hydraulic capacity of 40 l/s (144 m³/h) with three hydraulic stages and a maximum of 160 mg NO_3/l in the raw water. The guaranteed value for the treated water, in the case of maximum nitrate concentration in the raw water, is less than 50 mg NO_3/l. The special requirement for this plant was seasonal operation. The plant is remote controlled and works fully automatically. The plant was started up 1997 (Hell and Lahnsteiner 2002).

The main components of the plant are:

- Raw water intake
- Electrodialysis unit
- Disinfection unit
- Brine loop
- Electrode rinsing loop
- Concentrate discharge
- Dosing station

The raw water is abstracted from a well and pre-filtered with bag filters. According to the water demand, one, two or three hydraulic stages are selected by the remote control. The PLC controls the corresponding flow rate and distributes the raw water to one, two or three electrodialysis stacks.

The stacks are equipped with standard cation exchange membranes and monovalent selective anion exchange membranes. Each stack is allocated to one rectifier. The voltage of the rectifiers is manually adjusted according to the raw water conductivity and the requested nitrate content in the treated water. The polarity of the stacks is changed on a regular time basis by the PLC.

The effluent on the diluate side of the electrodialysis stacks passes an UV-disinfection unit. The quality of the product is checked by means of conductivity measurement. The treated water is recycled to the well, if a maximum value is exceeded. The product water flows into a buffer tank. From there the water is pumped into the distribution system.

The quality of the brine is controlled by means of conductivity measurement. According to the requested conductivity, the brine loop is replenished with raw water. The circulation tank overflow is connected to the circulation tank of the electrode rinsing loop. Thus the concentrate serves as the electrolyte solution for rinsing of the electrodes. The brine effluent of the electrode rinsing loop flows into a buffer tank. From this buffer tank the brine is pumped into a storage pond.

Normally the electrodialysis stacks are cleaned automatically with a hydrochloric acid solution once a month.

In the first three years, the plant was only operated from May to October. During winter, the plant was mothballed. Later on this concept was changed. During seasons, where the water demand is low, the treatment plant is only shortly operated from time to time. Thus stagnation of the water is avoided and the plant is available at all times.

Results of the Kleylehof plant

When the plant was started the nitrate content in the raw water was 120 mg NO_3/l. A maximum Nitrate removal of approximately 100 mg NO_3/l was achievable. However, the stack voltage was adjusted to a nitrate removal down to 40 mg NO_3/l. In proportion to the nitrate removal, the hardness of the drinking water was reduced by approximately 23%. Table 1 shows an analysis for the raw water, product water and brine.

Table 1 Results of the Kleylehof ENR Plant

Parameter	Unit	Raw water	Product	Brine
pH-value	-	7.4	7.5	7.6
Conductivity	µS/cm	850	640	2820
TDS	mg/l	704	550	2387
Total hardness	meq/l	9.04	6.97	31.86
Alkalinity	meq/l	4.21	3.97	8.51
Langelier index	-	0.0	0.0	1.0
Calcium	mg Ca/l	115	85	433
Magnesium	mg Mg/l	40	33	124
Sodium	mg Na/l	11	11	15
Potassium	mg K/l	2.6	2.5	4.6
Chloride	mg Cl/l	45	25	270
Bicarbonate	mg HCO_3/l	257	242	519
Sulphate	mg SO_4/l	113	110	132
Nitrate	**mg NO_3/l**	**120**	**41**	**889**

Water quality is also sufficient from hygienic view point. The colony count of the raw water and the treated water was zero.

The regular plant service is done after the winter season. The necessary membrane change was always below the guaranteed value of 10% per annum. Also the lifetime of the electrodes is much higher than expected.

The desalination performance is constant and no decrease in plant performance could be detected.

There are two possibilities for brine discharge. Both, blending with irrigation water and discharge into the local sewage treatment plant, proved to be suitable.

Comparison between BIODEN and ENR-process

Both processes have their strong points, so that the choice between the two processes depends on the particular circumstances of each individual case. The main advantages of the BIODEN-process are the degradation of the pollutant, the almost full water recovery and the biological stabilisation of the water – due to the bioactive filters all biodegradable substances are degraded. Due to the nearly complete nitrate degradation, it is only necessary to treat a part stream of the raw water with blending afterwards. On the other hand, biological processes require constant operation and some ripening time in case of marked changes in the operational point.

The strong points of the ENR-process are the possibility to change the operational points rapidly, the additional removal of hardness, the selective nitrate removal and the high brine quality. Unfortunately electrodialysis is not as wide spread as reverse osmosis, therefore membrane prices did not decrease as for reverse osmosis.

Investment costs are nearly the same for BIODEN- and ENR-process. Costs for electromechanical equipment are lower for the biological treatment. However the space requirement for electrodialysis is much lower. The effort for supervision is approximately the same for both processes. Whereas, due to costs for membrane replacement and brine discharge, total operating costs are normally higher for the ENR-process.

Conclusions

After more than eight years of operational experiences it can be concluded, that both the BIODEN- and the ENR-process are very stable processes and highly suitable for waterworks operation. The operational effort is in a reasonable range. The decision for biological or physical treatment requires proper assessment of the circumstances of each individual case. As a rule of thumb ENR is mainly suitable for small scale waterworks and applications, which require quick changes in operation such as stop and go operation. BIODEN is mainly suitable for medium and large sized waterworks and relatively constant operation.

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