Pergamon

Wat. Sci. Tech. Vol. 40, No. 4–5, pp. 285–292, 1999
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0273–1223/99 $20.00 + 0.00

PII: S0273-1223(99)00510-7

OPTIMAL COMBINATION OF FLOCCULATING FILTRATION AND ULTRA FILTRATION FOR ADVANCED EFFLUENT TREATMENT IN THE NETHERLANDS

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ABSTRACT

With changing policies to solve local environmental and dehydration problems and with increasing interest in differentiation of water qualities by industrial and domestic users, a growing need exists to improve the effluent quality of wastewater treatment plants (wwtp) in the Netherlands. The change of policy to retain water in its original environment as much as possible leads to an increasing interest in discharging wwtp effluent into polders and local water courses instead of large surface waters. Besides, a new element is the interest in the production of household and industry water by the Dutch drinking water companies.
At several Dutch wwtp's research on (the combination of) flocculating filtration and ultra filtration is done to develop the possibilities of (re)using effluent in the Netherlands. The results of the research have shown that flocculating filtration and/or ultra filtration are technically and economically applicable for the production of household and industry water.

KEYWORDS

Advanced wastewater treatment; flocculating filtration; ultra filtration; particle size distribution; phosphorus removal; (re)use of wastewater.

INTRODUCTION

Present situation in The Netherlands

In The Netherlands almost all wastewater (> 95%) is treated mainly in full mechanical and biological wastewater treatment plants (wwtp). Most wwtp include advanced nutrient removal with biological nitrification and pre- or simultaneous denitrification for nitrogen removal and various ways of phosphorus removal.

Remarkably, until now advanced effluent treatment by filtration techniques has not been applied in The Netherlands. Especially, sand or dual media filtration of wwtp effluent, which is widely applied in other European countries (e.g. Germany, Switzerland and the UK), is not yet used on Dutch wastewater treatment plants. In this field many explorative bench or literature studies have been done to investigate all kinds of possible polishing processes. These studies (Rienks, 1995), which were based on zero effluent concentrations, indicated high cost figures (Dfl. 50.- to Dfl. 500.- per population equivalent per year [p.e.y.] or Dfl. 1.- to Dfl. 10.- per m^3 (Dfl. 1,- ~ $ 0.5, April 1999) for effluent polishing compared with the costs of preceding basic treatment (Dfl. 40.- to Dfl. 60.- / p.e.y.). So, generally, there has been little interest in further or advanced effluent treatment due to financial reasons.

Application of advanced effluent treatment in the near future

However, with changing policies to solve local environmental and dehydration problems and with increasing interest in differentiation of water qualities by industrial and domestic users, a growing need exists to improve the effluent quality of wastewater treatment plants in the Netherlands (Van der Graaf, 1997). Local water management boards change policies to retain water in its original environment as much as possible for prevention of exsiccation (drying). This leads to an increasing interest in discharging wwtp effluent into polders and local water courses instead of large surface waters. Finally, a new element in the Dutch water management is the differentiation of the water quality produced in the drinking water industry. From the need to reduce groundwater abstraction and cost savings there is an increasing interest and demand from the part of the consumers, industries as well as domestic users, in a water quality that is different from drinking water. So water companies investigate and use other sources of water production, such as surface water and gradually also effluent from wastewater treatment plants. For example, water of inferior quality, called B- or E-water, is sold to industries as cooling and low quality process water. In the near future, polished effluent, treated by flocculating filtration and ultra filtration, will be delivered as household water for toilet flushing, washing machines and outdoor taps in a secondary water system to households in the town of Ede (Van der Graaf, 1997).

This paper presents research on flocculating filtration and ultra filtration of wwtp effluent done by the Department of Sanitary Engineering to develop the possibilities of (re)using effluent in The Netherlands. First, research on flocculating filtration will be described. After that membrane ultra filtration and combined use of flocculating filtration and ultra filtration will be discussed. Finally a short impression of the household water project in the town of Ede will be shown.

METHODS AND MATERIALS

Effluent filtration is generally used to separate suspended solids from wwtp effluent. As the solids usually have a reasonable content of phosphorus (4 - 5% weight of P / total weight of SS (Oosthof, 1996)) and micro pollutants (e.g. heavy metals), it also favourably affects the phosphorus and micro pollutants' removal. With deep-bed filtration, different filtration mechanisms, such as straining, adhesion or interception, remove particles (> 1 μm) and adsorbed or incorporated pollutants from the water phase. With membrane ultra filtration particles smaller than 0.01 μm, as well as bacteria and even some viruses can be removed, which greatly improves the hygienic properties of the treated effluent. Phosphorus removal can be increased by adding inorganic coagulant (mostly Fe^{3+} or Al^{3+}), within or in front of the applied filter technique, in order to precipitate the soluble phosphorus fraction.

Flocculating filtration

When phosphorus precipitation occurs inside the deep-bed filter medium, the filtration technique is called flocculating filtration. Within this technique two main processes take place simultaneously: the process of precipitation and flocculation and the process of filtration. Due to flocculation also more and smaller particles can be removed by flocculating filtration, compared with conventional deep-bed filtration. In flocculating filtration, the pore space in the filter bed reduces during filtration because of accumulating of particles and flocks in the filter medium: the straining process of the filter medium improves in the first place. This is called the space effect of a filter and results in the removal of very fine flocks and particles. After a definite filter runtime, clogging of the filter bed or break through of phosphorus and particles through the filter medium occurs. In the first case the maximum admissible head loss of the filter is reached. If particles wash through the filter bed, the break through point of the filter is reached. To guarantee the quality of the filtrate (filter effluent), the filter runtime has to be stopped before break through takes place. After finishing the filter runtime, the filter bed has to be cleaned by backwashing with clean water and air. The dirty backwash water has to be treated separately or can be re-circulated to the wwtp.

The major design criterion of a flocculating filter unit, is estimated to be the filtration rate related to the filtration runtime. Higher filtration rates result in shorter filter runtimes, caused by clogging or break through of the filter. Frequently double or triple layers of filtration media are advised to use more of the total height of the filter optimally. To use flocculating filtration for phosphorus and suspended solids removal in practice, the filtration costs have to be low. This is mainly achieved by applying high filtration rates to decrease the filter surface area as much as possible. With these high filtration rates, long filter runtimes are preferred to treat high effluent flows through a small filter surface area. To achieve this aim, an optimization research programme was carried out (Van Nieuwenhuijzen, 1996). With a pilot filter unit, experiments were done at the wwtp of Hoek van Holland ($COD_{eff.}$ ~ 45 mg/l; $SS_{eff.}$ ~6 mg/l; $P_{eff.}$ ~ 0.9 mg/l; in test period 1995-1996). The filter unit had a surface area of 0.013 m^2 (diameter = 129 mm) and could be operated automatically with addition of $FeCl_3$. The filter column was filled with a bottom layer of coarse sand (grain size = 1.7 - 2.2 mm) and a top layer of anthracite (grain size = 2.0 - 4.0 mm). With this pilot test unit, long time operation experiments were possible. The filter parameters were derived from the previous inventory studies and some testing experiences. Tested filtration rates were 10 m/h, 20 m/h and 30 m/h, to find the maximum permissible ratio between filtration rate and filter runtime. The average achieved removal efficiencies with this pilot plant were 90% for suspended solids and 63% for total phosphorus (Van der Graaf and Van Nieuwenhuizen, 1998).

After this successful optimization research, which indicated that filtration rates up to 30 m/h are possible with runtimes of 24 h, a long term semi full scale (15 m^3/h) research started at the wwtp of Ede (table 1). For this research project a new pilot plant was designed with an interior diameter of 800 mm (surface area = 0.5 m^2) and a column height of 4 m.

Table 1. Average effluent parameters of wwtp Ede, 1996 (Witteveen+Bos, 1998)

Effluent flow rate	12 million m^3/year (Min.: 16,700 m^3/day, Max.: 130,000 m^3/day)
Suspended solids	5 mg SS/l
pH	7.5
COD	42 mg O_2/l
Total phosphorus	0.5 mg P_{tot}/l
Ortho phosphorus	< 0.03 mg P_{ortho}/l (random grab sample)
Kjeldahl nitrogen	5.5 mg N_{kj}/l
E-coli	> $8 \cdot 10^4$ (random grab sample)

The top filter medium consists of a 800 mm thick layer of anthracite (density: 1,400 kg/m^3) with a grain size between 2.0 and 4.0 mm. As the second layer 400 mm of coarse sand (density: 2,600 kg/m^3), with an average grain size of 1.7 - 2.2 mm, is used. As third filter medium a bottom layer of fine garnet sand (grain size: 0.5 - 0.8 mm; density: 3,500 kg/m^3) is applied. The water level above the filter bed is approximately 2.5 m. As coagulant an iron(III)-chloride solution is used. The hydraulic capacity varies between 5 m/h (minimum, 2,5 m^3/h) and the maximum filtration rate of 30 m/h (15.1 m^3/h). The filter pilot plant can be backwashed with air (100 m/h) and water (100 m/h). The filtrate is analysed mainly on suspended solids, particles, phosphorus, E-coli and some (heavy) metals.

Ultra filtration

A technique for advanced effluent treatment that is being developed very rapidly is separation by membrane filtration. Especially ultra filtration appears to be an interesting option for effluent polishing because pathogenic bacteria and (some) viruses can be removed besides particles and small impurities. The idea behind application of this advanced kind of effluent polishing may be that high quality effluent is required and that advantages are created in relation with reuse. Therefore a long term research programme was set up between the Department of Sanitary Engineering, Witteveen+Bos Consulting Engineering and some membrane producing industries to test the technical and economical feasibility of several membrane options for effluent treatment in The Netherlands. The objectives of the research project were: what is the achievable filtrate quality, what is the achievable capacity (flux and energy consumption), what is the overall performance during long term testing (regarding Trans Membrane Pressure (TMP), overall recovery, flushing and cleaning procedures) and is ultra filtration applicable under practical conditions with a useful goal.

At the wwtp Elburg and Ede a pilot unit was tested, consisting of an ultra filtration unit in dead-end mode (Van der Graaf *et al.*, 1998). The pilot unit contained capillary membranes (polyethersulfon, polyvinilpyrrolidon), with a tube diameter of 1.5 mm and a pore size of 0.01 μm, having a total surface of 4 m^2. Further details on process applied parameters are shown in table 2. The experiments started at wwtp Elburg and after six months of testing the pilot unit was transferred to the wwtp of Ede.

Table 2. Process parameters of the applied ultra filtration pilot unit (Kramer *et al.*, 1997)

Type	Ultra filtration
Configuration	Dead-end capillary 1.5 mm
Filtration direction	Inside-out
Total surface	4 m^2
Design flux	approx. 100 $l/m^2 \cdot h$
Trans Membrane Pressure	0.3 - 1.0 bar
Pretreatment (optional)	Dual layer rapid sand filtration (at 30 m/h), with or without $FeCl_3$
Water flush procedure	Every 15 minutes: 20 sec forward flush (960 l/h) + 22 sec simultaneous forward (960 l/h) and backward (1,600 l/h) flush
Chemical flush procedure	Every 120 minutes: a 5 minute flush with 100 mg/l sodium hypochlorite
Advanced chemical cleaning	Optional average once a week: 1 hour soak with 200 mg/l NaClO

At the wwtp Elburg an ultra-low loaded activated sludge system is applied, with biological Nitrogen removal and chemical Phosphorus (simultaneous) precipitation. The effluent quality over January - March 1997 consists on average of 3.0 mg/l BOD_5, 41 mg/l COD, 3.4 mg/l SS, 2.8 mg/l N_{kj}, 2.3 mg/l NO_3-N, 5.3 mg/l N_{tot}, 0.69 mg/l P_{tot}, 0.58 mg/l filtered P_{tot} and a pH of 7.9. The effluent temperature during testing varied from 10 to 11°C. Wwtp Ede, also, consists of an ultra-low activated sludge system, but with biological nitrogen and phosphorus removal by the Biodenipho process. The produced effluent quality is good (see table 1).

To protect the membranes against high loads of particles and other suspended solids, a rapid sand filter could be applied in front of the membrane pilot unit. This prefiltration unit consisted of an open gravity-filter with a constant flow, which was earlier tested on the wwtp at Hoek van Holland (Van Nieuwenhuijzen, 1996). A top layer 800 mm of anthracite (2.0 - 4.0 mm) and a bottom layer of 400 mm coarse sand (1.7 - 2.2 mm) were used as filter media. The applied filtration rate was 30 m/h.

RESULTS AND DISCUSSION

Flocculating filtration

Some of the results obtained in duration tests with the flocculating filter at wwtp Ede are summarized in table 3. The quality of the effluent of the wwtp Ede was improved by filtration with respect to turbidity, total suspended solids, COD, and phosphate. The dosage of 1 mg/l of iron affected the removal of COD and phosphate positively. However, because of the high quality of the effluent the improvement is limited. Due to the relatively high pH (>7) and the low concentrations of suspended solids and ortho-phosphate (<0.5 mgP/l) the absorptive coagulation with iron was hindered. Probably the use of aluminium as coagulant can improve the absorptive coagulation process.

With respect to E-coli a log-removal of 1 to 2 was achieved.

Table 3. Water quality parameters for effluent and filtrate (pilot plant wwtp Ede)

		wwtp effluent		filtrate		
		average	range	average	range	removal (%)
Filtration Rate: 10 m/h, Fe-dosage: 0 mg/l, Run Time: 51 h (average), 19-91 h (range)						
Turbidity	(NTU)	2.5	1.6-3.7	0.9	0.6-1.1	66.3
Total Suspended Solids	(mg/l)	5.5	3.0-7.4	1.5	1.0-1.7	73.6
COD	(mg/l)	34.1	26.4-37.5	34.7	33.8-35.6	-1.7
Phosphate	(mg/l)		0.16->0.83	0.14	0.11-0.17	
Filtration Rate: 10 m/h, Fe-dosage: 1 mg/l, Run Time: 20-29 h (range)						
Turbidity	(NTU)	2.2	2.0-2.4	1.3	1.2-1.6	39.4
Total Suspended Solids	(mg/l)	4.7	4.3-5.3	2.0	1.8-2.3	58.2
COD	(mg/l)	32.3	25.4-42.2	28.6	21.8-38.2	11.6
Phosphate	(mg/l)	0.24	0.18-0.31	0.12	0.08-0.21	49.3

Figure 1 shows the of effect different iron dosages on the Particle Size Distributions in wwtp effluent and filtrate. As can be seen in the figure an iron dosage had an effect on the number of the smallest particles (2-5 μm). Especially an iron dosage of 10 mg/l had a large effect on the number of the smallest particles in the filtrate. This increase of the 2-5 μm particles in the filtrate compared with the number at other iron dosages was caused by a break through of small iron flocks. COD analyses of wwtp effluent and filtrate showed a removal of COD during filtration. This is an indication that the suspended solids in the wwtp effluent which consist partly of COD were removed in the filter.

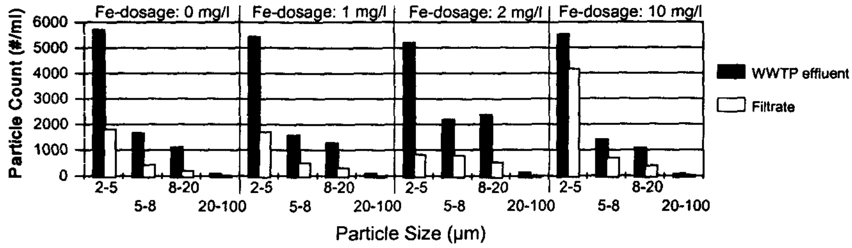

Figure 1: Particle Size Distributions in wwtp effluent and filtrate for different iron dosages at wwtp Ede.

Ultra filtration

The average achieved flux at the ultra filtration pilot unit at wwtp Elburg was 90 $l/m^2{\cdot}h$ or higher with a constant TMP of 0.6 and a recovery of > 90%. With the applied flushing procedures a constant and reliable operation could be achieved for several months. The filtrate showed an improved quality on turbidity, suspended solids (almost complete removal), phosphorus (50% removal) and COD (25% removal) (see table 4) and particles were removed to low concentrations (see figure 2). During analysis on bacteriological parameters no Coli-bacteria could be demonstrated in the ultra filtrate. Also, no faecal streptococcus and salmonella could be found in the ultra filtrate.

Table 4. Water quality parameters for effluent, pre filtrate and ultra filtrate (pilot unit at wwtp Elburg)

	Influent prefiltration	Prefiltration filtrate	Ultra filtrate
Turbidity (NTU)	2.6	1.9	0.05
Suspended Solids (mg SS/l)	2.7	1.8	0.0 (n.d.)
Total phosphorus (mg P_{tot} /l)	0.67	0.63	0.34
COD (mg O_2/l)	42	41	32

n.d.: not demonstrable in measurement

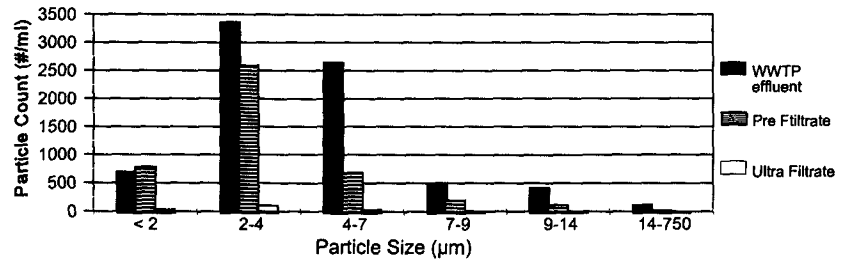

Figure 2: Particle counts of different particle sizes for effluent, pre filtrate and ultra filtrate at wwtp Elburg.

At the wwtp Ede the applied process conditions of the membrane ultra filtration unit resulted in an average flux of ≥ 105 $l/m^2{\cdot}h$ at an average TMP of 0.6 bar. Under this conditions advanced chemical cleaning was not necessary for three weeks. With a TMP of 0.9 bar the flux was approximately 160 $l/m^2{\cdot}h$, but advanced chemical cleaning had to be done twice a week. Recovery of this pilot unit was more than 90%. Again, the ultra filtrate showed improved quality parameters (see table 5). In contrary to the test at wwtp Elburg, for the tests at wwtp Ede prefiltration was not necessary, to achieve a constant high flux and reliable operation.

Table 5. Water quality parameters for effluent and ultra filtrate (during research at the pilot unit at wwtp Ede)

	Effluent wwtp Ede	Ultra filtrate
Turbidity (NTU)	4.2	0.05
Suspended Solids (mg SS/l)	6.1	0.0 (n.d.)
Total phosphorus (mg P_{tot} /l)	0.49	0.20
COD (mg O_2/l)	40	28

Combination of flocculating filtration and ultra filtration

Both pilot units, at wwtp Elburg as well as at wwtp Ede, were temporary operated with and without prefiltration. Although the prefilter did not produce high removal efficiencies, it appeared to be an important part of the total polishing concept. Figure 2 shows that larger particles, with a size range of 4 to 750 μm, are removed to a large extent by prefiltration. This conclusion corresponds with earlier German experimental results on membrane filtration (Griebe *et al.*, 1996). The results of the tests with the application of prefiltration differed at the two treatment locations. At the wwtp Elburg prefiltration was required to achieve constant high fluxes and reliable operation at a constant TMP. Without prefiltration the flux rapidly decreased from an average of 90 $l/m^2 \cdot h$ to a low level of 40 $l/l/m^2 \cdot h$, without successful cleaning possibilities by forward or backward water flushing. Only an advanced chemical cleaning was effective, but again within operation the flux decreased very rapidly. At the wwtp Ede operation of ultra filtration at a higher TMP (0.6 - 0.9 bar) was possible without prefiltration by a rapid sand filter. Without prefiltration and a constant TMP, fluxes did not rapidly decrease and it was possible to clean the membranes by water flushing.

Notwithstanding the fact, that the suspended solids content is higher in the effluent of the wwtp Ede (6.1 mg SS/l) compared with Elburg (2.7 mg SS/l), in Elburg prefiltration was necessary to make ultra filtration fully operational. So, the filterability of effluent by ultra filtration seems not to be related to the amount of particles or suspended solids in the effluent. The difference in necessity of the prefiltration may be determined by bio-fouling of the membranes due to biological activity of the ultra filtered water, by other types of scaling due to diverse components in the effluent, by differences in the particle size distribution in the effluent, by different local conditions or by seasonal fluctuations. Partly based on the results of the research described in this paper it is envisaged that the costs for the treatment of effluent consisting of flocculating filtration followed by ultra filtration will be app. Dfl 0.55 per m^3 or Dfl. 27.- per p.e.y. (excluding coagulant). The costs for flocculating filtration are app. Dfl. 0.05 per m^3 (excluding coagulant) (Van Nieuwenhuijzen, 1996) and for ultra filtration app. Dfl 0.50 per m^3 of which about 25% are formed by costs for membrane replacement (Kramer *et al.*, 1997). With an expected decrease in costs for membrane replacement in the near future the total costs will also decrease.

WWTP EFFLUENT AS HOUSEHOLD WATER IN THE TOWN OF EDE

In The Netherlands groundwater of good quality is increasingly considered as a scarce item. So, the drinking water company NUON Water has decided to construct a second water distribution system for household water for toilet flushing, washing machines and out-door tabs, which is fed with water of a lesser quality than the drinking water standard. This household water project is situated in the newly built residential area Kernhem in the town of Ede. Between the year 1999 and 2010, 4,600 houses for 11,000 inhabitants will be constructed in this neighbourhood where sustainability, quality and ecology are important points of departure. With the construction of a second distribution system for household water, 50% of the previous amount of drinking water can be replaced by water of inferior quality. Out of an investigative research polished effluent from the wwtp Ede was determined as the main source of the household water for Kernhem. Only 2% of the total effluent flow (approx. 200,000 m^3/year) is already enough to supply the area of Kernhem with household water. A second strong point is that the wwtp Ede is located only half a mile from the future neighbourhood. The basic effluent from the wwtp Ede will be polished onsite by flocculating filtration and/or ultra filtration. This polished effluent is called 'Basic Quality Water' and is discharged on a small surface water the 'Doesburgerslenk'. The water is recovered after a short ground passage and sold by the Waterboard Vallei en Eem to the water company NUON Water (Van't Oever, 1998). This case is a good example, which shows that wwtp effluent, and wastewater in general, is not a waste product but a valuable source of (re)usable materials.

CONCLUSIONS

- The combination of flocculating filtration and ultra filtration is applicable for an efficient production of household water for toilet flushing, washing machines, and outdoor taps and for the production of B- or E-water for industries.
- With respect to the treatment costs it is showed that the production of household water and B- or E-water becomes more and more economical feasible.
- The pilot plant investigations at several wwtp's showed that the local circumstances have an effect on the performance of both the flocculation filtration and the ultra filtration.
- Effluent of a wwtp is a valuable product. It can be utilized for the prevention of exsiccation and for the saving of drinking water of high quality.

ACKNOWLEDGEMENTS

We would like to thank Witteveen+Bos BV, especially Mr. J.F Kramer, for their cooperation and the graduation students Mr. J Pluim, Ms. M Weijs, and Ms. I Wasmus for their effort.

REFERENCES

Griebe T., Scaule G., Flemming H.C., (1996). A biocide-free anti-fouling strategy. Biodeteration and Biodegradation, 1996.

Kramer J.F., De Koning J., Van der Graaf J.H.J.M. (1997). Membrane filtration of effluent; investigative research at wwtp Enschede, Elburg and Ede. *Proceedings NVA-symposium Biologisch gezuiverd effluent; grondstof of eindproduct*, August 16 1997, Apeldoorn, The Netherlands (in Dutch).

Witteveen+Bos (1998). *Research on the exploitation of effluent from the wwtp Ede - An experimental research programme.* Research programme, Witteveen+Bos, Deventer, The Netherlands (in Dutch).

Oosthof J. (1996). *Reduction of the phosphate emission by effluent filtration.* MSc.-thesis, Department of Sanitary Engineering, Delft University of Technology (in Dutch).

Rienks J., Meinema K., (1995). Inventory and evaluation of effluent polishing techniques for wwtp's. *H_2O*, **28**(18), 541 - 545 (in Dutch).

Van Nieuwenhuijzen A.F. (1996). *Optimization of flocculating filtration of wwtp effluent.* MSc.-thesis, Department of Sanitary Engineering, Delft University of Technology (in Dutch).

Van der Graaf J.H.J.M. (1997). Advanced wastewater treatment. *Proceedings Third workshop Netherlands-Japan*, May 25 1997.

Van der Graaf J.H.J.M., Van Nieuwenhuijzen A.F. (1998). Experiments on high rate effluent filtration in the Netherlands. *Proceedings IAWQ Biennial Conference*, Vancouver.

Van der Graaf J.H.J.M., Kramer J.F., Pluim J., De Koning J., Weijs M. (1998). Experiments on membrane filtration of effluent at wastewater treatment plants in the Netherlands. *Post academic course on advanced wastewater treatment,* February 1998, Delft, The Netherlands.

Van't Oever (1998). Case 2: Household water. *Post academic course on advanced wastewater treatment*, February 1998, Delft, The Netherlands (in Dutch).