Discharge of treated sewage to groundwater using the hydraulic criteria for slow sand filtration

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ABSTRACT The infiltration of the effluents of the pilot plants on the TNO testing grounds was studied. The experiments were carried out indoors in filter columns and outdoors in a 5 m² experimental filter. The filtration rates varied between 0.06 and 24 cm h⁻¹, corresponding to a hydraulic load of 0.1 to 48 population equivalents per m².

For the (total) counts on nutrients agar, over a filter length of 10-20 cm, an 81% reduction was found, increasing to 99% over a length of 410-470 cm.

For the coliforms, over 10-20 cm of filter length a 92% reduction was found, increasing to 99.9% over a length of 410-470 cm.

About 40-60% of the dissolved oxygen in the supernatant was consumed within the first 10 cm of filter sand. Denitrification was responsible for a decrease of the nitrates by about 15%.

A provision for the regeneration of the filter surface worked satisfactorily.

INTRODUCTION

By discharge of sewage one primarily thinks of drainage to surface water. Discharge into the soil is not popular, for the following reasons:
- because of rapid clogging of the infiltration surface very low infiltration rates are required resulting in very large infiltration areas.
- pollution of ground water is considered more serious than pollution of surface water.

Only in arid areas sewage is used extensively in water supply for agricultural crops; the extensive use of the soil surface is not taken into account here and owing to the transpiration of the vegetation the load of the ground water is only small.

The aim of sewage treatment is to reduce the harmful effects of discharge to the receiving environment. When directly irrigating agricultural crops still the hygienic unreliability of the water has to be taken into account.
Weighing the environment impacts, it might be revealed that, locally, pollution of groundwater by discharge of treated sewage is less serious than pollution of the surface water. Locally, the banks of a receiving surface water might be used for further treatment by soil filtration. By means of infiltration the groundwater potential might be increased against the intrusion of salt water or for driving up the natural groundwater.

Slow sand filtration, with filtration rates of 10 cm h\(^{-1}\) up to 30 cm h\(^{-1}\), is well-known in the production of drinking water, but is scarcely known as an infiltration technique on a restricted area. This paper describes some aspects of the study of slow sand filtration at the Water and Soil Division of the authors' Institute. The changes in quality are stressed here, because more has to be known about the quality of the infiltrating water at the moment the natural groundwater is reached. Regeneration of the infiltration surface has been studied only provisionally, because the further development of this technique takes place mainly in actual practice.

LABORATORY SCALE EXPERIMENTS

During three successive years, research has been carried out on changes in the quality of effluents from sewage treatment plants subjected to infiltration. For the filtration, there were available:
- two columns with a diameter of 11 cm and a total length of 466 cm between the extreme sampling points situated indoors;
- one column with a diameter of 57 cm and a length of 120 cm situated outdoors.

![FIG. 1 Grain size distribution.](image-url)
The experiments were carried out with dune sand and builders grade sand (figure 1) at temperatures of 10°C and 20°C for the indoor filters and ambient temperatures between 0°C and 22°C for the outdoor filter. The percolating rates varied between 0.06 and 24 cm h⁻¹, globally corresponding to a hydraulic load of 0.1 to 48 population equivalents per m². To feed the sand columns, the following effluents were available:
- effluent from a very low-loaded activated sludge plant (oxidation ditch);
- effluent from a very low-loaded activated sludge plant with denitrification and phosphate removal (oxydenitroplant);
- effluent from a primitive high-loaded activated sludge plant.

In order to study the activity of the filter sand only, the filter feed was prefiltered by filter paper to avoid the formation of a sludge layer on the filter surface.

Grouped/bacteriological results

"Total "numbers of micro-organisms on nutrient agar The mean results of the experiments are grouped in Table 1.

<table>
<thead>
<tr>
<th>Percolating Length (cm)</th>
<th>Number of Observations</th>
<th>Mean Count per ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>0*</td>
<td>124</td>
<td>263×10³=100%</td>
</tr>
<tr>
<td>10 - 20</td>
<td>78</td>
<td>50×10³= 19%</td>
</tr>
<tr>
<td>60 - 80</td>
<td>101</td>
<td>15×10³= 6%</td>
</tr>
<tr>
<td>100 - 120</td>
<td>93</td>
<td>14×10³= 5%</td>
</tr>
<tr>
<td>210 - 230</td>
<td>46</td>
<td>11×10³= 4%</td>
</tr>
<tr>
<td>410 - 470</td>
<td>16</td>
<td>3×10³= 1%</td>
</tr>
</tbody>
</table>

* supernatant

For these mean results, the following must be remarked upon:
- An influence of temperature, rate of filtration and type of sand could not be determined unequivocally.
- The very high-loaded primitive activated sludge plant produced the worst results for 10 to 20 cm of percolating length, the reduction being only about 70% against a mean of 81% for all filter feeds. Probably, this is due to a very short detention time in the activated sludge plant resulting in a high oxidizable organic matter content and a very low mean sludge age.
- A sampling point at 10 cm depth has been exposed for some time to infection by excessive aftergrowth in the sampling conduit. Obviously, the biggest part of the reduction must be attributed to the first centimetres of sand. Besides, it was conspicuous that rather high reductions occurred in the supernatant.
Coliforms  Coliforms were tested in three ways, one of them is reviewed in Table 2.

TABLE 2  Number of coliforms according to Eijkman in the filtrate

<table>
<thead>
<tr>
<th>Percolating Length (cm)</th>
<th>Number of Observations</th>
<th>Mean Count per ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>0*</td>
<td>97</td>
<td>409 = 100%</td>
</tr>
<tr>
<td>10 - 20</td>
<td>47</td>
<td>33 = 8%</td>
</tr>
<tr>
<td>60 - 80</td>
<td>84</td>
<td>9 = 2%</td>
</tr>
<tr>
<td>100 - 120</td>
<td>57</td>
<td>3 = 0.7%</td>
</tr>
<tr>
<td>210 - 230</td>
<td>36</td>
<td>4 = 1%</td>
</tr>
<tr>
<td>410 - 470</td>
<td>3</td>
<td>0.4 = 0.1%</td>
</tr>
</tbody>
</table>

* supernatant

Comparison of the Eijkman test with cultivation on Endo agar and cultivation according to Mac Conkey shows changes in the composition of the coliform group during filtration. Escherichia coli was always present down to a depth of about 4 m. An influence on the reduction by temperature, rate of infiltration and type of sand could not be determined clearly.

Streptococcus faecalis  Streptococcus faecalis has the reputation of being more resistant against a strange environment than members from the coligroup. This appears also from the observations.

TABLE 3  Number of Streptococcus faecalis in the filtrate

<table>
<thead>
<tr>
<th>Percolating Length (cm)</th>
<th>Number of Observations</th>
<th>Mean Count per ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>0*</td>
<td>17</td>
<td>74 = 100%</td>
</tr>
<tr>
<td>10 - 20</td>
<td>14</td>
<td>54 = 73%</td>
</tr>
<tr>
<td>60 - 80</td>
<td>15</td>
<td>16 = 22%</td>
</tr>
<tr>
<td>100 - 120</td>
<td>15</td>
<td>15 = 20%</td>
</tr>
<tr>
<td>210 - 230</td>
<td>15</td>
<td>13 = 17%</td>
</tr>
<tr>
<td>410 - 470</td>
<td>2</td>
<td>0.5 = 0.6%</td>
</tr>
</tbody>
</table>

* supernatant

Sporeforming bacteria  From a very small number of observations, a variation in the reduction from 74% (effluent from oxidation ditch) to 37% (effluent from very high-loaded activated sludge) over a filter length of about 2 m was shown.

Chemical observations

Oxygen balance  The decrease in oxygen content during the fil-
Discharge of treated sewage

Trination process is analogous to the decrease in bacterial numbers: a very rapid decrease over the first centimetres of sand followed by a slow but continuous decrease. So, the filter surface is very active in biochemical respect. Measurable differences in oxygen consumption owing to temperature differences appeared to be the result of differences in the saturation value of the oxygen in the filter feed at the temperatures considered (figure 2). It should be noted that the filter feed had been filtered by paper and that the supernatant was aerated. The reason for this procedure was that hardly any oxygen should be consumed in a sludge layer and that enough oxygen should be available for measurements over the whole filter length.

![Figure 2 Oxygen profile depending on temperature.](image1)

**Figure 2** Oxygen profile depending on temperature.

**Figure 3 Oxygen profile at 20°C.**

Oxidizable organic matter In practice, the amount of oxidizable organic matter is represented by the biochemical (and/or chemical) oxygen consumption. In the laboratory scale experiments, the sampling volumes were small, so the TOC (total organic carbon) was chosen.

The determination of the correlation of the TOC with the actual oxygen consumption is not simple. From a separate investigation of
the filter feeds, a mean ratio of COD/TOC \approx 2.45 was found; for examination of this correlation, it was further assumed that the COD calculated from the TOC agreed with the BOD over an infinite time.

Figure 3 gives the mean result of a large number of measurements. It concerns here a connection in series of three filter columns at 20°C with a reaeration between the first and second filter. From the differences, \( \Delta \text{TOC} \), between the successive measuring points, using the ratio of COD/TOC = 2.45, the theoretical oxygen consumption in the filter was calculated and converted into calculated oxygen contents. Notwithstanding the greatly hypothetical character of the conversion, the curves for the oxygen content measured and the oxygen content calculated are in fairly good agreement with each other. There is only one striking difference between both curves in the first filter: much more organic matter is removed here than would agree with the actual oxygen consumption. Probably, this discrepancy is associated with the catchment of colloidal matter by the filter sand which has passed the paper filter of the filter feed.

**Nutrients**  
From a very limited number of measurements of total phosphate and nitrate contents, it appeared that there was no (bio)chemical reduction in the filters. Nor was there any measurable denitrification in a filtration period under anaerobic conditions, the supernatant being in equilibrium with a nitrogen atmosphere.

**TECHNICAL SCALE EXPERIMENTS**

A filter with a surface area of about 5 m\(^2\), filled with builders-grade sand (figure 1), was used. The height of the filter bed was 85 cm, but owing to the position of the drains only about 50 cm of the depth of the bed was effective. The maximum difference of potential between supernatant and filtrate was 28 cm. The filter feed consisted of effluent from the 500 p.e. pilot plant oxidation ditch. During the filtration experiments, other experiments were carried out in the oxidation ditch so there was a big variation in effluent qualities.

**Backwashing of the filter surface**

During slow sand filtration only the filter surface is clogged. With the production of drinking water, a very thin layer of sand is removed periodically. As a result of the relatively fast clogging with the filtration of sewage, this method would not be efficient. For the construction of the experimental filter, a simple distribution network for compressed air was placed at about 15 cm depth, where the top layer of sand could be fluidized and washed. The washing water was returned to the oxidation ditch.

The permeability of a filter is given by the constant, \( k \), from Darcy's law

\[
q = v_f A = -k A \frac{\Delta h}{\Delta x}
\]
where \( A \) = cross-sectional area of flow tube
\( h \) = fluid potential
\( k \) = permeability
\( v_f \) = seepage velocity
\( x' \) = length of flow tube

Because of the complicated flow pattern and the varying temperature of the water, a specific filter constant, \( C \), was deduced for this experiment from the generalization of Darcy's law:

\[
q = v_f A = \frac{\rho g A K \Delta h}{\eta} = -\frac{CAh}{v}
\]

where
- \( g \) = acceleration of gravitation
- \( \eta \) = dynamic viscosity
- \( v \) = kinematic viscosity
- \( \rho \) = specific mass

from which follows:

\[
C = \frac{qv}{\Delta h}
\]

where \( q \) = volume flow rate

By choosing dimensions which were not coherent, the constant \( C \) could be expressed in a simple scale of values.

FIG. 4 Permeability of experimental filter.
The clogging of the filter, starting from the moment of washing is represented in figure 4. In practice, the first seven days are important, which is shown in the figure by the hatched area covering
Discharge of treated sewage

68.2% of the observations. The drawn (mean) observations from the eighth day on concern a limited number of prolonged filter runs with relatively little clogging in the preceding seven days.

FIG. 6 Chemical analyses slow sand filtration.
The course of the value of C for the separate filter runs could not be correlated clearly with the quality of the oxidation ditch effluent. There was a feeble tendency to fast clogging in turbid water; effluent with sludge flocs did not give any problems.

In the course of the experimental year, a feeble tendency to a reduction of the regeneration effect by about 10% of the initial permeability was observed. Probably, the fluidizing capacity was too small; when the airwashing was supported by hand stirring the initial permeability was attained again.

Chemical observation

Oxygen consumption The supernatant was not aerated, its oxygen content varied between about 2 mg l\(^{-1}\) and about 6 mg l\(^{-1}\). The oxygen content of the filtrate was constant practically zero.

Chemical oxygen demand (COD) Because the samples of the filter-feed were always filtered by paper prior to the analysis, the average effect of sand filtration was probably higher than follows from the analytical data.

The mean values for the whole experimental period can be summarized as follows:

- raw sewage : COD = 585 mg O\(_2\) l\(^{-1}\)
- oxidation ditch effluent : COD = 54 mg O\(_2\) l\(^{-1}\)
- filtrate : COD = 47 mg O\(_2\) l\(^{-1}\)

Dividing all data into two groups, separated by the mean value for the effluent results in:

- effluent < 54
  - oxidation ditch effluent : COD = 41 mg O\(_2\) l\(^{-1}\) 66 mg O\(_2\) l\(^{-1}\)
  - filtrate : COD = 41 mg O\(_2\) l\(^{-1}\) 51 mg O\(_2\) l\(^{-1}\)

Filtration clearly has some levelling effect.

Total phosphorus Halfway through the experimental year, a partial simultaneous phosphate precipitation was started in the oxidation ditch. The mean analyzing result can be summarized as follows:

<table>
<thead>
<tr>
<th></th>
<th>period without dephosphatizing</th>
<th>period with dephosphatizing</th>
</tr>
</thead>
<tbody>
<tr>
<td>raw sewage</td>
<td>20.0 mg P l(^{-1})</td>
<td>24.0 mg P l(^{-1})</td>
</tr>
<tr>
<td>oxidation ditch effluent</td>
<td>13.9 mg P l(^{-1})</td>
<td>11.5 mg P l(^{-1})</td>
</tr>
<tr>
<td>filtrate</td>
<td>13.6 mg P l(^{-1})</td>
<td>10.7 mg P l(^{-1})</td>
</tr>
</tbody>
</table>
During the period with dephosphatizing, some phosphate was perhaps removed in the filter as a result of the trapping of colloidal phosphorous.

Nitrogen compounds In the months May, June and July, there was a clear indication of denitrification in the oxidation ditch. In the filtration process, there was constantly some denitrification, about 26% with low nitrate contents in the filter feed and about 12% with high nitrate contents. The mean nitrate contents for the whole experimental period can be summarized as follows:

- Oxidation ditch effluent: 35 mg N (NO$_3^-$) l$^{-1}$
- Filtrate: 29 mg N (NO$_3^-$) l$^{-1}$

It is not clear whether this denitrification occurred in the filter itself or in the sludge layer on the filter. Probably the latter is the case, because there was no denitrification in the laboratory scale experiments where a sludge layer did not arise.

There was a remarkably small increase of ammoniacal nitrogen in respect to Kjeldahl nitrogen during the aforementioned months of May, June and July. Usually, denitrification leads to nitrogen losses owing to the escape of gaseous nitrogen (compounds). However, denitrification to ammoniacal nitrogen may not be excluded.

The data for Kjeldahl nitrogen and ammoniacal nitrogen can be divided into two groups, separated by their mean values in the effluent of the oxidation ditch:

<table>
<thead>
<tr>
<th></th>
<th>Total Kjeldahl (mg N l$^{-1}$)</th>
<th>Ammonia (mg N l$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>effl.$&lt;10.9$ effl.$&gt;10.9$</td>
<td>effl.$&lt;9.2$ effl.$&gt;9.2$</td>
</tr>
<tr>
<td>Oxidation ditch effluent</td>
<td>4.6  25.3</td>
<td>2.7  23.0</td>
</tr>
<tr>
<td>Filtrate</td>
<td>6.4  19.8</td>
<td>4.3  19.4</td>
</tr>
</tbody>
</table>

With the high contents some reduction in the filter could be perceived. With the low contents (nitrification) the quality of the water became worse, perhaps as a result of denitrification to ammoniacal nitrogen.

Bacteriological Observations Because in the laboratory scale experiments, sufficient attention had been paid to the behaviour of the filters, the technical scale experiments had been restricted to fourteen samplings and two parameters, total count and coliforms. The results are summarized as follows:
For the coliforms, the 99.4% reduction was equal to that in the laboratory scale experiments. For the agar counts, the 85% reduction was also equal to that in the laboratory experiments taking the effective filter length of about 50 cm into consideration. In both cases, relatively high reductions were observed in the supernatant water.

DISCUSSION

Reviewing the whole set of experiments, it may be questioned as to what extent slow sand filtration can be placed into the framework of infiltration, soil filtration and enrichment of groundwater.

The reduction of micro-organisms by 90-99% are comparable with practice in the production of drinking water. This comparison is not possible with regard to the remaining numbers which can still be called high due to high initial numbers and a substrate still rich enough for survival. Besides, the criteria for the production of drinking water are directed to human consumption; as concerning sewage, the situation is completely different.

With regard to the chemical parameters, the COD is of importance in the first place. The reduction of the COD within 50 cm filter length, to more or less biologically inert compounds is favourable because the possibilities for biological conversion in the subsoil are nearly absent.

Reduction of phosphates cannot be expected but the reduction of the nitrate content can be favourable when discharging to the groundwater. Further treatment with respect to these nutrients must take place in the sewage treatment plant itself.

Visual improvement of the quality through filtration is difficult to measure, but is important. Not only the clarity as an aesthetic aspect is concerned here, but, by catching suspended solids, the water quality in respect of all parameters considered is improved. This is not expressed in the analytical data, because this kind of improvement had been presupposed and the interest was only directed at the filtration as a biochemical process. Therefore, all samples of the filter feeds were filtered through paper as a pretreatment for the analysis.

Slow sand filtration can be considered to be soil infiltration in a very compact form. In geohydrological conditions suited for soil
infiltration, a slow sand filtration with periodical regeneration of the filter surface would be a means for infiltration with a relatively small infiltration surface. Locally, soil infiltration may be the only way of discharging treated sewage; combination with slow sand filtration may be an advantage. Soil infiltration as a replenishment of groundwater may be important locally for agrarian use; it can be a barrier against the intrusion of salty groundwater.

In the groundwater, concentrated soil infiltration may lead locally to an increase of the potential, through which natural groundwater becomes stagnant and can be used for other purposes.

Because of the frequent washing of the filter surface, no trouble can be expected from an excessive algae growth and waterborn insects.

Soil filtration is not an instrument with which problems of insufficient treatment can be solved. It is rather an instrument of aid in the reuse of sewage.