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# SLOW SAND FILTRATION FOR WASTEWATER IRRIGATION


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**TABLE OF CONTENTS**


| | Page |
|---|---|
| Executive Summary | 3 |
| Section I: Scientific | 4 |
| A. Research Objectives | 4 |
| B. Research Accomplishments | 4 |
| C. Scientific Impact of Collaboration | 8 |
| D. Project Impact | 8 |
| E. Strengthening of Developing Country Institutions | 9 |
| G. Future Work | 9 |
| Section II: Managerial | 9 |

## EXECUTIVE SUMMARY

Groundwater and sea water pollution and the water shortage in Dakar-Thies region are the driving force behind this research project, which aims at the development of design and operational parameters for effluent treatment by simple slow sand filtration (SSF). The scientific objectives of the proposed research are to better understand the mechanisms governing slow sand filtration of effluents and to develop appropriate design and operation parameters.

The 4 years investigation is based on pilot plant work in Dakar, Senegal and on laboratory and computer work in Jerusalem, Israel. The following activities took place during the second year of the Project: (a) Establishing wastewater quality and flows that are transported to Camberene wastewater treatment plant from two neighborhoods of different social levels, (b) Construction of a slow sand filtration (SSF) pilot-plant in Camberene, and (c) Bench-scale SSF experiments in Jerusalem trying to isolate biological *vs.* physicochemical mechanisms as a basis for process modeling. The difference noted between the pollution loadings of the wastewater of the two districts investigated in Dakar is linked with the life standards. The inhabitants of Cité Fayçal have a purchasing power and a level of consumption higher than those of Parcelles Assainies, therefore the use of water is more significant, consequently wastewater is more diluted in Cité Façal than in Parcelles Assainies. SSF bench experiments showed, after pre-filtration, turbidity and dissolved organics reduction development up to 50% during 31 days in an unstable nature, possibly caused by the nutrients levels reduction by the pre-filtration, causing inhibition of microbiological growth in the filter. Normal SSF and SSF preceded by chlorination produced better results, the latter even better, indicating domination of physicochemical mechanisms. The above results improve process understanding towards international application of that technique. Collaboration that year was mainly based on scientific and managerial exchange of information and ideas through electronic and conventional means. A Filtration Workshop in Senegal and exchange of visits of investigators and students are planned for 2003 and 2004.

## SECTION I: SCIENTIFIC

### A. RESEARCH OBJECTIVES

The water shortage in Dakar-Thies region requires the development of reliable technologies for water reuse on one hand, and for groundwater protection on the other hand. Slow sand filtration (SSF) is a well known simple to operate, low cost, efficient and reliable technique for potable water treatment. However, secondary effluents characteristics may impose design and operation parameters very different from those used for potable water.

The overall aim of the proposed research is to study slow sand filtration of secondary effluents, in order to better understand the process and to enable the derivation of design parameters for its application to water reuse in developing countries.

The specific objectives of the investigation are:

a) To understand the mechanisms governing slow sand filtration of effluents, the role of the "Schmutzdecke" (upper biological layer) and the physico-chemical interactions within the porous bed.

b) To study the effect of filtration rate and filter medium characteristics on the attachment and detachment of incoming particulates and on bacteria removal.

c) To define the ripening period, and improve filtration run length between cleaning-up (surface scraping) periods, and

d) To derive design parameters, mainly filtration rate, media grain size and bed depth for process application.

The 4 years investigation will be based on pilot work at Camberene (Dakar) wastewater treatment plant, where experimental filter columns are designed and process modeling at HUJ.

**In the reported year the focus had been on objectives a) and b) mentioned above.**

### B. RESEARCH ACCOMPLISHMENTS

#### B1. Wastewater Characterization for Camberene

B1.1 Methods

**General:** The water composition along its course is fundamental in understanding the type of wastewater processed by Cambrene treatment plant. Wastewater coming from two surrounding districts of Camberene plant were characterized. The two districts, Cité Fayçal and Parcelle Assainies, were selected according the standard of living, one with high standard and another with medium standard, this was determined by doing a socio-economics study and survey.

**Sampling:** Sampling was conducted by two teams during three months, four days per month and 24 hours each day at the same place. Samples were taken every two hours.

B1.2 Results

**Water consumption:** Drinking water consumption in the two sites grow annually, consequently so are the quantities of wastewater. In Parcelles Assainies, drinking water consumed were 4,273,458 $m^3$ in 1998 and 4,959,444 $m^3$ in 2002. In Cité Fayçal the quantities were 278,458 $m^3$ and 311,242 $m^3$ in 2001 and 2002 accordingly.

**Wastewater quantities**: Wastewater flowrates measured at the pumps installed by ONAS (Senegalese National Office for Wastewater) were 27 $m^3/h$ for Parcelles Assainies and 66$m^3/h$ for Cité Fayçal.

**Wastewater quality parameters:** Results are summarized in the following tables.

TABLE 1. PRIMARY POLLUTION

| | Parcelles Assainies | | Cité Fayçal | |
|---|---|---|---|---|
| | SS (mg/l) | DS (ml/l) | SS (mg/l) | DS (ml/l) |
| Average value | 273 | 2.2 | 171 | 1.3 |

SS = suspended solids; DS = dissolved solids

TABLE 2. SECONDARY POLLUTION

| | Cite Fayçal | Parcelles Assainies |
|---|---|---|
| COD $mgO_2/l$ | 900 | 501 |
| $BOD_5$ $mgO_2/l$ | 653 | 356 |

BOD = Biochemical oxygen demand; COD = Chemical oxygen demand

TABLE 3. TERTIARY POLLUTION

| | Cite Fayçal | Parcelles Assainies |
|---|---|---|
| $N_k$ mg/l | 33 | 48 |
| $P_T$ mg/l | 10 | 17 |

$P_T$ = total phosphorus; $N_k$ = Kjeldahl nitrogen

TABLE 4. BIOLOGICAL POLLUTION

| | Cite Fayçal | Parcelles Assainies |
|---|---|---|
| (FC /100ml) x $10^7$ | 3.2 | 4.5 |

FC = faecal coliforms

TABLE 5. AVERAGE WASTEWATER CHARACTERISTICS

| | Volume l/capita/day | SS mg/l | COD $mg.O_2/l$ | $BOD_5$ $mg.O_2/l$ | $N_k$ mg.N/l | $P_T$ mg.P/l | FC 100ml |
|---|---|---|---|---|---|---|---|
| Parcelles Assainies | 47 | 273 | 900 | 653 | 54 | 16 | $4.10^7$ |
| Cité Fayçal | 270 | 171 | 501 | 356 | 33 | 10 | $2.10^7$ |
| Average value | 158 | 222 | 700.5 | 504.5 | 43.5 | 13 | $3.10^7$ |

TABLE 6. AVERAGE DAILY POLLUTANTS LOADING PER CAPITA

| parameter | Parcelles Assainies | Cité Fayçal |
|---|---|---|
| SS (g/head. day) | 12.83 | 46.17 |
| $BOD_5$ (g/head. day) | 30.69 | 96.12 |
| COD (g/head. day) | 42.30 | 135.27 |
| $N_k$ (g/head. day) | 2.54 | 8.91 |
| $P_T$ (g/head. day) | 0.75 | 2.70 |

The difference noted between the pollution loadings of the wastewater of the two districts is linked with the life standards. The inhabitants of Cité Fayçal have a purchasing power and a level of consumption higher than those of Parcelles Assainies, therefore the use of water is more significant, consequently wastewater is more diluted in Cité Façal than in Parcelles Assainies.

**B2. Pilot Plant Set-Up at Camberene**

The initial pilot plant constructed did not work and some changes had to be made in the construction, as a result a new device is installed in Camberene. Testing was done but the results were still bad due to the quality of the sand. Another obstacle that had to be overcome was the construction of a large governmental tertiary plant in order to have enough water for the golf course lawn 300m far from Camberene.

**B3. Bench-Scale SGF Experiments in Jerusalem**

Two major sets of experiments of long duration were performed during the reported period, both aimed at the isolation of the biological activity effects from the physical filtration mechanisms.

B3.1 Materials and Methods

**General:** By pretreatment with 1.2 micron paper filtration of primary and secondary effluents before entering the filters (Experimental Set I), we assume that we removed all particles that are normally removed in slow sand filtration by physicochemical mechanisms, so that only dissolved matter remains in the effluents. We also assumed that most of the improvement in those effluents quality, after they passed the SSF, is due to biological activity. Another method used in that respect was comparing a normal slow sand filtration of secondary effluents with a slow sand filtration of chlorinated secondary effluents (Experimental Set II). This experiment stopped unexpectedly after 32 days when the water treatment lab collapsed due to a snowstorm.

**Location, source of effluents:** The experiment, which served for this investigation, is located at the water treatment lab in the Hebrew University of Jerusalem. The Soreq Wastewater treatment plant is a comprehensive inter-regional scheme for the collection, treatment and reclamation of municipal wastewater, encompassing a densely populated industrialized urban area, including the west part of Jerusalem and several adjacent municipalities. Roughly 90% of the total wastewater is of domestic origin, the remaining 10% being derived from industrial sources. The new mechanical biological treatment plant is based on an activated sludge system. Effluents supply is brought to the experiment every 4 days and stores in 4°C refrigerator. Before use, the effluents are brought to room temperature.

**Filtration system:** Two column filters, 0.9 m (Exp. I) or 0.6 m (Exp. II) high with 30 mm internal diameter were constructed, bed depth of 0.6 m (Exp. I) or 0.2 m (Exp. II) was used. In Experimental Set I, column one, pre-filtered secondary effluents are used and in column two, primary effluents are used. In Experimental Set II, column one, normal secondary effluents were

used and in column two, secondary chlorinated effluents were used. Filtration rate was 0.15 m/h. Flowmeter (Dwyer VA1045) and volumetric measurement is used to determine filtration rate. Head loss was determined by piezometers.

**Feeding and sampling systems:** *Exp. I* - Two 10 liters tanks, one for primary effluents and the other for secondary effluents, were placed 1.5 m above the filters. The effluents flew by gravity to the filters. Sampling valves are drilled into the filters 7cm and 55 cm below the sand surface. The sampling valves penetrate approximately 1 cm into the filter bed. *Exp. II* - A 20 liter tank was stationed 1.5 m above the filters. The effluents flowed by gravity to the filters. At the height of 40 cm a hose was installed in order to drain excessive effluents. Above one of the filters a tank with a NaOCl solution was stationed. A peristaltic pump continuously added the solution to the filter. A sample valve was drilled in the base of each filter. A second valve was connected to a flowmeter. A third valve was connected to a piezometer to measure head loss.

**Filter media characteristics:** The sand was sieved manually through a stainless steel sieve 0.64 mm in diameter in order to sort the raw sand for the experiment. Grain effective size, $d_{10}$, was 0.64 and the uniformity coefficient, $d_{60}/d_{10}$, was 1.5. Sand porosity = 0.42.

B3.2 Results and interpretation

B3.2.1 *Experiment I – Eliminating Particle Presence*

**Turbidity:** The mean primary effluent inlet turbidity was 13.1 NTU and the mean outlet was 11.1 NTU. Filter efficiency declined with time, with 30% in day 7 and 3% in day 31.

The mean secondary effluent inlet turbidity was 1.87 NTU and the mean outlet was 1.20 NTU. Filter efficiency increased with time, with 10% in day 7 and 55% in day 31.

The turbidity in the secondary effluents filter outlet was unstable. One hypothesis refers to the pre-filtration that sharply reduced the nutrients levels causing inhibition of microbiological growth in the filter. Undeveloped Schmutzdacke decreases the filter efficiency. Calculations of accumulated deposit in the filters show that in the primary effluent filter there was twice the deposit than in the secondary effluents filter. This result can be explained by the fact that the inlet turbidity in the primary effluent filter was ten times higher than the turbidity in the secondary effluent filter.

**Dissolved organic carbon:** The primary effluent inlet mean DOC was 61.8 ppm and the mean outlet value was 37.8. This filter efficiency ranged between 20% - 60%.

The secondary effluent inlet mean DOC was 35.8 ppm and the mean outlet DOC was 23.1 ppm. This filter efficiency showed instability (like in the turbidity) and ranged between 5% - 50%.

B3.2.2 *Experiment II – Eliminating Bacteria Presence*

**Turbidity:** Inlet turbidity ranged 2-10 NTU. Outlet turbidity from the normal filter ranged 1-1.8 NTU with an average of 1.42 NTU. Outlet turbidity from the chlorinated filter ranged 0.36-2.37 NTU with an average of 1.12 NTU.

Inlet turbidity was unstable, and there was no correlation between inlet and outlet turbidity from both filters. For example, between days 11-22 inlet turbidity levels reached 10 NTU while outlet turbidity was lower then 2 NTU. In the first two weeks of the experiment, turbidity levels in the normal filer were lower than in the chlorinated one. From day 15 until the end of the experiment,

the turbidity outlet levels were lower in the chlorinated filter. This phenomenon may be attributed to flocculation enhancement due to the effect of the oxidant on coagulation potential. A complimentary jar test confirmed that chlorine in 25 mg/l dosage has flocculation influence on secondary effluents. The instability of turbidity efficiency values indicates that the ripening period was not completed.

**Total suspended solids:** Inlet TSS concentrations ranged 4.4 – 22.3 mg/l, with an average of 11.4 mg/l. There was no significant difference between the filters in outlet TSS, ranging 0.3 – 3 mg/l with average of 1.9 mg/l. Naturally TSS measurements were not very accurate for such low values. Comparison between TSS and turbidity showed no match. This can be explained by the fact that in TSS measurements 0.45 μm filter is used, so sub-micron particles smaller than 0.45 μμ can pass. Those small particles have a relatively effect on turbidity due to their large specific area (surface area/volume).

**Particle size distribution ($d_p$>2μm)**: Inlet PSD concentrations ranged 8,400 – 14,300 particles/ml, with an average of 11,100 particles/ml. Outlet PSD from the normal filter ranged 1100 – 3700 particles/ml with an average of 2500 particles/ml. Outlet PSD from the chlorinated filter ranged 94 – 4100 particles/ml with an average of 2000 particles/ml. Most of the particles were between 2 – 5 μm. PSD removal ratio increased with particles size increase. Total particle concentration in the normal filter reveals that no significant filter ripening has developed. In the chlorinated filter, between days 11 – 16, there was an increase in the removal efficiency. Another increase was measured in day 32, which probably indicates the beginning of the ripening period.

**Total Organic Carbon**: Inlet TOC concentrations ranged 16 –20 ppm, with an average of 16.8 ppm. Outlet TOC from the normal filter ranged 11.8 – 17.5 ppm with an average of 14.4 ppm. Outlet TOC from the chlorinated filter ranged 3.7 – 7.9 ppm, averaging 6.2 ppm. One extreme result could be explained as a measurement error. TOC removal with time reveals a slow filter ripening development.

**Head loss:** No head loss was detected in the normal filter. In the chlorinated filter a very small head loss had developed.

## C. Scientific Impact of Collaboration

Communication continued between the two research groups, via e-mail, fax, regular mail and by telephone on occasion. These channels have ensured the flow of information between the two collaborators both for scientific information exchange and administration.

A visit of the Senegalese P. I. to Israel had been also planned, dates and program had been made. Unfortunately, the political situation in the area during that period presented big obstacles in obtaining the Visa to enter Israel, a new attempt, hopefully successful would be made within the next few weeks.

## D. Project Impact

Nothing to report yet. The anticipated uses are design and operational parameters for slow granular filters for water reuse in Senegal as well as other developing nations, application of modeling to slow sand filters and improvement in teaching and training of environmental scientists and engineers in the area of filtration, tertiary treatment and wastewater reclamation and reuse.

## E. STRENGTHENING OF DEVELOPMENT COUNTRY INSTITUTIONS

A pilot-plant for slow granular filtration has been constructed, including civil works and installations. The know-how had been first transferred by the Israeli team, adaptations to local conditions and necessary improvements were made later on by the Senegalese team. The Senegalese team has acquired skills in putting a pilot plant together from the pre-design phase to field completion and in surveying and selection of local filtering materials on the basis of filtration theory and practice. A computer system for project control has also been purchased and put into action.

## F. FUTURE WORK

The project advances according to the original program, with some delay due to the construction of the pilot plant problems that have reportedly ended, and the collapse of the Jerusalem lab. Now the pilot in Camberene is set and the bench-scale filtration system in Jerusalem has been re-constructed in an adjacent lab and is producing results again. We will try to keep-up with the original time table. We are also planning a Filtration Workshop in Senegal, which will probably take place in October 2003. The Israeli P. I. and the Israeli graduate student who is working on the project intend to visit at that time for collaborative work and the Workshop.

## SECTION II: MANAGERIAL

A) Managerial issues: See F above

B) Budget issues: None.

C) Special concerns: No change.

D) Collaboration, Travel, etc.: Nothing to report in addition to C and F above mentioned.

E) American Embassy in Tel-Aviv assistance: We will be in touch when necessary.

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