“If you want to reach the source, you have to swim against the stream.”
Unknown

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The application of biological filtering

Key words: bank filtering, biological filtering, dimensional analysis, wastewater treatment

Content summary

The processes of water supply (water production and water distribution) and canalization (wastewater disposal and wastewater treatment) may be compared along system technical considerations. Regarding canalization subprocesses there is no feedback, however, in the case of water supply this does exist. When providing the missing link, wastewater utilisation has to be spoken about in the future. Starting from this, the necessity of paradigm change may be deduced related to the activity in the wastewater branch. In order to maximize biogas yield, modifications in the widest possible sense are needed thus replacement of activated sludge technology also emerges. The possibility of taking this step was provided in relation to modelling bank filtering.

By the help of the new approach the insufficiencies of presently predominant procedures may be highlighted, and the issue of the possible dimensioning of biological spaces based not only on experience may be outlined. By means of system technical considerations a more efficient water treatment technology may be reached.

1 System technical considerations

1.1 The establishment of wastewater disposal

The branch of canalization consists of wastewater disposal and wastewater treatment. The establishment of the systems spans decades and centuries. In densely populated settlements, the establishment of canal networks was started due to the drainage of internal water and prevention of epidemics. The end point of rainwater drainage and wastewater disposal is the receiving river (Figure 1-1/A). The only aim of the constructed canals was to drain water.

The construction of multi-storey blocks of flats resulted in the general spreading of flush toilets. For the disposal of communal wastewater no separate network was established, drain connections were made to the existing canals (Figure 1-1/B). The end point of the so established unified canal network still remained the river, despite the fact that water pollution significantly increased.

A considerable decrease in the self-purification capacity of rivers raised the necessity of purifying wastewaters, as a result of which wastewater treatment plants were established (Figure 1-1/C).

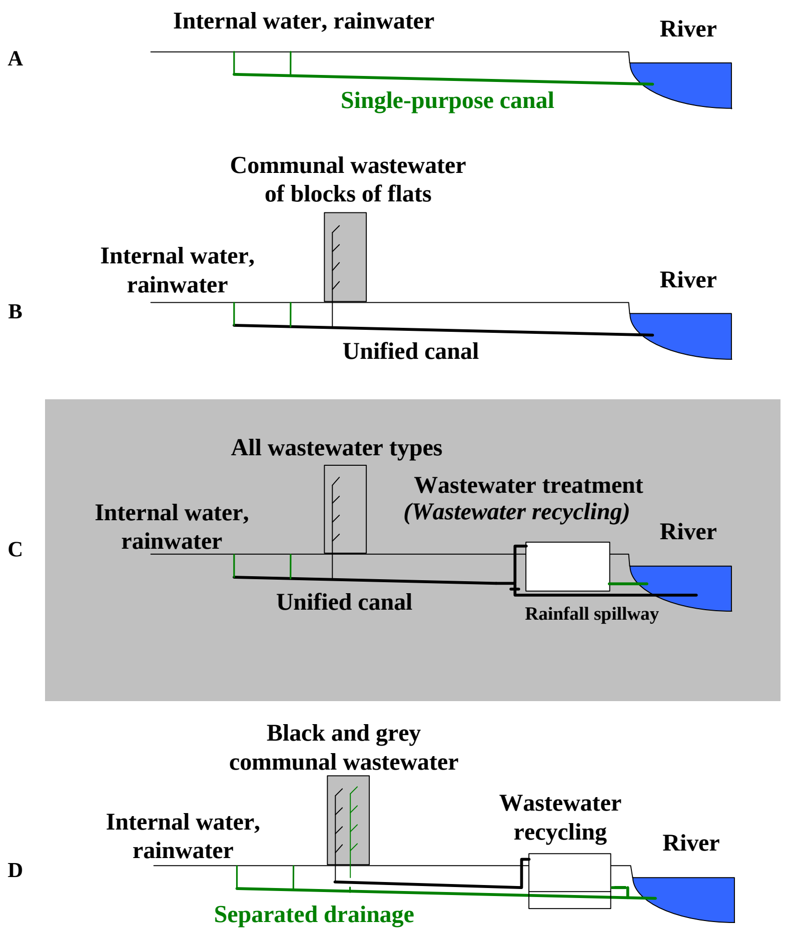


Figure 1-1 The development of wastewater disposal and wastewater treatment

The capacities of wastewater treatment plants are determined based on the volume of wastewater arriving at the plant. In order to decrease dimensions, the idea of establishing a separated canal system was raised. Separate collection of rainwater and communal wastewater means different end points. Rainwater would have got directly into the river without purification, whereas communal wastewater would have gone to the plant. The high costs of establishing a dual-network strongly hindered and hinders today as well the spreading of separated canals. However, for rational reasons wastewater plants are not dimensioned for peak loading. Drainage of rainfall loading happens through a spillway. At this time a part of wastewater diluted by rainwater gets into the river without purification. This solution could not be objectionable from the aspect of environment protection as rainfall peaks occur in an insignificant percentage of the yearly number of hours. The loading of living water is far within its self-purification capacity.

The fee of water public utility service was far below its prime costs before the change of the economic system. This fact led to wasting water but a more serious consequence was that capacities were established according to this as well. Following the change of the economic system the price of water became a market price, which led to the decrease of water consumption thus to reduced water volume appearing in the canals. The appearance of tax contents realized in the price, directly not serving water public utility service resulted in an even more significant extent of decrease, which reached 40-60%. Due to this, dwell time increased on the canal system side, which resulted in an intensive odour effect of the canals. The canal system works as a biological reactor. Low water volume also promotes dry substance sedimentation. In the case of a rainfall, the increased water volume washes out the canal system thus the water let out through the spillway does not belong to the category of diluted wastewater, but to the category of wash-water with highly concentrated pollution. Contrary to the dimensioning effort determining the capacity of the wastewater plant, the realized environmental loading may not be considered moderate. The incorrectly interpreted water price policy relies on the self-purification capacity of nature.

Water supply again and again raises the dilemma of putting drinking water or pure water into the network. In the Western value system only network water of drinking water quality may be accepted despite the fact that internal use of water only accounts for an insignificant proportion of total water use. The Asian approach is more permissive or more economical and only demands pure water for network water quality. It says internal use always has to happen after boiling. The dilemma to face is similar in the case of wastewater as well. Separation of wastewaters by quality runs into considerable infrastructural thus financial difficulties. The separation of rainwater and wastewater was brought up by the requirement for a reasonable dimensioning of the wastewater plant. Contrary to the effort for separation, the emphasis is on the purification of wastewater.

According to another concept, separation is reasonable in respect of the so called grey and black wastewaters, which starts from the demand for **wastewater recycling**.

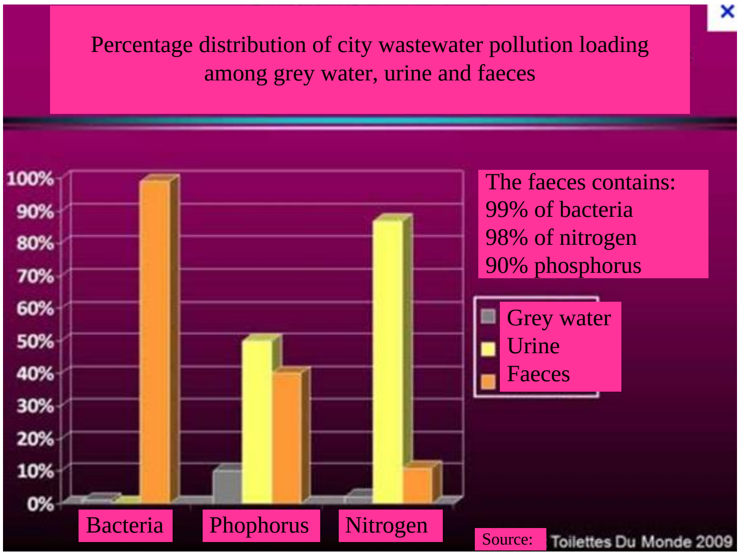


Figure 1-2 Parameters of grey and black wastewater

The category of grey wastewater means that it does not contain the faeces portion that is produced by the use of flush toilets. The latter is also called black wastewater. Grey wastewater only contains 1/9 of the pollution of black wastewater thus its purification only needs some treatment. However, the grey to black wastewater volume ratio has a reverse trend, black wastewater represents slightly more than 10%. Faeces-free grey wastewater is defined by the no. 12056-1 European Standard as *slightly dirty* wastewater.

Starting from the separation of either *rainwater – communal wastewater,* or *grey – black wastewater*, the establishment of a dual-network would be needed. The extremely high costs of establishment, as well as the already established century old canal systems classify subsequent separation into the category of utopia (Figure 1-1/D). The wastewater collected in the unified network has to be counted with as reality. As for regulation, the only issue to be raised is that industrial wastewaters should not appear in the canal network as their efficient purification can be solved and should be solved rather locally as the materials getting into the water during the technology are precisely known. In this case only the combination of communal wastewater produced as a mixture of grey and black water and rainwater appears in the canal network.

However, the wastewater arriving at the plant in the new approach is not considered as wastewater but as raw material from which valuable materials may be recovered. This also raises the issue that the principle of “the party causing pollution has to pay” is not sustainable due to the simple reason that the communal consumer using canal network service is not the party causing pollution but a basic material supplier. Water as medium plays a logistic role which is used up during the execution of the task. It dissolves a certain quantity of the carried material. Following the separation of the recoverable materials, disposal of the remaining pollution is a pre-requisite of admission into living water.

The spirit of this new approach also needs changing water public utility terminology.

1.2 Terminological interpretations

It is widely known that by following the course of water, both branches consist of two clearly separable processes. In the case of water supply water production is followed by water distribution, and the subprocesses of canalization: wastewater disposal and wastewater treatment. In addition to this, water supply has a very live feedback, according to which the quality of supplied water has to be guaranteed on the water distribution side, but this may only be influenced in merit on the water production side. Feedback is implemented through water quality.

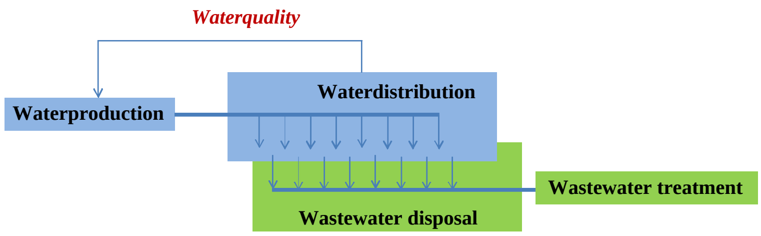


Figure 1-3 The missing feedback

Canalization is not such a process. Wastewater disposal collects the produced wastewaters and allows them to arrive at the wastewater plant. Then the wastewater treatment process tries to purify water according to the prescribed limit values. Between these two subprocesses there is no feedback in the sense as it is in the case of water supply.

If the missing feedback is provided, the orientation of the task in the plant is changed. The supplementation is only possible if the concept of wastewater treatment is replaced by **wastewater recycling**.

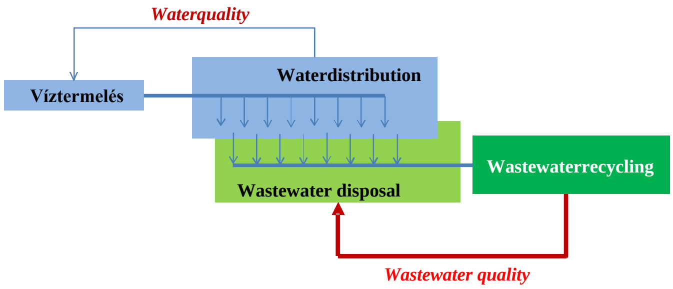


Figure 1-4 Providing the missing feedback

If this paradigm change is implemented, the quality of the wastewater arriving at the plant does make a difference. Wastewater disposal receives an objective function. It is important that it should not be the canal system that works as a biological reactor, and the energy content of wastewater should not be wasted there but the organic material and the medium carrying it should reach the plant as soon as possible.

At this point wastewater energy content should be focussed instead of wastewater loading. The aim is utilisation and recovering the most possible energy. This change of approach needs giving up the previous practice.

1.3 Where is the point of intervention?

The paradigm change does not keep the scope of wastewater treatment, or wastewater utilisation as referred to in the new technology within the wastewater plant, but manages it at system level. Accordingly, it also searches the group of possible interventions in the field of wastewater disposal.

It does not mean relocation of the main points in the activity chain but radical alterations of activities in the given field.

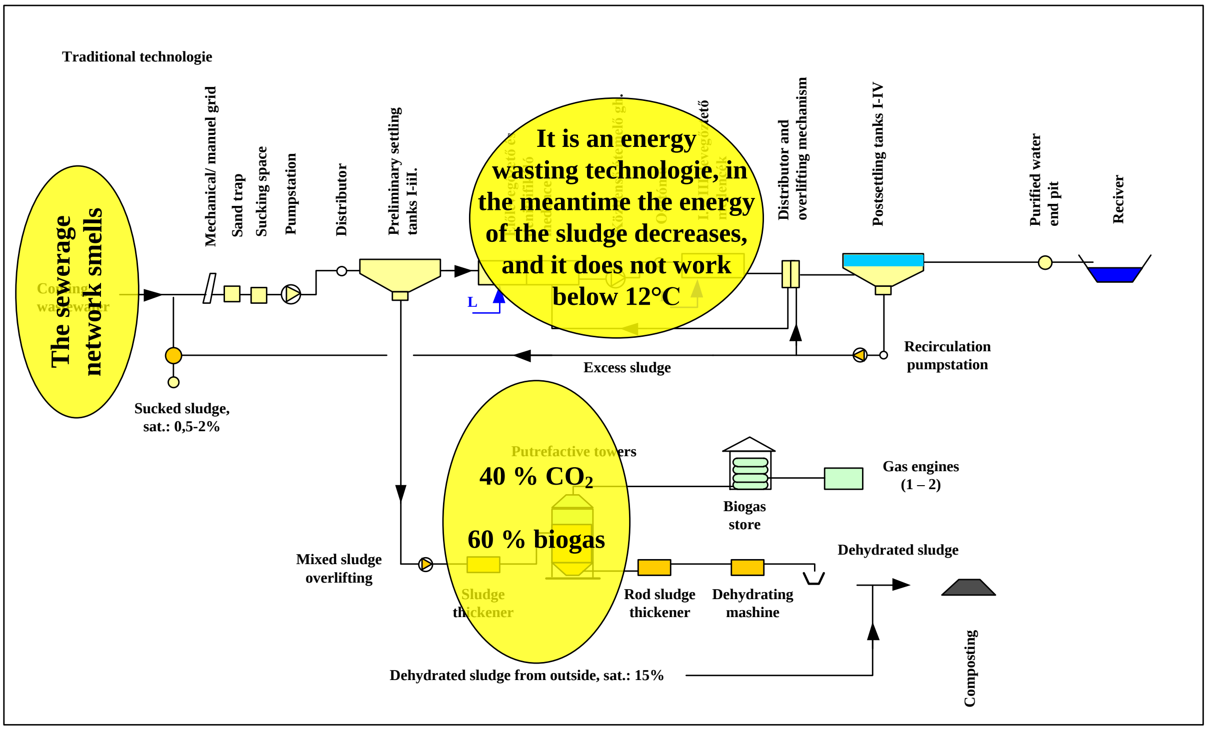


Figure 1-5 Intervention possibilities

Figure 2-2 shows a traditional (activated sludge) technological line, in which the places are indicated where changes in merit in the sense of the above written are needed.

1.3.1 Objective function of wastewater disposal

Regarding the so far wait-and-see canal network operation policy, in the future wastewater should be expected to lose as little energy content as possible along its course, i.e. dwell time in the network should be as short as possible. The objective function described in this form exposes a task on both the designer and operator. When establishing new canals, the designer has to reconsider slopes, and the method of arrangements, whereas the operator has tasks in relation to harmonising the operation of pumping machine houses.

However, price authority also has a lot to do. When determining the fees, the operation method, more precisely the operability of wastewater disposal "based on wet logistics" has to be taken into consideration. The *water closet* works with water. And in a system thus established the presence of sufficient water volume is a pre-requisite. If it is missing, dwell time increases, the odour effect of canals will be strong, due to which recoverable energy may only be less. The volume of water appearing in the canal system may be most influenced through fees. In the last period the increase of fees – also through charging with taxes – led to a significant decrease in water consumption. The rate of decrease exceeds 50%. The not properly considered method of increasing water and drainage fees thus may have a negative technological effect.

1.3.2 The utilisation of sludge

1.3.2.1 Producing biogas and composting the remaining proportion

By means of rotting, biogas may be obtained from sludge. The maximization of biogas yield requires that the whole amount of sludge should undergo rotting after pre-sedimentation. This also means that a water purification technology is required that does not use sludge in its operation.

After a proper preparation sludge gets into the so called rotting towers. Rotting happens among anaerob conditions, and during this biogas (a mixture of methane and carbon dioxide) is produced, and wet sludge deprived of its energy is left in its solid state. Due to its high (approximately 40%) carbon dioxide content, biogas has to be purified by means of a rather expensive method.

The question has to be raised: is it cheaper to prevent carbon dioxide from getting into than to extract it? The main point of sludge preparation is dehydration. The shaking tables and presses execute sludge thickening by a physical principle. However, neither shaking nor pressing happens by excluding air. Consequently, the thickened sludge during these operations absorbs a considerable amount of oxygen, which then deteriorates anaerob conditions in the rotting tower thus promoting the increase in the carbon dioxide content of biogas.

Probably the carbon dioxide content of biogas cannot be totally eliminated, however, content may be decreased, and the prevention of its getting into or appearing surely needs lower investments than subsequent removal.

Rotting towers have to be heated, which is a condition for operation, in addition to this sludge content has to be mixed on a continuous basis. Waste heat of gas engines can also be used for heating. However, the heat quantity that is several times unnecessarily produced during energy production can also be applied for drying the sludge to be composted. The often used solar drying seems to be cheap, however, it is less intensive.

1.3.2.2 Composting the whole sludge amount

There are some opinions according to which biogas production is not the method of utilising sludge. These state that the whole sludge amount has to be composted. Using the compost in agriculture is a fundamental interest of mankind as thus soil erosion can be prevented and the food producing capacity of the Earth can be preserved [3].

This idea raised the necessity of separating grey (soaped) and black (faecal) wastewater and gives sense to it. Grey wastewater practically only has to be treated, the purification of black wastewater is not grounded in this approach as now the aim is to maximize the compost amount.

In big cities the subsequent separation of grey and black wastewaters could only be implemented with great investments. As a remaining option, this may be corrected in the wastewater plant to the extent that from the preliminary clarifier the whole sludge amount is directed to the sludge line. Thus the whole sludge amount is totally composted. The remaining water used up during the logistic process (*used water*) is purified. This water only contains solute pollution.

1.3.2.3 Burning of the sludge

Some are against composting of the sludge. In the case of city wastewaters collected through unified system canals, the quality of admitted wastewaters is not sufficiently checked. The incoming water may contain heavy metals, spent oil, etc. Therefore composting then disposing in arable lands is excluded as agricultural lands would become contaminated this way. Therefore they say burning the sludge to be a better alternative as it also happens to grid waste as well.

Naturally, this opinion is based on reality, and at this point the opinion saying "*it is not the quality of wastewater that is important but that it should be paid for"* becomes unacceptable. The tasks of authority may be designated here for the protection of nature. The water quality of admissions has to be checked by the Environmental Protection Authority the same way as it is done by the National Public Health and Medical Officer Service.

1.3.3 Purifying the used water

Following presedimentation water may be considered pure from the aspect of filterability. Two presedimentation stages could be applied however, it is not needed. Substances to be removed may only be found in a dissolved state in the water coming from the preliminary settling tank. The situation is totally similar to bank filtering. From a molecular aspect, the water of Danube contains the same elements as wastewater. Let us think of the case when wastewater gets into living water in an unpurified state. The only difference is the extent of dilution, and concentration.

The question is whether water can be purified by biological filtering or not.

The criterion of **wastewater utilisation** according to which energy output should be the maximum may be met if no sludge is used to water purification. In the pools with oxic-anoxic operation of traditional wastewater treatment the energy content of sludge necessarily decreases, thus reducing the extent of biogas output.

> *(Remark: In the covered Budapest Wastewater Treatment Plant, oxic/anoxic spaces are explosion hazardous spaces therefore they are closed by glass wall. Entry is only allowed with the use of protective tools.)*

The degradation of nutrients needs a lot of air, whose method of introduction is not indifferent. Plate deep-aerators have such a great pressure demand because air is led to them in a very disadvantageous method, and it has to be made to get through activated sludge of high viscosity. The operation of blowers consumes lots of energy. Following pre-sedimentation, in the case of filterable pure water it is possible to replace blowers with fans.

Below this issue will be analysed by means of using the technique of comparison. From this point on, general water treatment has to be discussed, and there is no point in separating **drinking water purification and wastewater purification**.

The quality of water to be purified deserves a more shaded interpretation. The point to be discussed is what is to be removed from water. As it will be illustrated later, here the diffusion coefficient of organic materials will be decisive. How much is a question of totally different nature. The concentration measuring quantity (TOC, BDOC, COD, BOD_5) is generally considered identical with water quality. Later this should be rather considered **loading** in relation to water purification, and **the extent of the recoverable energy content** in relation to the incoming wastewater.

2 Biological filtering

2.1 Features of bank filtering

Actually, the former co-existence of GDR and GFR can be considered as an experiment as well to demonstrate the viability of socialism and capitalism. In this test the main point was that the two states were established almost at the same time after the war thus by comparing their momentary developments it was possible to measure the difference between the two ways of development.

In the history of the Waterworks of Budapest there was also such a parallel, an experiment which went on for a round 25 years. The comparison of the since then already stopped on-surface water treatment plant and bank filtering allowed this.

The water obtained from the wells became pure in a **natural** method, by means of bank filtering.

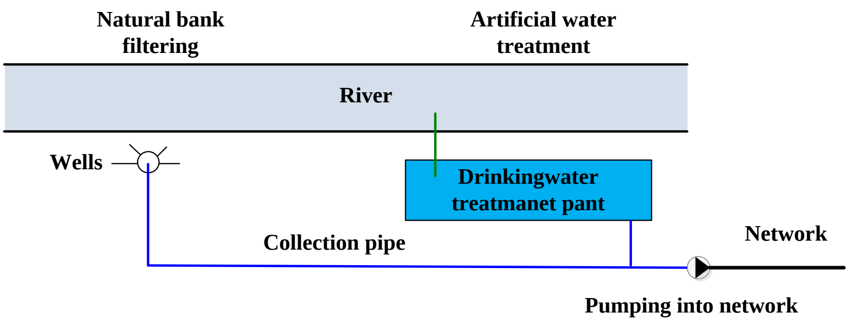


Figure 2-1 The experiment

In the on-surface water plant **artificial** technology was applied. The most important common feature of totally different water purification methods is that both work from the water of the same quality, i.e. the same raw water may be found at the inputs of both procedures. Nevertheless, the quality of water produced by the artificial technological line constituted by flocculation, clarification, and rapid filtering was by grades worse than well water. In order to guarantee the microbiological water quality prescribed in the standard, artificial water purification needed considerable chlorine dosing, whereas in the case of bank filtered water, chlorination to a small extent for safety purposes already proved to be sufficient.

Regarding its benefiting services, Danube is also a wastewater receiver thus the elements contained in wastewater appear in it as well in a molecular sense. Budapest led its wastewater into the Danube for long years without purification. The wells operating along the river section under the city – the wells of Csepel Island – had to treat wastewater, not from the aspect of loading but regarding the molecules contained in the water. Along the bank section with well constructions there is no chemical dosing, no UV light fittings, and no activated sludge recirculation, still water gets purified. What is more, much better than it happens in the case of artificial technologies. Thus getting familiar with and applying the techniques of bank filtering means a reasonable effort.

The effect mechanism of bank filtering may be understood by the help of modelling. By using the technique of dimensional analysis, the relationship describing the process was deducible [1]. Let us summarize the most important statements:

Bank filtering is biological filtering and based on the degradation of nutrients contained in water. According to the generally accepted concept, nutrient degradation has the following schematic diagram:

dissolved O_2 + organic matter → Microorganisms → CO_2 + biological growth

Figure 2-2 Schematic diagram of the biochemical process

The biochemical process requiring the presence of oxygen and participation of microorganisms happens in the biofilm. The end product is biological growth and carbon dioxide. The role of the biofilm has key importance, and it is a dynamic formation regarding its construction. Its attachment needs a **solid surface**.

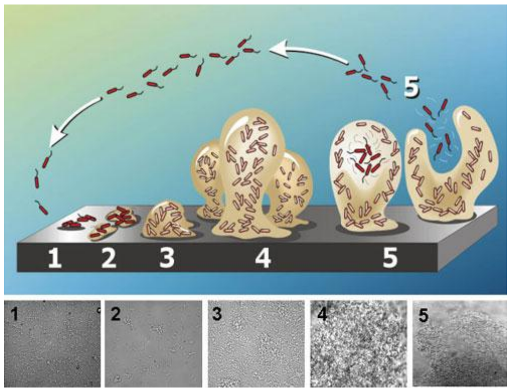


Figure 2-3 Dynamism of the biofilm

In the case of bank filtering, this solid surface is constituted by the sand grains of the filtering layer. The continuous biofilm forming on the filtering layer is standing, and in relation to this the infiltrating liquid is moving.

For the occurrence of pulsation characterized by *attachment-growth-dispersal*, however, pre-requisites are needed. Microbes are fixed to a place. Therefore so that nutrient degradation may be implemented inside the biofilm, nutrients have to be transported there and have to be made to get in. The operation of this logistic task is best illustrated in the flow diagram.

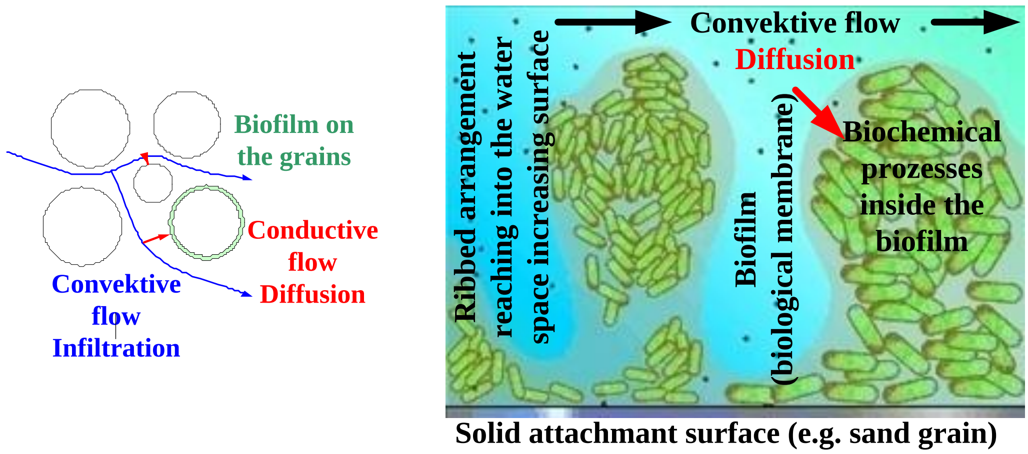


Figure 2-4 Flow diagram and the steps of the process

Nutrients dissolved in water are delivered in two steps:

- on the one hand in a convective method, by means of infiltration,
- on the other hand in a conductive form, by means of diffusion.

Both infiltration and diffusion are slow processes. Convective flow is maintained by the depression generated in the well, and is produced to the effect of pressure difference. (This means bank filtering is not present by itself, but generated and maintained by us by means of pumping.)

The driving force of diffusion is concentration difference, which occurs between the spaces outside and inside the biofilm. Nutrients get into the biofilm, get degraded there by the participation of bacteria, and following this they already represent the concentration of another material, thus reproducing the concentration difference. If degradation does not happen inside the biofilm, the driving force of diffusion also disappears.

Grain size also plays an important role in the nutrient degradation process, more precisely in its extent. In the case of smaller-sized grains the diffusion route length is shorter, which is favourable regarding the accomplishment of diffusion. In addition to this, smaller grains represent a greater surface in a given space part, thus more microbes may be made to act on the greater surface.

It is also very important to observe that biological nutrient degradation consists of subsequent steps, or it may also be referred to as a **serial** process. The convective substance flow (infiltration) is followed by the conductive flow (diffusion) in sequence. The biochemical degradation inside the biofilm only becomes possible after the logistic steps are implemented. If any step is damaged in the sequence, the efficiency of the process decreases.

The disattachment of the biofilm is a consequence of the dispersal, which may cause the blockage of the filtering layer. Floods happening at regular intervals cyclically rinse the filtering layer of the bank section, thus also regenerating it.

In accordance with our observations so far, it is worth outlining the arrangement of bank filtering. The conditions are best characterized by the cross section figure:

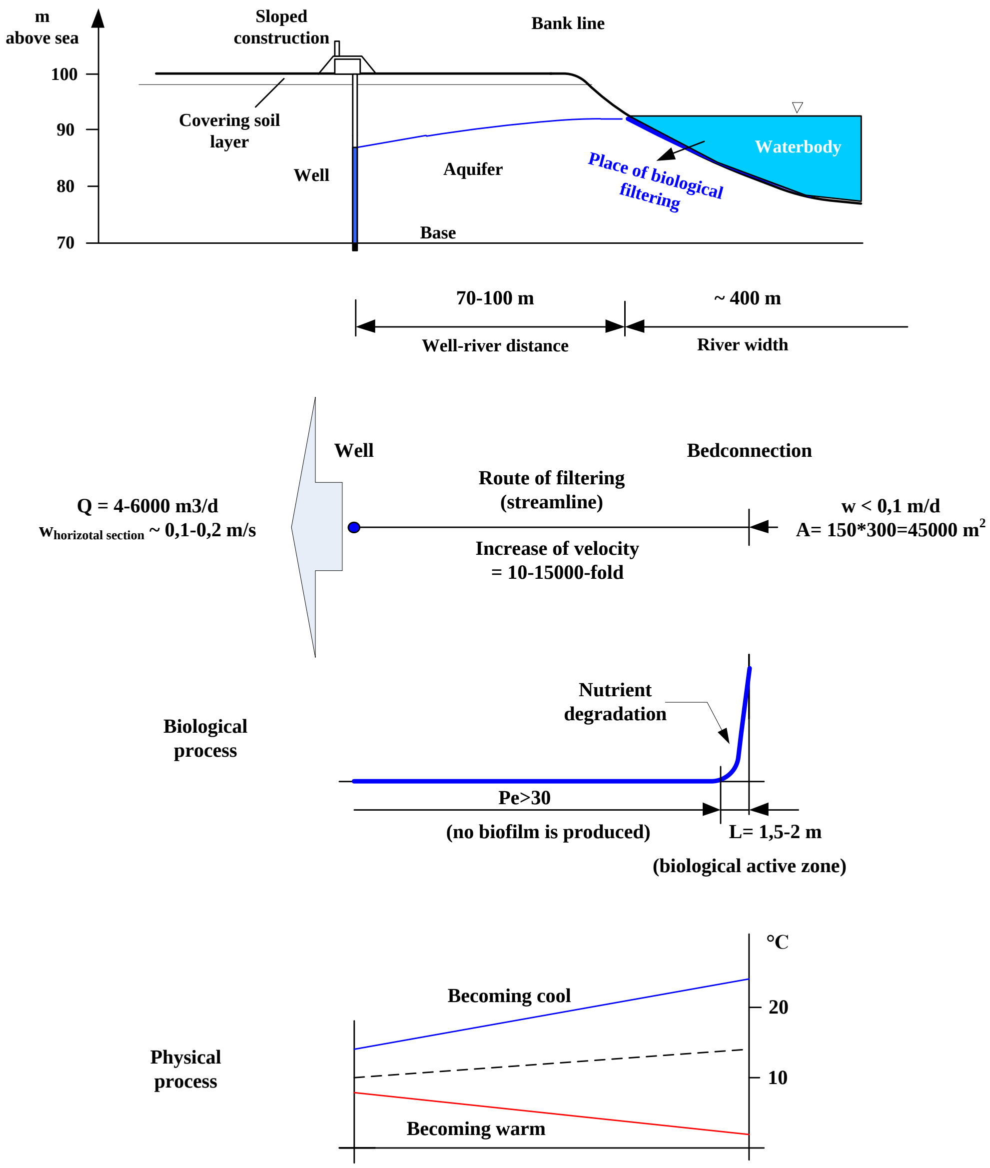


Figure 2-5 Conditions of bank filtering

Based on Figure 2-5 the following statements may be made:

- Bank filtering is a filtering of varying speed. Along the route of filtering, the extent of speed increase may reach even a 15,000-fold extent.
- Filtering speed is the lowest in the bed connection layer, its value is lower than 0.1 m/d.
- The biologically active layer forms at the bed connection, and its thickness is estimated in special literature [12] 0.5-1.5 m.

- Nutrient degradation may decrease or stop for four reasons:
    - if oxygen runs out (no more supply in the layer)
    - if nutrients run out (no more substance to degrade)
    - if filtering speed increases by such an extent that nutrients pass by in front of the biofilm, not leaving time for slow diffusion (the logistic pre-requisite is not met)
    - if "climatic" conditions are not given (ph and rH wet environmental values are unfavourable)
- The part of the filtering layer outside the biologically active zone does not take part in filtering, it primarily plays a role in heat budget; the freshness of water in summer and the warmer temperature of water in winter are due to this.
- In modelling the process the so called Pe-number (Peclet) plays an important role:

$$\mathbf{Pe} = \frac{{}^{\textit{operational parameter}}\,\mathbf{w}\,\mathbf{d}\,{}^{\textit{feature of filtering layer}}}{\mathbf{D_S}\ {}_{\textit{characteristic of purified water}}}$$

where

w	filtering speed
d	grain diameter
D_S	diffusion coefficient of the substrate

,which includes the features of the operation, the filtering layer, and the water to be purified as well. In other words, the Pe-number combines the features referring to the convective and conductive flows, as well as to the size of surface.

- The Pe-number value of bank filtering varies between 5 and 15.
- Calculating the dimensionless variable consisting of the three factors is difficult due to the problematic measuring and definability of quantities.

2.2 Features of artificially implemented nutrient degradations

In traditional drinking water treatment methods usually no effort is made to degrade nutrients. The aim is usually achieved by chemical, electrochemical reactions, supplemented by physical elements such as gravitational separation or mechanical filtering.

This cannot be told about wastewater treatment. Wastewater treatment may also include supplementary elements – such as grid wastes removal, or sand and fat traps – however, basically the main element of the technology is a biological procedure. The most widespread procedure is the so called activated sludge technology.

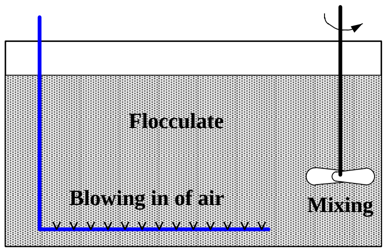


Figure 2-6 Diagram of activated sludge technology.

Biological nutrient degradation happens here in the biofilm as well. The biofilm carrier is the sludge itself, and its floccules. Biofilm is not a fixed formation but it has a broken structure, which is distinguished from static biofilm and is called flocculate.

When analysing the features of bank filtering it was stated that the accomplishment of logistic elements is a pre-requisite of nutrient degradation inside the biofilm. The fact that the elements of convective and conductive flows cannot be recognized easily in the activated sludge reactor space does not mean that these features do not exist here and that they should not be dealt with.

Due to high loading of the wastewater, degradation needs a lot of oxygen. Therefore the method in which air is led there has a great importance. Blowing in of the air, however, does not only serve oxygen supply but by means of mixing, it also induces convective flow. In bank filtering the grade of convective speed was interpreted in relation to the standing sand grains, i.e. **the standing biofilm**. Infiltration speed is very low (0.1 m/d), which is imperceptible to the eye. If you would like to determine the same speed for activated sludge technology, it would be difficult, however, *perceptibly* this value is by grades higher than what is experienced in the bed connection layer of bank filtering.

If you would like to calculate the Pe-number of the biological reactor space of the activated sludge technology, practically you can only make qualitative statements:

- Flocculate, i.e. the small grain size of floccules will surely balance the relatively greater convective speed.
- The diffusion coefficient of the substrate is the same as with bank filtering.

According to the nutrient degradation model [1] efficient nutrient degradation happens with Pe > 50. According to the present practice of wastewater purification the Pe-number is not calculated. The concept of convective speed is replaced by the easily definable concepts of *dwell time* and *sludge age*. For these, intervals are defined in an empirical method. The greater dwell time and the smaller convectional speed are though variables pointing in the same direction, however, it is easy to acknowledge that dwell time, regarding the main point of its sense is not identical with the concept of convective speed. Nutrients are transported to the biofilm by means of convective flow. If this flow speed is too great, nutrients "walk by" in front of the biofilm, not leaving enough time for diffusion. Dwell time though leaves enough time, however, it does not "transport". Therefore it is unfortunate to characterize the process with it.

Convective flow is produced by external force, in bank filtering by pumping, in activated sludge technique by air blowing in or mixing. Conductive flow is driven by pressure difference, diffusion is driven by concentration difference. However, for a permanent concentration difference, biochemical reactions have to happen inside the biofilm.

If the diffusion coefficient of the nutrient is great, diffusing in takes place quicker and easier. This would involve the conclusion that degradation of smaller molecules – such as ammonia – happens earlier and quicker. Still, it happens reversely. The explanation to this is that a part of biochemical reactions – thus two-step nitrification as well – involve carbon use. To start nitrification, first carbon has to be produced, i.e. first organic carbon compounds with great molecules have to be degraded. This is the reason why nitrification may only start later. Diffusing in of the ammonia with considerably better diffusion parameters becomes continuous when nitrobacteria are already working, producing the concentration difference between the external water space and the space inside the biofilm, for the ammonia.

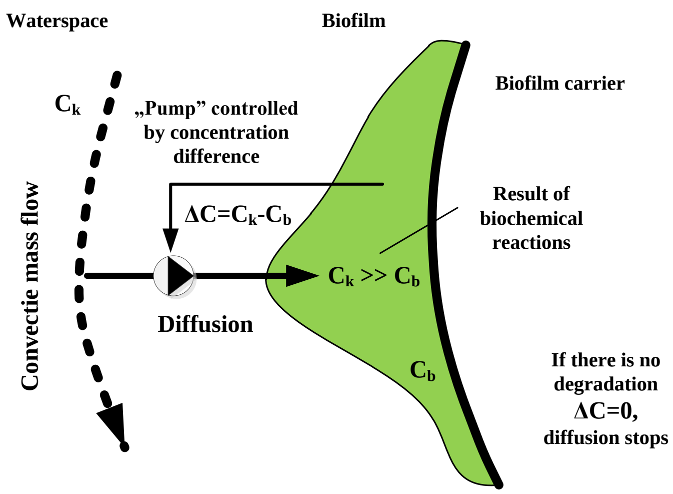


Figure 2-7 Continuous diffusion becomes permanent though feedback

This order of molecule degradation also means at the same time that our concept created on the serial nature of the nutrient degradation process has to be somewhat shaded as the formation of conductive flow in the sequence depends on subsequent biochemical processes happening later in the sequence. If there is no degradation, there is no concentration difference, and diffusion. This means there is a kind of feedback between the last two chain-links.

Attention should be called to another thing as well. The only difference between oxic anoxic pools in a structural sense is that in one of them air feed is provided, whereas in the other one it is not. These roles are sometimes interchanged. The adjectives oxic and anoxic suggest as if different biochemical processes are going in the two pool spaces. However, considering the mixing role of aeration causing convective flow, different conclusions may be drawn. By terminating air feed, the Pe-number is actually decreased. In order to know what this precisely means, the T-diagram of biological filtering has to be measured (see later).

The processes of hydraulics and biological filtering are similar phenomena [1]. Hydraulics may be considered a closed chapter by measuring out the Moody-diagram, however, the completion of biological filtering theory still has to be waited for. In the following table the already taken and still missing steps are indicated, without details.

Hydraulics

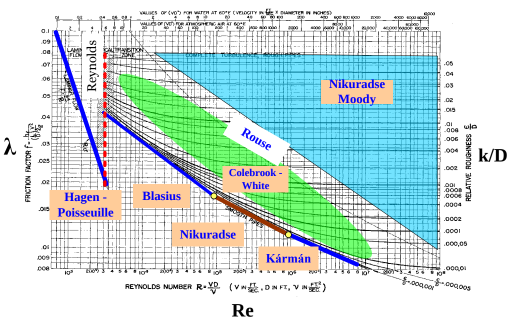
	$\Delta p'$	l	μ	ρ	D	c
M	-1	1	-1	-3	1	1
kg	1	0	1	1	0	0
S	-2	0	-1	0	0	-1
Π_1	1	0	0	-1	0	-2
Π_2	0	1	0	0	-1	0
Π_3	0	0	1	-1	-1	-1

$\Pi_1 = \Delta p'/\rho c^2 \sim \Delta p'/(\rho/2)\, c^2))$ Euler number

$\Pi_2 = L/d$ relation between the pipe section length and diameter

$\Pi_3 = \nu/(cd) = 1/Re$ reciprocal of the Reynolds number

$$\Delta p' = \lambda \frac{L}{d} \frac{\rho}{2} c^2$$



Moody-diagram

Biological filtering

	ΔS	ν	w	D_{O2}	E_h	L	F	T	R	D_S	C_{O2}	d
m	-3	2	1	2	2	1	0	0	2	2	-3	1
kg	1	0	0	0	1	0	0	0	1	0	1	0
s	0	-1	-1	-1	-3	0	1	0	-2	-1	0	0
K	0	0	0	0	0	0	0	1	-1	0	0	0
A	0	0	0	0	-1	0	1	0	0	0	0	0
mol	0	0	0	0	0	0	-1	0	-1	0	0	0
Π_1	1	0	0	0	0	0	0	0	0	0	-1	0
Π_2	0	1	0	0	0	0	0	0	0	-1	0	0
Π_3	0	0	1	0	0	0	0	0	0	-1	0	1
Π_4	0	0	0	1	0	0	0	0	0	-1	0	0
Π_5	0	0	0	0	1	0	1	-1	-1	0	0	0
Π_6	0	0	0	0	0	1	0	0	0	0	0	-1

$\Pi_1 = \Delta S / C_{O2}$ concentration ratio

$\Pi_2 = \nu / D_S$ Schmidt-number for the diffusing substance

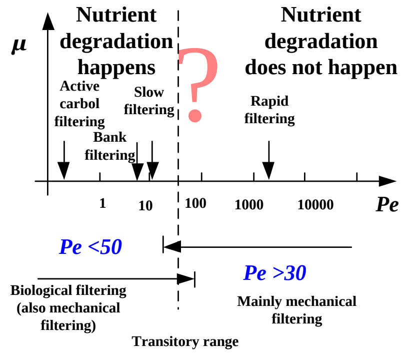
$\Pi_3 = w\, d / D_S$ Peclet number

$\Pi_4 = D_{O2} / D_S$ rate of diffusion coefficients

$\Pi_5 = E_h\, F / RT$ Nernst coefficient, or corrected rH

$\Pi_6 = L / d$ geometrical ratio

$$\Delta S = \mu\, C_{O_2} \frac{D_S}{w\, d} \frac{\nu}{D_{O_2}}\, rH\, \frac{L}{d}$$



T-diagram

Figure 2-8 The missing, the unmeasured T-diagram

Modelling of the two processes that seem to be far from each other happened by means of dimensional analysis. The first step is listing variables, i.e. setting up the dimension matrix, which is followed by reducing the number of variables, establishing the dimensionless numbers. Methodology to this is provided in [9]. By means of heuristic considerations a relationship describing the phenomenon may also be obtained then the function of pipe friction (λ) and filtering (μ) coefficients have to be determined by measurement. We already have the Moody-diagram, the T-diagram still have to be measured out.

T-diagram allows the correct dimensioning of biological spaces. Until this tool becomes available, dimensioning may only be based on estimations.

3 Dimensioning of biological filtering

3.1 Similarity transformation

The basic idea of dimensioning biological filters is very simple. Bank filtering is given, and it is known that it produces excellent water quality from occasionally strongly polluted river water. Let us fix these parameters along natural, i.e. dimensionless variables then let us determine the dimensions of the artificial process by using the possibilities provided by similarity transformation.

The value of the *Pe-number* characterizing bank filtering is between 5 and 15. Bank filtering is efficient biological filtering, by means of *similarity transformation* this feature is preserved. The condition for keeping the Pe-number may be expressed in the following way.

$$\mathbf{Pe}_{\textit{artificial filtering}} = \frac{\mathbf{w}\uparrow \quad \mathbf{d}\downarrow}{\mathbf{D}_S \uparrow} \quad := \quad \mathbf{Pe}_{\textit{bank filtering}}$$

In the formula the “arrows” indicate the direction of change. Compared to the low filtering speed typical of the small sample (bank filtering), for the large sample (in the case of an artificial filter to be dimensioned), in order to increase flow-through performance, filtering speed has to be increased. Consequently, in order to keep the *Pe-number* at the same value – which is a criterion of similarity – d grain diameter of the filtering medium in numerator has to be decreased, whereas D_S diffusion coefficient in the denominator has to be increased.

Decreasing the grain diameter needs the use of filtering filler material with great specific surface instead of sand. Increasing of the diffusion coefficient may happen by means of ozone treatment. In response to ozone dosing, the great-molecule structure of organic nutrients becomes fractured. Whereas the thus produced smaller-sized molecules, according to the well-known *Stokes-Einstein* relation has a higher diffusion coefficient.

Consequently, rapid filters can only show biological features if the filtering medium itself is changed, and the wastewater to be filtered is subjected to ozonisation.

As the Moody-diagram is the basic relation of hydraulics science, the so called T-diagram is the basic relation of filtering theory. The Moody-diagram is well-known, all course book dealing with hydraulics contains it. However, T-diagram is not measured out yet. Consequently, the value of **μ** filtering coefficient does not exist yet.

3.2 Difficulties of determining the coefficients

The task is made even more difficult as determination of the different coefficients run into difficulties as well therefore estimations have to be used:

3.2.1 Determining filtering speed

In the case of filters filtering speed is defined as the quotient of the water volume flowing through and the filter diameter. The thus interpreted speed value is however not the real filtering speed but only proportional to it. It would be more sensible to correct the defined value with the specific void volume characterizing the filtering medium. In this thesis – in accordance with custom – the filtering speed value is not corrected either when estimating bank filtering bed connection speed, or when dimensioning.

3.2.2 Value of diffusion coefficient

It is not simple to define the diffusion coefficient of the substrate to be substituted in the formula. The straight method would be if the wastewater laboratory measured the value after sampling. However, measuring the diffusion coefficient does not belong to easy measurements, in addition to this a great number of different substance qualities may be found in the wastewater in dissolved state. Which one counts from the aspect of modelling? It seems to be practical to introduce a kind of equivalent diffusion coefficient, which may be defined be means of the following formula:

$$\mathbf{D}_S = \frac{\sum_{i=1}^{n} \mathbf{D}_i\ \mathbf{C}_i}{\sum_{i=1}^{n} \mathbf{C}_i}$$

, where n is the number of nutrients to be found in the wastewater

In this approach C_i concentration of the nutrients in the water to be purified is measured. The D_i diffusion coefficients belonging to the different substance qualities are known as physical features, by which the equivalent D_S diffusion coefficient may be calculated as well. This value is then used in the similarity numbers (*Pe, Sc*).

Another method may be used as well. According to Von Gunten's observation [14] waters contain the following typical molecule:

$$\underline{\left(CH_2O\right)_{106}\left(NH_3\right)_{16}\left(H_3PO_4\right)} + \underline{\underline{138\,O_2}} = 106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+$$

On the left side of the above formula no specific molecule is found but the composition of initial compounds by atomic groups. It is also well visible that happening of the biochemical process needs very much oxygen. After the degradation, mostly water and carbon dioxide are obtained however, nitrate and phosphate are also produced.

Molecular mass of the atomic group to be degraded:

Element	Atomic mass	Mass quantity	Total
C	12	106*12	1,272
H	1	212*1 + 48*1 + 3*1	263
O	16	106*16 + 4*16	1,744
N	14	16*14	224
P	31	1*31	31
Molecular mass		M	3,554
Relative molecular mass: Mr = 3,554 / 12			296

Between the molecular mass and the Schmidt-number there is measured out and formulated relation [5]. By the help of this relation, in our case, the following value will be obtained for the Schmidt-number:

$$Sc = 140M^{0,507} = 140 * 3354^{0,507} = 8838$$

By using the formula of the Schmidt-number, the numeric value of the diffusion coefficient will be:

$$D_S = \frac{\nu}{Sc} = \frac{1,3 * 10^{-6}}{8838}\left[\frac{m^2}{s}\right] = 1,47 * 10^{-10}\left[\frac{m^2}{s}\right]$$

Oxygen also has to be diffused in, however, the diffusion coefficient of oxygen is extremely high, similarly to chlorine, having a round value of

$$D_{oxygen} = 20 * 10^{-10}\left[\frac{m^2}{s}\right]$$

By means of dosing ozone, the atomic group to be degraded falls into smaller-sized "parts". However, the result of ozone's operation as a "chopping knife" still has to be measured out. We would like to measure the result of intervention in the increase of diffusion coefficient.

3.2.3 Equivalent grain diameter

Grain distribution of the filtering layer along the bank is not even either. The equivalent grain diameter is determined by measurement. Measurement happens by determining the so called grain distribution curve. The filtering layer containing different fractions (sand, gravel) is identified with a medium of even grain distribution, showing the same surface. The grain size belonging to this is the equivalent grain diameter.

Sand and gravel grains only show surface regarding their outside. By considering the grains as approximate spheres, the magnitude of the surface suitable for the settlement of microbes may be easily calculated. The smaller the grains are, the greater the total surface is.

Substances of great specific surface, in addition to their outside also have surface in the internal structure of the granulate. These special substances are usually characterized by three features:

- granulate size, i.e. the average, real diameter of the grain,
- density or specific weight of the substance,

- specific surface of the material.

By the help of these three features – to which only the formulas to calculate the sphere volume and sphere surface have to be known – equivalent grain diameter can be calculated. The size of a grain that only shows surface on its outside. Thus the different filtering substances become comparable in the formula of the Pe-number.

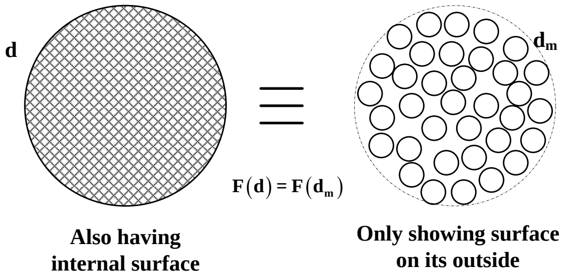


Figure 3-1 Equivalent grain diameter

In the case of substances of great specific surface, the equivalent or standard grain diameter gives a very low value, which would be very benefiting from the aspect of dimensioning biological filters. However, it was observed [8] that in the narrow internal cuts of substances with great specific surface, the biofilm only partly forms. The barrier is the relation between the sizes of the bacteria and cuts.

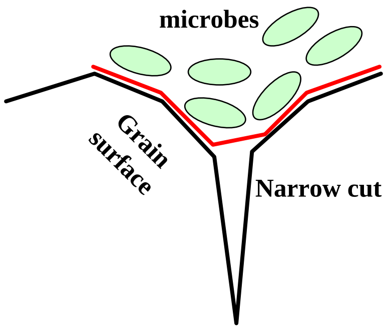


Figure 3-2 Obstacles to the formation of biofilm on internal surfaces.

As it is plastically and well observable in the figure: if the bacterium size is greater than the opening of the cut, the microbe cannot get into the internal spaces (facing the "how a big elephant can go into a lion's cave" dilemma). This means the surface available for the settlement of microbes is actually smaller than it could be calculated based on the size of specific surface.

Measuring the specific surface does not happen directly, by planimetration, but in an indirect method, by means of gas absorption. If the size of gas molecule used for measuring is small, a great surface is obtained, which cannot be used due to the above mentioned reasons. This means measuring the specific surface would be correct from the aspect of biological filtering if gas molecules corresponding to microbe sizes would be used.

As the solution by measurement of the above outlined problem is not known, the standard grain diameter also has to be estimated. It is supposed that a fivefold microbe size may be a good value.

	Sign	Zeolite	Active carbon
Granulate size [mm]	d	5	1.5
Density [kg/m^3]		850	2,100
Specific surface [m^2/g]		1,600	12
Equivalent grain diameter [m] (according to the logic of Figure 3-1)	d_m	**5.88* 10^{-7}**	**1.76* 10^{-9}**
Size of bacteria [m]	b	(0.5-5)*10^{-6} := 2.5***10^{-6}**	
Standard grain diameter [m] (corrected value)	d_m	d_m:=5* b = 1.25***10^{-5}**	

4 Samples of application

4.1 Wastewater treatment dimensions

The following excel calculation table includes the most important steps of dimensioning.

Data/Formula	Explanation	Value	Dim.
Pe:=	Pe-number of bank filtering	10	[-]
d_m:=	5-fold bacteria size	1.25E-05	[m]
D_S:=	supposing ozonisation	5.00E-10	[m^2/s]
$w = Pe*D_S/d_m$	this has to be adjusted to the desired Pe	4.00E-04	[m/s]
w	filtering speed in m/d	34.56	[m/d]
Q:=	the capacity of North-Pest wastewater plant	180,000	[m^3/d]
F= Q / w	required filtering surface	5,208	[m^2]
n:=	number of filtering unit	40	[pcs]
f = F/n	surface of one filter	130	[m^2]
a:=	shorter side of one filter	5	[m]
b = f/a	longer side of one filter	26	[m]
L:=	biologically active layer at the bed (according to Jekel)	1.50	[m]
d:=	size of bank grain	1.30E-03	[m]
L/d	similarity number in the model	1,154	[-]
L_m=L/d * d_m	thickness of the biologically active layer in the filter if it should purify Danube water	1.44E-02	[m]
BOI_{ww}:=	BOI value after presedimentation	400	mg/L
BOI_{Danube}:=	BOI value in the Danube	5	mg/L
BOI_{ww}/BOI_{Danube}	wastewater is more concentrated by this extent	80	
$h = L_m * BOI_{ww}/BOI_{Danube}$	thickness of filtering layer by proportioning	1.15	[m]
V = h * F	volume of filter	6,010	[m^3]
ro:=	density of filtering filler material (zeolite)	850	[kg/m^3]
m = V / ro	mass of filtering filler material	5,108,173	[kg]
price:=	price of zeolite (based on quotation)	45	[HUF/kg]
K = price * m	cost demand of filtering filler material	230	[mHUF]
t =(V / Q)	dwell time at the filter	48.08	[min]
$V_{living\ sludge}$:=	volume of biological reactor space in the North-Pest plant	108,000	[m^3]
$I_{rate} = V_{living\ sludge} / V$	rate of biological reactor spaces	17.97	[-]

Dimensioning would be considerably more grounded with the T-diagram known. However, the table gives a good estimation. The obtained numbers clearly show that wastewater utilisation-based filter bed technology is viable. It is worth supporting and correcting the forced estimations by measurements. It is not excluded that regarding main dimensions some changes are possible in the light of the measurements to be made.

Filter bed and activated sludge technologies are compared by listing the advantages and disadvantages. The following table is though not too communicative, still points out at the important differences:

	Filter bed technology (dimensioned on the basis of the similarity of bank filtering)	Activated sludge technology
Baseline	Wastewater recycling	Wastewater treatment
Biogas production	The whole sludge quantity may be gasified.	Biogas yield is significantly lower as in the process of water purification sludge becomes exhausted.
Necessary biological reactor space	If rounded: 20-fold smaller reactor space is needed.	Greater investment cost.

Biofilm carrier	It is needed and requires considerable additional costs.	The sludge itself performs this task.
Rinsing	Rinsing is needed, which involves the following: filters should be rinsed in the case of bank filtering twice yearly, here approximately every 2 days.	The task does not occur.
Mixing	It is not needed.	Mixing involves the use of electric energy.
Depth of the reactor space	Thickness of filtering layer is 1.5 m.	The depth of the reactor space is great, 8 m.
Air feeding	From below, by low-capacity fan, through a 1.5 m thick filtering layer. Rinsing is air feeding as well.	The energy demand of blowers providing deep aeration is great.
Operation in winter	Bank filtering has a stable operation in winter as well, and filter bed technology also does so.	Below 12°C nutrient degradation practically stops.
Operation	It needs a totally different thinking. Attention actually has to be paid to the rinsing of filters.	Flowing through is continuous, the task of operation consists of interchanging oxic-anoxic spaces.
Sending to technology by means of pumping	It has to happen in the case of both technologies. Going through the technology is gravitational in both cases.	

And the alternative solution in figure:

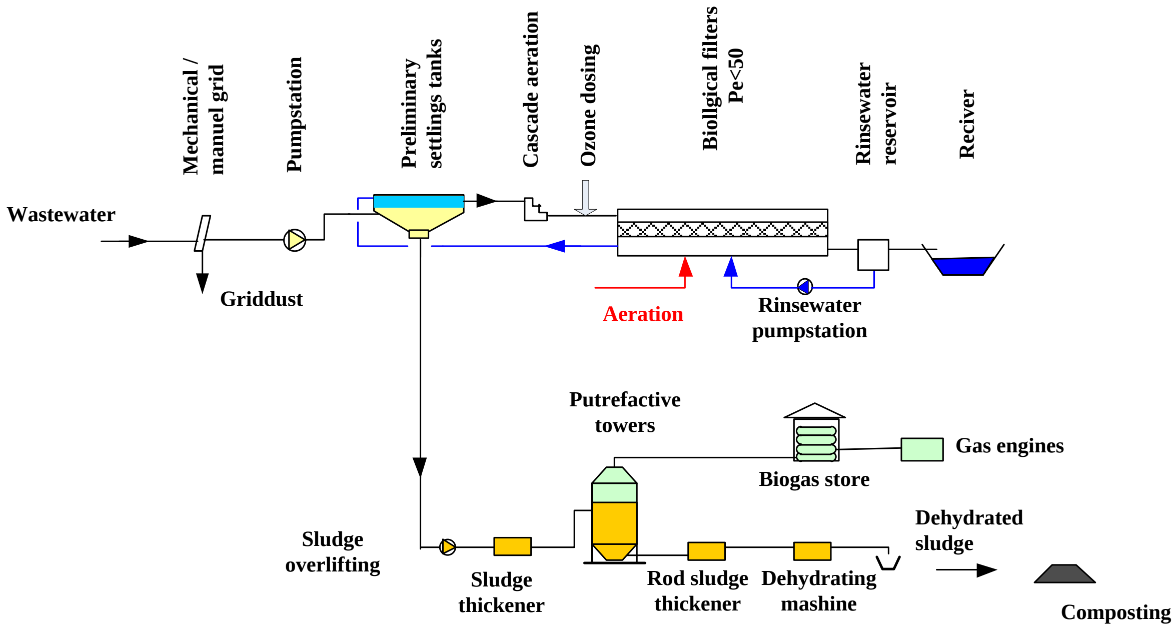


Figure 4-1 The *new version* of wastewater recycling in simple form.

4.2 The conditions of biological ammonia removal in the case of drinking water purification

Biochemical equations of the two-step nitrification are well-known:

$$NH_4^+ + OH^- + 1{,}5\,O_2 \text{ Nitrosomonas} \rightarrow NO_2^- + H^+ + 2\,H_2O$$

$$NO_2^- + 0{,}5\,O_2 \text{ Nitrobacter} \rightarrow NO_3$$

Following the first step nitrite is produced then nitrite becomes nitrate. It is well-known that this reaction needs oxygen. It is significantly less than earlier therefore air blowing in is not needed, simple aeration is sufficient.

The diffusion coefficient of ammonia is well-known: $D_{ammonium} = 19.4*10^{-10}$ m^2/s. This value may be considered very good due to small molecule size.

Let us take a filtering unit which is said by experts to be dimensioned for ammonia removal:

Filtering filler material: sand of 1.5 mm grain size
Filtering speed: 3.16 m/h

Let us calculate the value of the Pe-number with these parameters:

$$\mathbf{Pe = \frac{wd}{D} = \frac{1,5*10^{-3}m \quad 8,8*10^{-4}m/s}{19,7*10^{-10}m^2/s} = 670}$$

Conclusion:

It is highly probable that this filter is not the most suitable for ammonia removal as efficient biological nutrient degradation may only be implemented with Pe < 50.

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