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NEPTUME; NO-DISCHARGE ENERGY-EFFICIENT PROTOTYPE FOR THE TREATMENT OF URBAN MUNICIPAL EFFLUENT

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ABSTRACT: NEPTUME is an R&I project funded by the Malta Council for Science and Technology (MCST), dealing with the treatment of raw municipal effluent to produce quality second class water for irrigation (and other) purposes. This paper presents an innovative two-stage process which uses the combination of a Moving Bed Biofilm Reactor (MBBR) coupled with a Membrane Bioreactor Filtration (MBR) incorporating the benefits of both processes. This setup produces a very high quality disinfected second class treated sewage effluent (TSE) (COD<100mg/l, TSS<10mg/l, NH_4-N<5mg/l). Furthermore, TSE is further polished through either a Reverse Osmosis (RO) system or Phytoremediation. The relative treatment performance of the various stages is assessed, compared to Conventional Activated Sludge (CAS) method of treatment and related to energy use as well as overall consumer perception.

Keywords: Treated Sewage Effluent (TSE), Moving Bed Biological Reactor (MBBR), Membrane Bioreactor (MBR), Conventional Activated Sludge (CAS), Phytoremediation (PR)

1 APPROACH

Malta has the highest Water Competitivity Index in the world (a measure of the scarcity of renewable water available on a per capita basis) [8] and has resorted to over-abstraction of its groundwater reserves and desalination technology to meet the national water demand. This situation is acknowledged to be unsustainable by the Malta Resources Authority and other more sustainable water sources have to be sought. NEPTUME researches a model designed to extract all the ecological and economic benefits inherent in the reuse of treated sewage effluent (TSE) which can be treated and polished to a quality suitable for use in public landscaping projects. The project brings together the latest developments in compact wastewater treatment technology and the nutrient-removal potential of biological phytoremediation processes. Wastewater output is being currently applied for the landscaped areas as part of the regeneration of the inner harbour area. Both processes are designed for low energy consumption (phytoremediation uses the sun as its energy source in particular) and water recovery from a waste product, sewage.

2 NEPTUME SCOPE

The two-year NEPTUME project was granted funding through the MCST R&I 2010 programme. Its primary aim was to research an alternative source of good quality water for irrigation purposes for use in landscaped public gardens, fountains, sports facilities and for other uses. The project was designed to integrate seamlessly into the recently completed Dock 1 Landscaping project, run by the Grand Harbour Rehabilitation Committee (GHRC) on behalf of Government and partly funded through EU funds. The Dock 1 gardens are located on the shores of the Grand Harbour within the spectacular historical heart of Cottonera. They create a new urban centre for the community on grounds previously belonging to the former Malta Dockyard's and encompassing one of the first dry-docks to be built in the Mediterranean. Now completed, the project will serve to catalyse the regeneration of the whole area by giving the community access once again to the harbour's waters and creating a much needed green lung for leisure and socialising.

In order to understand how TSE, sourced on site, would perform in our environment, NEPTUME sought to:

- Research the performance of flat bed membranes in treating sewage at municipal scale.
- Identify which aquatic macrophytic species are more suited for phytoremediation in Malta
- Study and monitor the first water self-sustaining urban public garden in Malta.

Figure 1: Project Schematic

The Wastewater treatment plant (WWTP) installed at the Dock 1 site and schematically shown in Figure 1 consists of a hybrid setup. A Moving Bed Biological Reactor treatment stage combined with a membrane filtration separation process. This setup adopted is better known as the Moving Bed Biofilm Membrane Reactor (MBB-M-R).

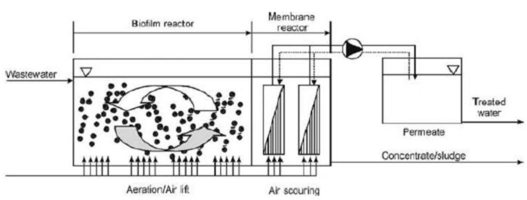

Figure 2: MBB-M-R Configuration

The setup consists of a macerating pump (reduces anything solid to 3mm in diameter) which pumps the wastewater from a nearby wastewater pumping station to the treatment plant. Using a series of valves, the inlet pump's delivery is matched to the design flow for the treatment plant which is continuously monitored by an in-line flowmeter.

Prior to the biological reactors, a self-cleaning rotating screen with an effective clearance of 1mm, blocks the larger solids from entering the reactor. The screenings are collected in a wheeled bin. In case of screen blockage/malfunction, an overflow system re-directs the excess sewage to the wastewater pumping station.

Screened sewage, flows by gravity from the screen to the biological reactors. Within the biological reactors, microorganisms grow upon the floating carrier which is kept in suspension by the air supplied through the diffusers situated at the bottom of the reactors. The air supplied is consumed by the microorganisms which require oxygen to proliferate (activated sludge treatment process).

Mechanical blowers are used to supply the required oxygen to the microorganisms. Within the reactors, the microorganisms remove the soluble pollutants from the wastewater, namely Ammonia and BOD (Biological Oxygen Demand). The reduction is such to achieve the desired permeate quality for landscaping purposes. Following biological treatment, wastewater flows by gravity to the membrane tank. An ultra-filtration (UF, 0.04µm pore size) membrane acts as a sieve to separate the biological solids composed of sloughed off biofilm from the effluent. Solids content within the membrane tank is kept under control by wasting excess solids to the pumping station. A blower continuously supplies air to the membrane for cleaning by bubbling air. Clear disinfected effluent is discharged to the collecting tank which and subsequently further treated by a reverse osmosis (RO) or Phytoremediation stage (PR).

Ceramic microfiltration membranes were originally tested but these were fouling irreversibly within hours of operation. Research elsewhere has shown that this is mostly due to cake formation and can be remedied by a 2.5 minute backwash using ozonated water [6]. The membranes were exchanged for more conventional PolyEther Sulphone (PES) flat plate membranes which contrary to ceramic membranes, require minimal user intervention other than a cleaning-in-place (CIP) procedure every six months of operation.

Furthermore, research was undertaken on the species suitability and performance of PR using different freshwater emergent macrophytes (aquatic plant species) grown in shallow basins. PR aims to achieve a further reduction of any solids and soluble solutes including nitrate, phosphate and potassium (NPK) loads and heavy metal pollutants found in treated water; sodium chloride content is however not reduced by this PR system. Notwithstanding that UF should technically reduce the microbial load by 99.99%, the PR process helps to reduce any residual coliform content and perceptible residual odours; the combined action of root adsorption and biofilm formation which allows beneficial microorganisms and protozoans help to further polish the TSE.

A comparison of plant growth in three distinct and separate landscaped areas is being carried out by irrigating plants with treated water after phytoremediation polishing and the others by irrigating with rain water and water polished with an RO system. The comparison of growth is based on recognised healthy growth parameters including new shoot formation, rate of growth, flowering, chlorophyll content, signs of induced deficiency, leaf burn and/or necrosis, signs of disease and resistance to disease. These parameters are being monitored against a backdrop of soil tests focusing especially on soil sodium chloride content and fluctuations.

3 TREATED SEWAGE EFFLUENT - PROCESS SELECTION AND TREATMENT PERFORMANCE

The main advantages of the setup employed are the following:

1. Savings over a conventional activated sludge (CAS) process footprint. MBBR-MBR presents roughly a 50 percent reduction on CAS with a reduced volume bioreactor and a membrane in place of a final clarifier.

2. The MBBR process is very robust being an attached growth process and the ultra filtration physical filtration barrier overcomes settleability issues that can be experienced by clarifiers under certain operating conditions.

3. MBBR has a comparatively low sludge production compared to a conventional activated sludge process (approx. 50% less) 0.12kg TSS per kg of COD removed (using proprietary filter media) as opposed to 0.28 kg TSS per kg of COD removed [7] for CAS.

4. High quality of TSE, thanks to the membrane ultra-filtration pore size of 0.4µm. The membrane acts as a physical barrier for almost all bacteria and viruses (up to 99.9999% removal rate).

During the period June to October 2014 the average values of influent COD/TSS/NH4-N in mg/l were 952/403/109 and the corresponding permeate quality 150.99/9.97/2.83. This constitutes a mean removal rate for COD/TSS/NH4-N of 84/98/97 % respectively.

Influent COD figures occasionally exceeded the design by up to 22% whereas average NH4-N design loading was consistently exceeded by 60% during the same period. Results measured for outlet COD and TSS between Nov 2014 and Feb 2015 were deemed not to be representative, as subsequently confirmed by further tests in March 2015. A slight contamination of the sampling bottles was distorting TSS and COD results. NH4-N results were consistent throughout the testing period.

4 TREATED SEWAGE EFFLUENT – FURTHER POLISHING WITH RO AND PHYTOREMEDIATION

During the period June to July 2014 the conductivity of the outlet TSE from the MBB-M-R averaged 3,078 μScm^{-1}. Corresponding polished RO permeate averaged 261.7 μScm^{-1}.

Four PR basins each measuring approximately 8m by 6m by 0.9m were used for the trial with a fifth smaller basin measuring 7m by 3m by 0.5m. The depth in the larger basins was kept in the range of 0.75m to a total volume of $144m^3$ and in the smaller basin to a depth of 0.40m for a total volume of 8.4 m^3.

A water recirculation system set up to recirculate and aerate the water in the larger basins with a 15:45 minute on and off regime for 12 hours starting at 8.00 am and switching off completely at night. The emergent macrophyte species (A – G) listed in Table 2 were started off in the preceding year from seeds, cuttings or by root division and grown in peat in 10 cm plastic pots. Before inserting in the basins they were mounted on purpose-made floating rigs and allowed to acclimatise in rain water for one month before the water was replaced by TSE from the MBB-M-R plant. In addition to these two ferns, the Water Hyacinth and duckweed (a' – d') were also used as free floating and rapidly multiplying infill between the rigs. The number and distribution of rigs per species in the different basins is shown in Table 3.

Though the trials on the PR basins were started in January 2014, fresh growth was only evident when day temperatures started to increase in March. The first measurement of the changes in TSE water parameters and plant growth started at this time. The water in the basins was emptied periodically and new TSE pumped in to follow on fresh cycles of plant growth and phytoremediation.

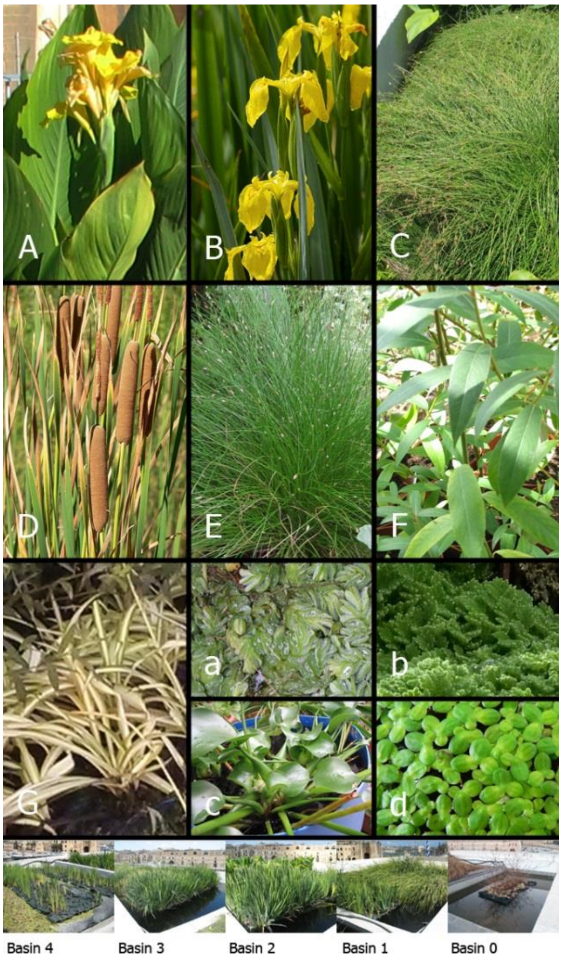

Figure 3: Emergent macrophyte and free floating species used in the PR basins

Table 2: List of emergent macrophyte and free floating species used in the PR basins

Ref	Latin Name	Common Name
A	*Canna indica* L.	Indian Shot
B	*Iris pseudacorus* L.	Yellow Flag Iris
C	*Carex hispida* Willd.	Hispid Sedge
D	*Typha domingensis* Pers.	Southern Cattail
E	*Isolepis cernua* Vahl.	Tufted Clubrush
F	*Salix alba* L.	Weeping Willow
G	*Chlorophytum comosum*	Spider Plant
a	*Salvinia molesta*	Giant Salvinia
b	*Azolla caroliniana*	Moquito Fern
c	*Eichhornia crassipes*	Water Hyacinth
d	*Lemna minor*	Duckweed

Table 3: Distribution of macrophytes and floating species in the four basins with x value for the number of rigs installed.

Basin 4	Basin 3	Basin 2	Basin 1	Basin 0
B x 4	B x 6	A x3	D x 4	G x1
C x 1		B x 2	B x 2	F
D x 1		E x 1		
b, d	a, b, d	c, d	B	b

Weekly measurements taken were as follows: Water parameters measured in situ included pH, conductivity and total dissolved solids. Chemical parameters on water samples after laboratory analysis included nitrates, nitrites, phosphates, levels of calcium, potassium and sodium ions. Measurements of plants growth included overall increase in height of stem, average elongation of root for three random samples per plant, general observation and photographic record of condition of plants. For the free floating species the general spread and condition of the species was noted.

5 ENERGY CONSIDERATIONS

The following Table 4 presents the energy requirements of the setup by treatment stage.

Table 4: Energy Requirements for the various units.

Treatment Stage	Energy Requirements per m^3 of TSE
MBBR	2.07/2.82 kWh/m3
MBBR + MBR	3.75/4.50 (2.07/2.82 +1.68) kWh/m3
MBBR + MBR +RO	4.69/5.44 (3.75/4.50+0.94) kWh/m3
MBBR + MBR + PHYTO	3.95/5.30 (3.75/4.50+0.2/0.8) kWh/m3

The lower figures provided in Table 4 correspond to an MBBR with COD removal *without* complete nitrification taking place. The plant was designed on an effluent that cannot be defined as being domestic. COD and NH4-N concentrations exceeding 1000mg/l and 100mg/l, respectively, diverge from typical domestic figures expected, and namely COD and NH4-N of 600mg/l and40mg/l, respectively. An MBBR plant sized for a domestic load is estimated to have otherwise consumed 2.07 kWh/m3, lowering the total energy requirement to 4.69 kWh/m3 as opposed to 5.44 kWh/m3 (Table 4). For most landscaping applications were chlorides are not an issue and NH4-N in the region of 20mg/l can be tolerated, the RO stage can be eliminated leaving us with an MBB-M-R setup consuming 3.75 kWh/m3.

Assuming scarce groundwater resources of a relatively lower quality the closest equivalent source of water in terms of quality would be a seawater RO plant. Such a plant would consume circa 4 kWh per cubic metre of permeate produced. For an installation that is remotely located from the shore one has to factor in additional pumping or transportation energy requirements.

From an energy point of view, provided raw wastewater is available with a low chloride content an MBB-M-R is a more viable solution than a seawater RO installation. Furthermore, if the landscaped area is situated away from the shore, an MBB-M-R plant would make sense further still, even with RO polishing in place. In the Dock 1 case an MBB-M-R alone is anticipated to satisfy the landscape requirements as is, and particularly so if wastewater salinity is further controlled.

The phytoremediation energy requirements are considered to be small and can probably be reduced further from what is included below since the only energy needed is to circulate the water in the ponds sufficiently to prevent anoxic areas. The estimated electricity consumption for the four submersible recirculation pumps rated at 0.736kWh and working on the recirculation regime described above amounts to 8.8 units daily to treat a total of 152 m^3 of TSE. For a fully established PR system where plant growth is at its maximum, a residence time of two weeks is considered sufficient to treat a fresh batch of TSE. This works out to 0.8 kWh/m^3. Current experiments are focusing on lowering the frequency of the recirculation to 15minutes every two hours and also reducing the residence time to 7 days as originally planned, If these trials prove to be successful, the energy consumption can be reduced to a quarter of the value given per cubic metre.

6 CONCLUSIONS

The research aims at setting new standards for sustainability in water use not only for use in agriculture but also for landscaping projects, golf courses and recreational areas where sufficient water supply is not available. Designed to be accessible to the public, the project has an educational value, setting an example through water reuse in a public national urban regeneration project and promoting environmental sustainability in infrastructure projects.

Localised sourcing of the raw material and its processing and utilisation of the finished product thereafter provides a reliable supply of treated effluent from a renewable resource without reverting to alternate sources situated away from the demand region.

A comparative assessment of RO and Phyto polished TSE will be carried out in the coming months.

REFERENCES

[1] European Environment Agency (2010), State and Outlook Land use – State and Impacts (Malta), EEA.

[2] European Environment Agency Website (2010) Corine Land Cover for the Maltese Islands, EEA.

[3] Eurostat website (2013), Eurostat Land Use/Cover Area Survey (LUCAS) statistics Malta, Eurostat.

[4] Malta Environment and Planning Authority (2006) State of the Environment Report Part 4: Land, MEPA, Malta.

[5] National Statistics Office (2008), NSO Census on Greenhouses, NSO Malta.

[6] Fujioka, T and nghiem., L D Fouling control of ceramic microfiltration membrane for direct sewer mining by backwasking with ozonated water. J of Separation and purification technology 142 (2015) 268- 273

[7] Biological Wastewater Treatment, IWA Publishing, ISBN 1843391880, (2008).

[8] Margat & Vallee, 1999; MRA Draft Water Policy 2005