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Mekorot's research activity in technological improvements for the production of unrestricted irrigation quality effluents

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Abstract

Israel is a country situated in a semi-arid zone with insufficient natural water resources. Due to the excessive abstraction as compared to water availability, some of the seashore aquifers have been depleted and there is a danger of excessive salinity in the aquifers. Wastewater effluent reuse and desalination have become the main alternative sources of water to compensate for the future water shortage. The main reuse activity in Israel is agricultural irrigation (65% of the connected sewage in Israel is reused for this purpose), while most technological efforts are spent for the improvement of unrestricted irrigation quality water. This paper presents the recent years' research activity, in Mekorot National Water Co., in tertiary effluent treatment and effluent desalination in order to achieve high quality water suitable for unrestricted agricultural reuse as well as for public park irrigation, industrial reuse and aquifer salinity reduction. .

Keywords: SAT; UV disinfection; Biofilm; UF/RO

1. Introduction

In the last decade and mainly from 1997, annual rainfall rates have dropped drastically in Israel. The increase in the demand for water accompanied by the declining water levels and quality reduction in the aquifers, and the need to accommodate and treat large amounts of urban wastewater, triggered the process, which led to the construction of many wastewater treatment plants (WWTP) that treat the effluents to at least secondary effluents quality (20 mg/l BOD and 30 mg/l TSS) disinfected by chlorine before reuse in agricultural irrigation.

Today, more than 290 MCMY of secondary chlorinated or tertiary treated effluents are reused in agricultural irrigation.

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Most of the tertiary treated and reused effluents are produced in three types of reuse projects:

1. The Dan Region Reclamation Project is the largest in Israel that produces "Accidental Drinking Water" quality for agricultural reuse by the SAT process following secondary mechanical biological process. The plant was first operated in 1977 and has been expanded in several stages during the 27 years of operation, with the latest expansion in 2003 that will enable to produce more than 140 MCMY reclaimed water.

2. The Hakishon Project is the second largest reclamation project in Israel that produces by long storage polishing reservoir process and disinfection following secondary mechanical biological process, unrestricted irrigation quality water. It was expanded also in several stages (lately in 2001) to more than 35 MCMY.

3. Other WWTPs treat and produce mostly secondary chlorinated effluents for irrigation.

In order to improve the quality and quantity of effluents for unrestricted irrigation and replace the fresh water that is used for this purpose, further technological improvements had to be introduced.

In parallel, out of concern for health risks, the Ministry of Health (the Halperin Committee) renewed in 1999 the old (1974) guidelines for water reuse (Table 1). In 2003, concerned for the increasingly saline fresh water aquifers, the government appointed another committee (Inbar Committee) which issued new recommendations designed to limit, besides the organic parameters, the nitrogen, phosphorous, boron and chloride concentrations in effluents for unrestricted irrigation and effluents to be discharged to water bodies. In the current situation, the 1999 guidelines are applied and the Inbar committee recommendations are still awaiting approval.

In the last decade, Mekorot, Israel National Water Company, has initiated a series of research projects intended to improve the technologies used to produce effluents mainly for unrestricted irrigation but also for public irrigation and industrial reuse. The main objective was to improve the technologies so as to fit them to the new water reuse guidelines.

Table 1
1999 Halperin Committee guidelines vs. 2003 Inbar Committee proposal

Parameter	1999 Guidelines	Inbar Committee proposal
BOD, mg/l	—	10
TSS, mg/l	10	10
Fecal coliforms, MPN/100	10	10
Residual chlorine (minimum), mg/l	1	1
Contact time (minimum), min	30	30
Total nitrogen, mg/l	—	25
Ammonia, mg/l	—	20
Total phosphorus, mg/l	—	5
Boron, mg/	—	0.4
Chloride, mg/l	—	250

The main challenges were:

1. Improvement of the other tertiary treated effluents to meet the unrestricted irrigation guidelines.

2. Improvement of the production capacity of the largest reuse project — Shafdan.

3. Prevention of salting of the aquifers by other alternatives to SAT like double membrane processes.

2. Description, results and discussion of different research projects

The different research projects relevant to the above mentioned challenges presented in this paper are:

1. The optimization of two common disinfection methods (chlorine and UV) to produce water for unrestricted reuse in agricultural irrigation [1–3].

2. Investigation of pre-treatment methods for the prevention of fouling of the infiltration fields

in a (SAT) system. Conventional sand filtration or UF [4].

3. Monitoring and treatment of biofouling in effluent carrying pipelines [5].

4. Manganese dissolution in the soil–aquifer treatment (SAT) system [6].

5. Effluent desalination by the use of MF/UF pretreatment and low fouling RO membranes [7].

2.1. The optimization of two common disinfection methods (chlorine and UV) to produce effluents for unrestricted reuse in agricultural irrigation

The research program (that will end next year) includes the optimization of two common disinfection methods (chlorine and UV) to produce effluents for unrestricted reuse in agricultural irrigation. This optimization will be performed taking into account the disinfection effect to bacteria, protozoa and viruses, the DBP formation, photoreactivation and regrowth, and biofilm formation.

In the first part of the this research project that was already completed, the use of chlorine, to produce in situ chloramines in filtered effluents or flocculated-filtered effluents containing ammonia, was compared to the use of low-pressure UV (LP–UV).

In the second part, photo-reactivation and re-growth phenomena will be studied. It is known from the literature that LP–UV can be effective against bacteria and specially protozoa which is not affected by chlorine, but photo-reactivation or dark biofilm re-growth in distribution lines may occur since not all the DNA is damaged. It is also known that medium-pressure UV (MP–UV) can seriously damage the DNA and prevent reactivation and re-growth. But MP–UV may also cause more formation of DBP's.

Chlorine is known as a strong disinfection agent (for bacteria and viruses) and as a preventive agent for biofilm regrowth but is less effective against protozoa, forms a weaker disinfectant (chloramine) with the ammonia in effluents and there is a need for large concentrations of chlorine in presence of organic matter if a residual free chlorine concentration is needed. On the other hand, chloramines formed by the in situ chlorination of ammonia containing effluents, can have a residual disinfection effect, prevent biofilm formation in long distribution lines and produce low concentrations of DBP's. The research will compare the benefits and disadvantages of these disinfectants.

2.1.1. Pilot plant

The pilot plant (Fig.1) is designed to filter secondary effluents at Natanya mechanical–biological WWTP (36,000 m^3/d) with nitrification–denitrification, by deep bed high-rate (15 m/h) filtration using two filters in parallel (flow rate 5 m^3/h each), with poly-aluminum chloride (PAC) at 1–2 mg/l doses or without flocculant, and disinfection either by chlorine or by LP–UV lamp (WEDECO). Filter runs lasted 6–8 h. Mainly, physical (turbidity, TSS, PSD, UV abs.) and microbiological parameters (faecal coliforms, *Clostridium perfringens*, bacteriophage, *Cryptosporidium* and *Giardia*) were analysed.

2.1.2. Results

The Point Source Summation (PSS) method designed to calculate the UV intensity profile in a well-mixed photoreactor [8] was used to calculate the UV dose. The lamp aging, transmittance of the water sample and residence time in the UV chamber (determined by the flow rate) was also considered in the dose calculations.

The change in the residual fluence rate as a function of turbidity and number of particles <10 μm during a typical filtration–disinfection cycle was investigated. The residual fluence rate increased as the turbidity and the number of particles <10 μm decreased showing all along an inverse relationship. The fluence rate was affected by the turbidity and the small particles rather than the particles >10 μm which may affect the microorganism removal efficiency.

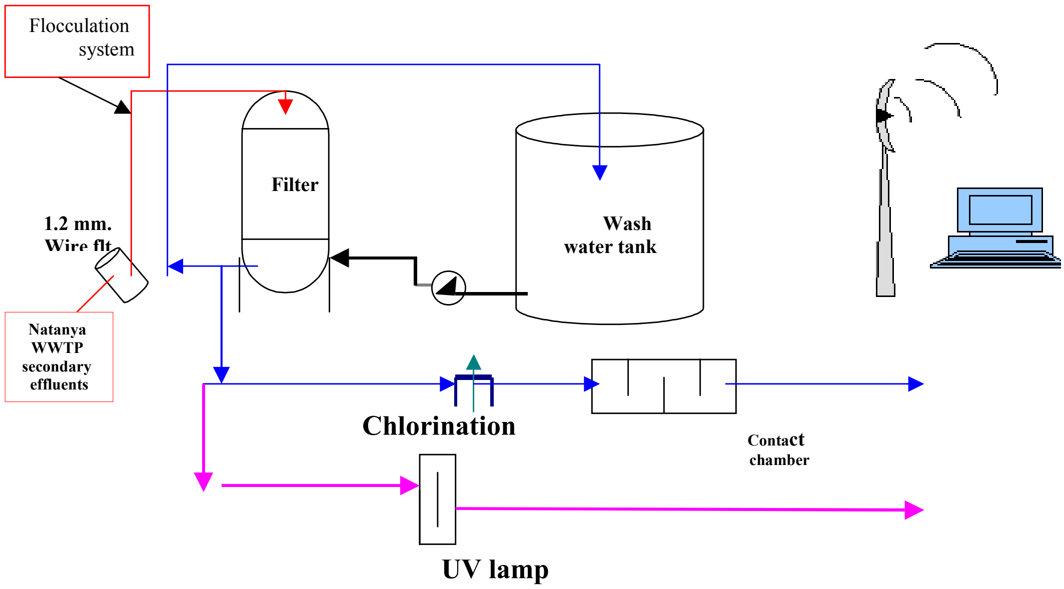

Fig. 1. Pilot plant for comparison of filtered and flocculated-filtered effluents disinfected with chlorine or UV.

The 10 FC/100 ml regulation for unrestricted irrigation was met by a LP–UV dose of >55–60 mWs/cm^2 with non-flocculated-filtered effluents while the same quality could be obtained by >35–40 mWs/cm^2 dose for flocculated and filtered effluents (Tables 2 and 3). The results relate to the hot summer period. At the same period Tables 4 and 5 show that disinfection with 4 mg/l residual chlorine (as chloramine) does not always result in an unrestricted effluent quality.

Table 2
UV disinfection of non-flocculated and filtered effluents

Experiment No.	1	2	3	4	5	6	7	8	9
UV dose, mW.s/cm^2	47.7	83.3	84.8	60.4	58.3	63.5	62.7	62.1	33.0
Effluent turbidity, NTU	1.2	1.2	2.2	1.9	1.3	1.2	1.5	2.0	1.8
N_0–FC_{in}, /100 ml	90,000	300,000	580,000	620,000	590,000	630,000	65,000	500,000	360,000
N_0–FC_{out}, /100 ml	1	1	1	19	2	6	1	16	21

Table 3
UV disinfection of flocculated and filtered effluents

Experiment No.	1	2	3	4	5	6	7	8	9
UV dose, mW.s/cm^2	48.9	86.0	87.0	61.8	60.7	64.4	63.7	63.1	33.7
Effluent turbidity, NTU	0.7	0.7	1.2	1.1	0.7	0.6	1.4	1.7	1.1
N_0–FC_{in}, /100 ml	60,000	140,000	450,000	620,000	370,000	630,000	51,000	500,000	300,000
N–FC_{out}, /100 ml	1	1	1	1	1	6	6	4.4	9

Table 4
Chlorine disinfection of non-flocculated and filtered effluents

Experiment No.	1	2	3	4	5	6	7	8	9
Residual chlorine, mg/l	4	4	4	4	4	4	4	4	4
Contact time, min	30	30	30	30	30	30	30	30	30
Effluent turbidity, NTU	1.2	1.2	2.2	1.9	1.3	1.2	1.5	2.0	1.8
N_0–FC_{in}, /100 ml	90,000	300,000	580,000	620,000	590,000	630,000	65,000	500,000	360,000
N_0–FC_{out}, /100 ml	1	0	5	18	80	38	18	1	

Table 5
Chlorine disinfection of flocculated and filtered effluents

Experiment No.	1	2	3	4	5	6	7	8	9
Residual chlorine, mg/l	4	4	4	4	4	4	4	4	4
Contact time, min	30	30	30	30	30	30	30	30	30
Effluent turbidity, NTU	0.7	0.7	1.2	1.1	0.7	0.6	1.4	1.7	1.1
N_0–FC_{in}, /100 ml	60,000	140,000	450,000	620,000	370,000	630,000	51,000	500,000	300,000
N_0–FC_{out}, /100 ml	0	0	6	2	22	33	20	0	56

Using UV doses of 40–80 mW.s/cm^2 (both for flocculated or non-flocculated filtered effluents) 4–6 logs of faecal coli (FC), 1–3 logs of coliphages (MS2) and 1–5 logs of Clostridium perfringens (CP), were inactivated (Table 6).

Fecal coliforms (4–6 logs), coliphages (2–3 logs) and *Clostridium Perfingens* (1–5 logs) inactivation was achieved with 4 mg/l of chloramines formed in situ by the chlorination of ammoniated effluents (Table 6).

The pre-flocculation of the effluents by PAC was effective. 46–64% of the turbidity, 36–89% of TSS and 54–88% of total particles were removed by filtration without flocculant as compared to 67–83% turbidity and 40–93% TSS removal and 87–95% total particles removal for flocculated filtered effluents.

2.1.3 Conclusion

UV fluence rate for effluents is affected by particles smaller than 10 µm and by turbidity that is dominated by particles in the smaller range. Also, a LP–UV dose of, 35–50 mW.s/cm^2 is required while applying 1–2 mg/l PAC as flocculant to comply with the Israeli unrestricted irrigation bacteriological regulations of 10 faecal coliforms per 100 ml. For non-flocculated filtered effluents 60–70 mW.s/cm^2 UV dose is required to have the same results. Disinfection with 4 mg/l residual chlorine (as chloramine) does not always produce an unrestricted effluent quality. In the summer (28–33°C), due to high bacterial activity, higher doses are required.

2.2. Investigation of pre-treatment methods for the prevention of fouling of the infiltration fields in a (SAT) system. Conventional sand filtration or UF

The Dan Region Reclamation Project (Shafdan) is the largest wastewater treatment and reclamation project in Israel. In 2003 it reclaimed 128 MCMY of wastewater from the Tel-Aviv Metropolitan area and several other neighbouring municipalities. The wastewater is treated in an activated sludge plant with single-stage simultaneous nitrification–denitrification. After secondary treatment, the effluent is then further treated

Table 6
Microorganisms removal efficiency by UV and by chlorine

Sample No.	Flocc. filtered effl. + chloramine				Unflocc. filtered effl. + chloramine				Flocc. filtered effl. + UV				Unflocc. filtered effl. +UV			
	Residual chlorine (mg/l)	log removal			Residual chlorine (mg/l)	log removal			UV dose (mW.s/cm^2)	log removal			UV dose (mW.s/cm^2)	log removal		
		MS-2	CP	FC		MS-2	CP	FC		MS-2	CP	FC		MS-2	CP	FC
1	4				4				33.7	–3	–1	–5	33	–2	–1	–4
2	4				4				63.1	–1	–2	–5	62.1	–1		–4
3	4			–5	4			–5	63.7			–4	62.7			–5
4		–2	–3	–6		–3	–5	–6		–3	–3	–4		–2	–2	–5
5		–2	–3	–6		–2	–1	–4		–2	–1	–6		–2	–1	–5
6							–3	–5		–2	–2	–4			–1	–5
7	4	–3	–2	–4	4	–3	–3	–4	64.4	–3	–3	–5	63.5	–3	–3	–5
8	4	–3		–4	4	–3		–4	60.7	–3		–5	58.3	–3		–5
9	4	–2	–5	–5	4				61.8	–2	–5	–6	60.4	–2	–2	–5
10	4			–5	4			–5	87			–6	84.8			–6
11	4	–3	–5	–5	4	–3		–5	86	–3	–3	–5	83.3	–3	–3	–5
12	4			–5	4			–5	48.9			–5	47.7			–5

through recharge to the aquifer and subsequent recovery using a specific Soil Aquifer Treatment (SAT) system, with retention time of 6–12 months. This process was developed for the Dan Region Reclamation Project. The SAT system improves the effluent quality to an unrestricted irrigation and accidental drinking water quality standard.

The soil aquifer treatment is based on rapid infiltration of pretreated wastewater effluent to the confined local aquifer by means of infiltration basins. The infiltration is usually conducted at intermittent schedule of flooding/drying cycles. In 2003 the average hydraulic load for all infiltration fields was 120 $m^3/m^2/y$, while in summer the high temperatures enabled 130 $m^3/m^2/y$ hydraulic load in winter the hydraulic load was only 110 $m^3/m^2/y$.

In the course of 25 years of operation, there have been chemical changes in the soil composition of the infiltration fields and also some physical clogging has slow down infiltration rates.

In the period 1999–2004, in order to improve the infiltration capacity, 3 types of filtration experiments were conducted:

1. Pretreatment before SAT by wire filtration or sand filtration (1999–2003).
2. In view of the obtained results another research was started in (2004) that aimed to investigate how the clogging of the fields was related to the effect of dissolved organic matter (DOM) concentrations in the infiltered effluents and in the soil solution.
3. Pretreatment before SAT by ultrafiltration (UF). This method was checked in 2003 to see if effective removal of suspended and colloidal solids could improve SAT.

2.2.1. Pretreatment before SAT by wire filtration or sand filtration

The purpose of this research was to find the most feasible method to improve the infiltration rates of recharged secondary effluents by conventional filtration methods (wire filtration or sand filtration).

The investigation was conducted in two levels:

- Small pilot plant in new constructed infiltration fields (each 20 m^2) in a previously non-flooded area.
- Field experiments in a mature infiltration field where pre-filtered and unfiltered effluents were recharged in 100 m^2 constructed infiltration fields.

2.2.1.1 Small pilot plant

The experiment was run in new infiltration fields constructed near the WWTP and not in the mature infiltration area. Secondary effluents filtered by five different filtration methods and the unfiltered secondary effluents were recharged in 20 m^2 area infiltration fields, at a starting infiltration rate of 12 (m/d). The filtration methods used were:

a) Shallow-bed travelling-bridge filter.
b) 7 μm sieve filter.
c) Deep bed pressure filter.
d) Shallow bed pressure filter.
e) 700 mm wire pre-filter.
f) Unfiltered effluents (coarse filtration by 3000 mm brush filter only).

Recharging the effluents pretreated by the different filtration methods and comparing the infiltration rates relative to the untreated secondary effluents, the most feasible way of improvement could be obtained.

It was shown that in previously non-flooded fields where the sand is still clean and organic matter did not adsorb to the grains, removal of particles greater than 1 micron by surface or deep bed filtration improved considerably the infiltration rates.

The order of best performance for different treatments was: deep bed pressure filter (10.9 m/d), shallow bed gravity filter (10.2 m/d), shallow bed pressure filter (9.5 m/d), 7 μm sieve filter (6.25 m/d), wire pre-filtered (2.7 m/d), untreated effluents (1.75 m/d).

2.2.1.2. Field pilot plant

Based on these results, the second stage included optimization of operational conditions in the actual infiltration fields by building 100 m^2 fields in the middle of a mature infiltration field. At this stage, three kinds of effluents were compared:

a. Deep-bed filtered (v =15 m/h) secondary effluents.
b. Effluents filtered through 100 and 400 μm wire filters.
c. Unfiltered effluents.

The infiltration rates varied between 2–4 m/d. These rates were much slower than the ones obtained in the previously non-flooded fields. In mature fields the differences in hydraulic loading between deep-bed filtered effluents, wire filtered effluents and unfiltered effluents were found to be much lower than in the recently flooded fields. Even drinking water that was recharged in these mature infiltration fields did not considerably improve the hydraulic loading as compared to unfiltered effluents. 10–15% improvement in hydraulic loading was obtained by 100–400 μm wire filters, depending on soil characteristics, seasonal conditions, soil and water temperature and recharged effluent characteristics.

2.2.1.3. Conclusion

The research showed at this stage that an effective pre-filtration can help improve infiltration velocities previously non-flooded infiltration fields but has much less effect in mature infiltration fields with a high organic concentration in the upper layers of the SAT system.

2.2.2. The investigation of the causes of clogging of the SAT system

Following the results of the multi-annual investigation that showed any type of filtration as pretreatment to be less effective in a mature infiltration field, an investigation of the causes of clogging of the SAT system was started in 2004.

Preliminary results show that accumulation of DOC by adsorption to the sand grains causes a hydrophobic media that decreases the infiltration rate of water through the SAT system.

This is still under investigation but it could be a good explanation for the case where in a mature infiltration field even drinking water did not infiltrate efficiently.

2.2.3. Pretreatment before SAT by ultrafiltration (UF)

In that case the methods for the improvement of the infiltration and improvement of the final quality of the water by preventing particulate organic and inorganic matter down to 0.01–0.05 μm were investigated. The evaluation of most effective membrane pretreatment was performed by two UF systems:

a. X-Flow – Norit, encased type membranes
b. ZeeWeed 1000 submerged type membranes.

The main characteristics of these membranes are shown in Table 7.

Table 7
Characteristics of the two UF membranes investigated in the Shafdan pilot plant

Parameter	After secondary treatment			After UF treatment		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Turbidity, NTU	2.5	6	21	0.05	0.15	0.3
TSS, mg/l	6	8	13	0.1	0.9	1.3
TOC, mg/l	14	18	33	9	10	15
BOD, mg/l	5	7	10		<1	

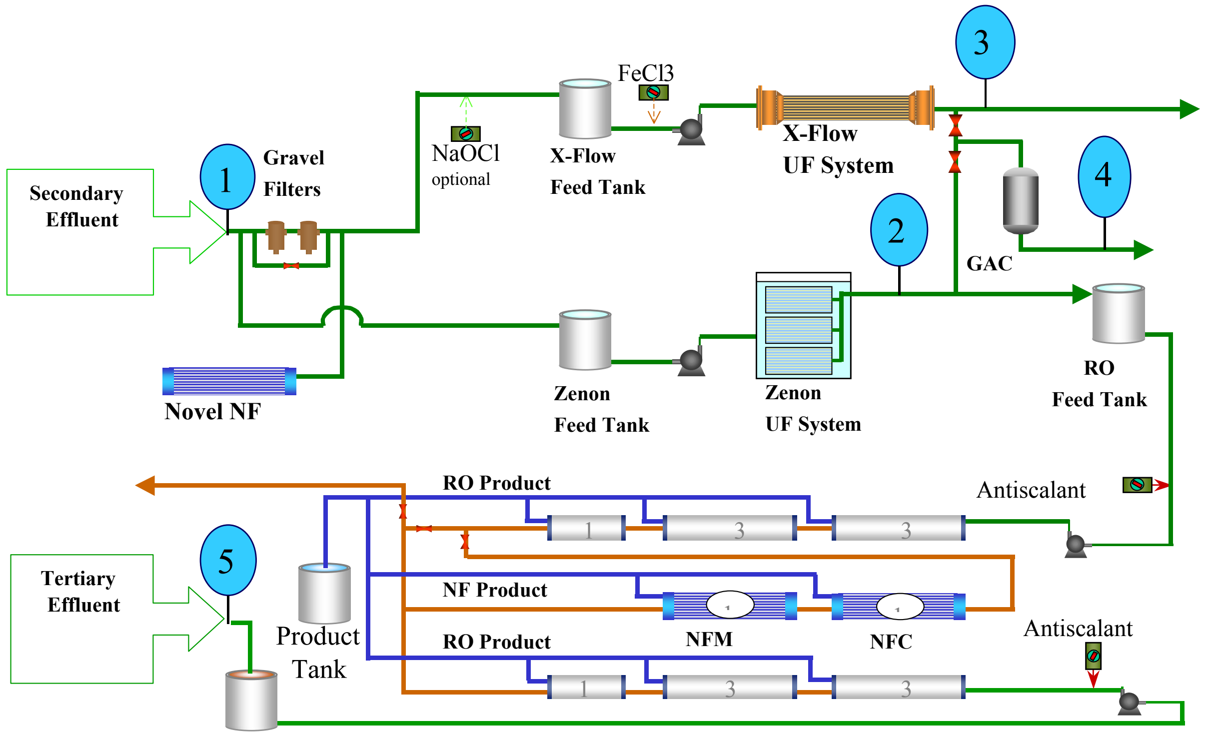

Fig. 2. Schematic diagram for the Shafdan UF and RO pilot plant.

In the pilot plant (Fig. 2) the secondary effluents are pre-filtered through gravel filters and than pretreated by the two UF systems in parallel. The composition of the secondary effluents and the UF effluents are given in Table 8.

2.2.3.1. Brief conclusions of the research

1. The X-Fow UF membrane produced a good bacteriological quality permeate when feed prechlorination was applied.

2. Due to prechlorination and in-line coagulation the TOC (colloidal and suspended matter) removal was improved by almost 30%.

3. Optimization of the main operational parameters allowed a decrease in wash water quantities and washing time of 8.8% and 10.1% accordingly

Table 8
Chemical composition of secondary and UF effluents at the Shafdan plant (2002–2003)

UF model	Type	Total area (m^2)	Configuration	Nominal pore diameter (micron)	Max TMP (bar)	Filtration principle
X-flow S-150 UFCM5	Encased	45*	Inside–out hollow fiber	0.08	0.8	Dead-end
ZeeWeed 1000	Immersed	110**	Outside-in hollow fiber	0.02	0.8	Dead-end

* Inner area of 2 elements installed in a pressure vessel of 3m. length
** Outer area of 3 elements installed in a feed tank

in the summer period and of 7.4% and 4.2% in the winter period.

4. For the ZeeWeed membrane which was operated later, preliminary trials indicated stable performance at 20–30 lmh fluxes.

There was major improvement in TSS (particulate and colloidal) but no difference in TDS. The UF permeate still contains a lot of organic matter, nitrogen and phosphate that can be further treated in the SAT system. If an alternative solution for SAT is to be sought further investigations of pre- or post- UF membrane treatments should be conducted. These include: filtration of UF permeate through GAC and/or advanced oxidation processes (AOP).

2.3. Monitoring and treatment of biofouling in effluent carrying pipelines

In the case of long distance distribution of effluents the concentration of dissolved organic matter (DOM), suspended solids, different types of micro and macro organisms under high ambient temperatures, can cause rapid biofilm growth, leading to hydraulic problems in the distribution and the irrigation systems.

The aims of this study were:

1. To characterize the biofilm development and shifts in microbial population.
2. To compare chemical bio-fouling control regimes.
3. To monitor biofilm development, seasonal changes and effect of the treatment.

During the first stages of biofilm formation or at a mature stage either the attachment effect or the detachment effect (shear forces) dominates the process. The net balance determines the accumulation rate in different seasons (Fig. 3). Several parameters like flow velocity, temperature and biocides affect the biofilm community, and should be take in account in keeping the pipes free from biofilm.

A pilot plant similar to the 7 km 54″ pipe has been built in order to investigate the biofilm build-up in the secondary effluents carrying pipe. The pilot plant is based on five parallel 4″ cement coated steel pipes, where different conditions are tested. Each pipe contains a number of biological analysis chambers (made of steel) used for observation of the biofilm formation. In each pipe the head-loss and flow rates at the first 10 m. are monitored and noted, so that the Hazen-Williams coefficient can

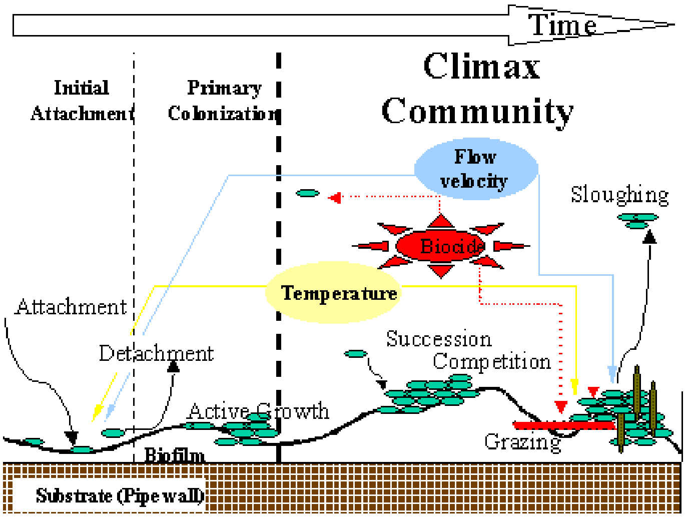

Fig. 3. Attachment, detachment and accumulation of the biofilm.

be calculated. The daily flow rate fluctuations in 54″ pipeline is adjusted to the pilot 4″ pipes using equal shear stress principle.

Liquid chlorine was used as a preventive agent for biofilm formation. An optimization for the dosage and addition program was carried and the biofilm formation monitored on-line by head-loss measurements. The biological, microbiological, and chemical analyses and the measured temperatures, showed a good correlation with the Hazen–Williams coefficient.

The direct measurement of biofilm was performed by quantifying total dry matter, inorganic and organic matter, calcium and silica from two half pipes, in each deposit chamber. An indirect measurement of biofilm was conducted by analysing specific biofilm constituents: polysaccharides, protein and microbial activity within the biofilm (live/dead staining).

An attempt was made to obtain an overview of structural diversity of microbial communities by using gradient gel electrophoresis analysis. It is based on the separation of ribosomal gene sequence directly amplified from community DNA by using conserved primers on a denaturing gel according to their melting point.

2.3.1. Results and discussion

A few factors that affect biofilm formation were identified:

1. Temperature.
2. Feed effluent characterization.
3. Attachment strength of the different bacterial strains.
4. Flow rate (or flow velocity) that affects the detachment.
5. The effect of biocide on bacteria and polysaccharides dissolution.

Two distinct formation steps were observed:

a. Biofilm formation stage (young biofilm):

High temperatures in summer (28–33°C) affect the feed composition and the growth rate. The fact that no biocide was applied accelerated biofilm growth in the build-up period (biofilm formation). At this stage the detachment rate was minor.

b. Mature biofilm:

Once the biofilm is mature, there were seasonal changes in the microbial community diversity. During a period of 80 days in the spring season, rapid changes in the number of *Chironomidea* habitats (tubes) and micro- and macro-organisms were observed. On the other hand there is stabilization in the biofilm thickness due to grazing by macrobiota, and increased detachment on the upper biofilm layers. Biofilm thickness reaches a plateau state. Even after 80 days in the spring season, no particular change in the macroorganism population was seen in the treated samples. This can be explained by the low amount of *Chironomidea larvae* and tubes count in samples treated by chlorine that affected the bacterial attachment strength.

2.3.2. Chlorine treatments

The best chlorine treatment for keeping a clean pipe was found to be 7 times a week, 2 h a day, 10 mg/l chlorine injection. Using this treatment even in the hot summer season the degree of fouling was minor.

2.3.3. Conclusion

The head-loss measurement and other analyses results showed that:

For the untreated pipe:

a. In a relatively cold (10–15°C) and free of *Chironomidea* (non-biting midges) period, the biofilm growth is slower and is differently characterized. Filamentous type organisms develop in the absence of *Chironomidea* and lower macroorganisms like *Oligochaeta* were observed. As a result, lower head loss increase was observed (or Hazen–Williams coefficient of 140 going down to 85 in 45 days)

b. In the summer (May–September) season *Chironomidea* was very dominant. In this season, the rate of biofilm formation is very high. This can be illustrated by the fact that the head-loss increase resulted in a decrease in the Hazen-Williams coefficient from 140 to 70 in a fifteen-day period. The attachment of *Chironomidea* habitats strongly affected the Hazen–Williams coefficient.

For the treated pipes:
10 mg/l dose of liquid chlorine at addition mode of 7 times a week 1 h in the morning and 1 h in the afternoon was able to maintain the pipe clean even at the hottest season. The *Chironomidea* habitats that can serve as a basis for more bacterial attachment were prevented from attaching to the pipes. The cleanliness of the pipe was also approved by the relatively low polysaccharides and protein mass (2 mg/mm of pipe wall) compared to the untreated pipe.

2.4. Manganese dissolution in the SAT system

Studies that have been performed over the past few years show a problem as a result of manganese and iron dissolution from the soil structure of the infiltration basins into the effluent. Its movement is then into the depth of the aquifer and accumulates in the reclaimed water. The main problems that are foreseen from the dissolving of the manganese in the reclaimed water are the possibility that the reclaimed water containing particulate oxidised manganese would cause blockages in the agriculture irrigation systems.

Most of the manganese arrives in the main distribution line of the Dan Region Project (The Third Line) primarily from a small number of wells where the concentration of manganese is very high. Along the Third Line, the dissolved manganese oxidizes with the assistance of bacteria that are found in biofilms, which have grown on the pipe walls, to create a black layer on the pipe wall (up to 1 cm.). When hydraulic changes occur in the pipe, portions of the thick black layer, which has built up, dislocates from the pipe wall and travels with the water to the irrigation systems. Mekorot is putting big efforts in reducing the manganese source and preventing clogging by effective filtration.

Research on “Chemical Changes in the Deep Soil/Sediment Profile of the Recharge Basins at the Shafdan site” conducted during 1997–2002 has shown the following geochemical changes:

1. The redox potential in the soil of the re-charge basins was found to cycle with the repeated effluent flooding and drainage sequences.
2. The degradation of accumulated organic matter and the lack of oxygen (anaerobic con-ditions) caused acidic dissolution of carbonates and reductive dissolution of manganese oxides and probably also of iron oxides.
3. Some elements showed accumulation in the top horizons of the soil/sediment profile and part of them (Mn, Co, V and probably Fe) were leached from the top horizons.
4. These geochemical processes results in some soil plugging and in some reduction of the hydraulic efficiency of the SAT system.

The abovementioned conclusions were made by studying 2-m depth SAT soil layers.

Lately (in 2004) a new study was conducted on parts of the SAT system going down to the whole depth of the unsaturated zone. The preliminary hypothesis is that the dissolution of manganese occurs mainly above relatively impermeable clay layers which slow down the vertical flow of the water through SAT. Since the horizontal flow too is much slower anaerobic conditions prevail which eventually cause the manganese dissolution.

2.5. Effluent desalination by the use of MF/UF pretreatment and low fouling RO membranes

As a result of improving wastewater treatment, the available treated effluent amount is continuously increasing. These effluents together with other marginal waters will reach a total of

500 MCMY in 10–20 years. There is an economic potential for desalination of these marginal waters. Reported cost studies of desalination of effluents by IMS systems (UF/RO) indicate an average cost of \$0.4/m^3, while the average specific energy consumption is 1.5 kWh/m^3 while for seawater desalination the average cost of unit water is \$0.8/m^3 and the average specific energy consumption is 6.0 kWh/m^3 showing the economic advantage of effluent desalination.

A research conducted, in the framework of the EU research framework (RENOMEM), in a Mekorot pilot plant in Shafdan, had the aim to optimize the RO or the hybrid RO/NF system by applying the latest developments in effluent desalination such as special membranes with reduced fouling sensitivity and proprietary antiscalants aimed to avoid specific scales like calcium phosphate scale.

This study was conducted together with the evaluation of UF membrane pretreatment before SAT that was already discussed (Fig. 2).

The setup for the RO train can be seen in Fig. 2. The pilot setup consists of seven 4″ elements which are fed with the X-Flow UF membrane effluent. Antiscalants are added before the RO. Brine from the RO process is treated by two 2.5″ NF membranes. Another similar RO train is fed directly by tertiary effluents and operates at the same conditions as the first train.

2.5.1. Brief conclusions of the research

1. High flux of 21 lmh was obtained for the RO system when fed with secondary effluents treated by UF. This flux is at the higher limit of reported typical value range of 17–21 lmh.

2. Chloramination of the feed kept the biological growth in the RO system at a low level and stabilized the membrane performance, in spite of high organic content. The 3–6 mg/l chloramine dose that was used is almost similar to the typical range of 2–5 mg/l chloramines shown to be efficient bio-stat for UF/MF treated water. Low cleaning frequency (3 months) has been used so far, which is according to published data.

3. Stable operation of RO train fed by tertiary effluent without pretreatment, produced a recovery of 63% and a flux of 21 lmh.

4. The investigation of the performance of two NF$_{270}$ spiral wound 2.5″ membranes for brine desalination (one conventional and one modified) indicated that the modified element was more stable than the conventional one also exhibiting higher flux and salt rejection. It seems that the effect of modification was significant in increasing the stability against calcium phosphate scaling.

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References

[1] T. Kraitzer, A. Brenner, R. Messalem and H. Cikurel, Comparison of chloramine and UVdisinfection of filtered and unfiltered secondary effluents, MSc thesis of T. Kraitzer, Ben Gurion University, Beer-sheva, 2005.

[2] T. Kraitzer, H. Cikurel, N. Tsadik, A. Nasser, U. Zukerman, A. Meir, A. Aharoni and A. Adin, Particle size distribution and filter performance in association with UV disinfection of wastewater effluents, Presented at IUVA 3rd International UV conference, British Columbia, Canada, 24–27 May 2005.

[3] A. Nasser, A. Adin, H. Cikurel, U. Zukerman, A. Aharoni, N. Tsadik, A. Meir and T. Kraitzer, First year report on UV Disinfection of Tertiary Treated Effluents for Unrestricted Irrigation, preliminary report for a 3 years' research project for the Water Commissioner, 2004.

[4] T.N. Icekson, O. Avraham, J. Sack and H. Cikurel, Water reuse in Israel — the Dan Region Project: evaluation of water quality and reliability of plant's operation. Wat. Sci. Tech. Water Supply, 3(4) (2003) 231–237.

[5] J. Sack, H. Cikurel, T.N. Icekson, M. Danon, P. Harmant, B. Teltch, B. Limoni, U. Zuckerman, M. Halpern, M. Broza and Y. Cohen, Monitoring and treatment of biofouling in effluent carrying pipelines

in Dan Region WWTP, Biofilm Conference, Porto, 2002.

[6] A. Banin and C. Lin, Chemical Changes in the Deep Soil/Sediment Profile of the Recharge Basins at the SHAFDAN Site, Final Project Report to Mekorot Water Co. Faculty of Agricultural, Food and Environmental Quality Sciences, The Hebrew University, Israel, 2003.

[7] A. Thoma, Y. Gelman, M. Priel and P. Glueckstern, Mekorot's research activity in advanced tertiary treatment and desalination of secondary effluents, Proc. IDS 6th Annual Conference — Upgrading Groundwater and Recycled Water by Desalination, 2003, pp. 131–140.

[8] S.M. Jacob and J.S. Dranoff, Light intensity profiles in a perfectly mixed photoreactor. AIChE J., 16(3) (1970) 359.