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# Near zero energy wastewater treatment plants for the Greek islands

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ABSTRACT

Conventional wastewater treatment is an energy-intensive process, requiring electric energy of about 1.1–2.4 MJ/$m^3$, being higher in plants with relatively small hydraulic capacity (<5,000 $m^3$/d). Solar energy can be used to supply electric energy, particularly for the Greek islands; however, the huge energy demand of the wastewater treatment is a drawback for the use of photovoltaic energy, due to the additional capital cost and electricity storage requirements during the night. Here, a novel approach for wastewater treatment is proposed, based on enhanced primary solids removal, by the use of advanced sieving and filtration processes, utilizing a proprietary rotary fabric belt microscreen followed by a proprietary continuous backwash upflow media filter. Raw municipal wastewater treated with the above process results in about 80–90% reduction in TSS and 60–70% reduction in $BOD_5$. The overall electrical power requirements for a novel configuration plant with hydraulic capacity of 1,000 $m^3$/d (typical capacity for small settlements in the Aegean islands) have been calculated to about 10 kW, as compared to over 25 kW for a conventional activated sludge system with the same capacity.

*Keywords:* Wastewater; Treatment plant; Near zero energy; Solar energy; Photovoltaic

## 1. Introduction

Energy cost becomes year by year a hard, difficult issue for the municipalities putting major economic barriers to their sustainability and to supply quality services to their citizens. It has been estimated that over 20% of the total energy spent by the municipalities is for the operation of the wastewater treatment plants [1]. Apart from the high energy cost, the utilization of electric energy for wastewater treatment has a noteworthy impact on the emission of Greenhouse Gases, as electric energy is primarily produced from fossil fuels, especially in off-grid insular systems.

Activated sludge treatment is the most common process in municipal wastewater. It has been estimated that the energy requirements for wastewater treatment using conventional activated sludge process is between 1.1 and 2.4 MJ/$m^3$ [2]. The problem becomes stronger in small islands, because usually they constitute sensitive ecosystems with unique attributes of a natural and cultural heritage that impose a limitation on the development of energy generation plants [3].

Especially for wastewater treatment plants with small hydraulic capacities (less than 50,000 $m^3$/d), the

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energy requirements are significantly higher (Fig. 1). The electrical load profile of conventional activated sludge process indicates that more than 55% of energy is consumed in the aeration tank (Fig. 2); also, about 10% is also consumed in primary clarification and 10% in biosolids processing and plumbing. Lately, efforts have been made to reduce the energy demand of wastewater treatment, focusing in processes fine tuning, so to reduce energy consumption or in installing more efficient electrical apparatuses [4]. Such practices, definitely contribute to the reduction of electric energy consumption, up to a point, beyond which further reduction is not feasible. For example, an organized effort in Switzerland's wastewater treatment plants, 10 years ago, resulted to about only 12% reduction in energy consumption [5]. On the other hand, the chemical energy content of wastewater has been calculated as being well higher than the energy demand for wastewater treatment [6,7]. Thus, utilization of treatment byproducts for the power generation has been practiced and is still under investigation. Anaerobic digestion, combustion, and, recently, gasification have been employed [8] for energy production. However, it is under discussion if the utilization of the chemical energy content of activated sludge wastewater treatment plants can lead to zero energy requirement facilities [9–11]. Biosolids gasification is a promising process, if combined with low-energy requirements wastewater treatment plants [12,13]. On the other hand, electrical power from renewable energy resources, such as solar and wind power can be employed to replace partially or even totally, the electrical energy bought from the grid. Some wastewater treatment facilities have already installed solar or wind power generators, but in most of those facilities the power produced is used to partially substitute energy bought from the grid [14–16], while no essential reduction in energy requirements has been achieved. The use of renewable energy for wastewater treatment is a sustainable option, and for relatively small wastewater treatment plants, like the ones installed at the Greek islands, can be beneficial. It is wise though, to use novel approaches in wastewater treatment processes to reduce the energy requirements per volume of treated wastewater rather than employing the conventional activated sludge process.

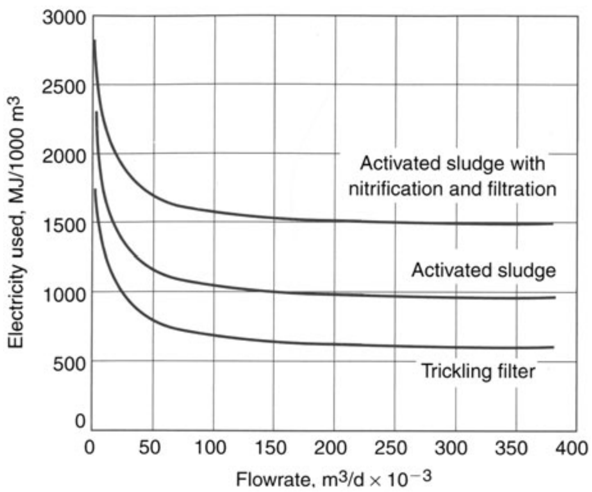


Fig. 1. Electrical energy usage for different types of wastewater treatment processes, as a function of daily flowrate [17].

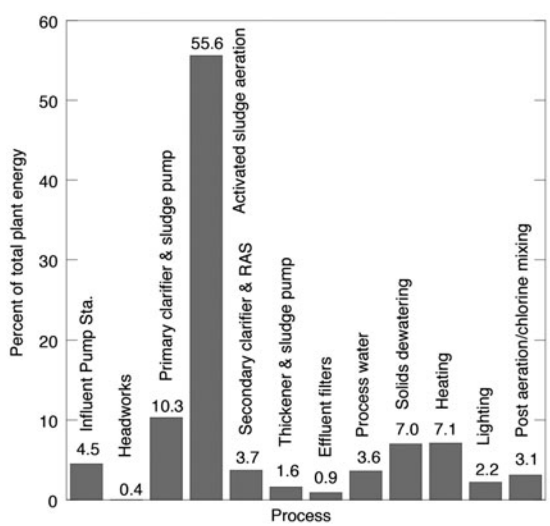


Fig. 2. Energy distribution in a typical activated sludge wastewater treatment process [18].

It is obvious that conventional activated sludge wastewater treatment plants require relatively large amounts of energy, thus it is difficult to achieve self-sustainability with respect to energy. Alternative systems which will reduce meaningfully their power demand, but which will not compromise in treatment efficiency, should be explored. An obvious alternative is the use of constructed wetlands. The later require significantly lower energy [19], however, constructed wetlands require large areas to be installed, and are not suitable for the Greek islands, where land is expensive and availability is limited. Thus, an ideal wastewater treatment system should have low-energy requirements, low footprint, and ideally low capital and operational cost.

The aim of the present article is to propose a novel wastewater treatment process, with reduced energy requirements, reduced footprint, and reduced capital and operational cost, which will be ideally combined with the use of photovoltaic systems as electric energy providers. The wastewater treatment system should be suitable to be used at the Greek islands.

## 2. Wastewater production pattern vs. solar radiation potential

Seasonal wastewater production at the Greek islands follows a unique pattern, due to the high summer demand [2]. Thus, high wastewater flows are encountered during the hot months (from May to September), while a significant reduction is observed during the rest of the year (Fig. 3(a)). A quite similar pattern has been measured for the solar energy radiation (Fig. 3(b)). Apart from the seasonal variation, similar patterns have been monitored also for the hourly inlet wastewater flowrate and for the hourly solar energy potential (Fig. 4). Both rates exhibit a peak during noon. Obviously there is no solar radiation before sunrise and after dusk, but at the same time reduced flowrates are entering the wastewater treatment plant. The above unique patterns show that photovoltaic systems are advantageous in supplying wastewater treatment plants with electrical energy, as compared with other renewable sources, such as wind power. However, even if the wastewater treatment plant is equipped with photovoltaic panels capable to supply the system with electrical energy during daytime, energy storage will be required for the system after the dusk hours. The problem can be softened, if an equalization tank is used to store the night wastewater flows (which in any case are reduced (Fig. 4)), which can be pumped and processed during daytime. As wastewater treatment processes consume high amounts of energy, it is wise to redesign the wastewater treatment plants by replacing the energy consuming processes with energy efficient ones.

Alternatively, the waste treatment plant could operate with the use of photovoltaic as a near zero energy system (Fig. 5), minimizing the peak load in the grid during the day time and be fed by the grid during the night time.

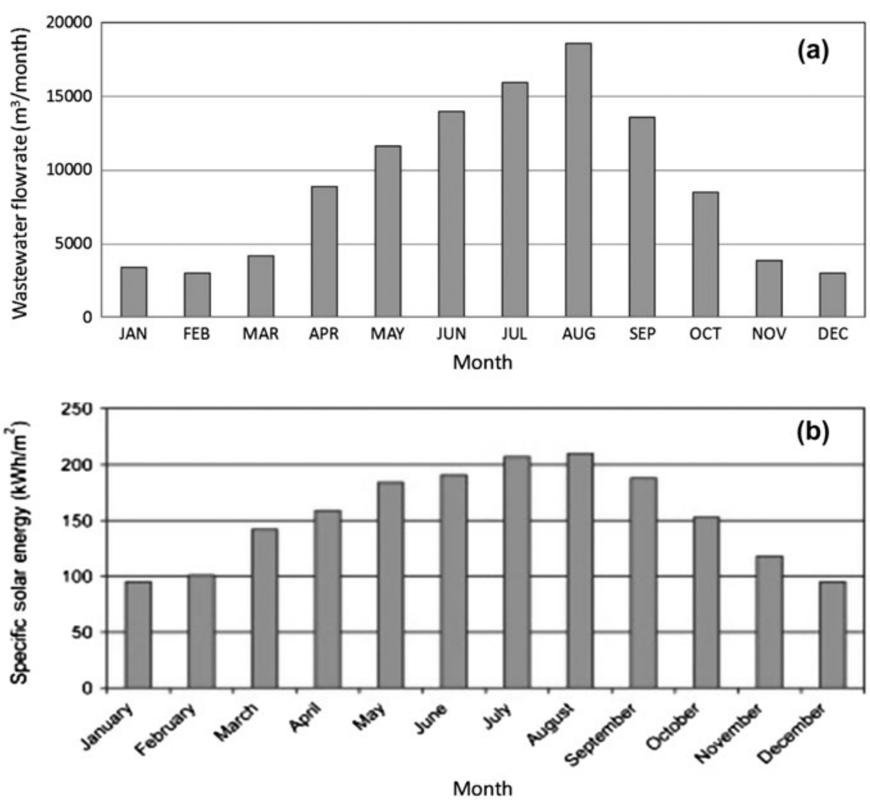


Fig. 3. (a) Wastewater flow to a wastewater treatment plant (Oia, Santorini Island) (Personal communication with wastewater treatment plant manager) and (b) solar energy potential (Rhodes Island) [20]. Solar radiation has a similar pattern to wastewater flowrate on a monthly basis.

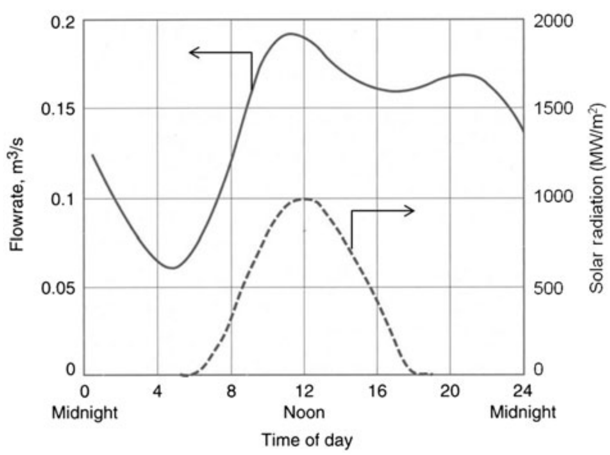


Fig. 4. Diurnal curves of typical wastewater flowrates into a treatment plant and solar radiation for an Aegean Island (adapted from [3] and [21]). Solar radiation has a quite similar pattern to wastewater flowrate during the daylight hours.

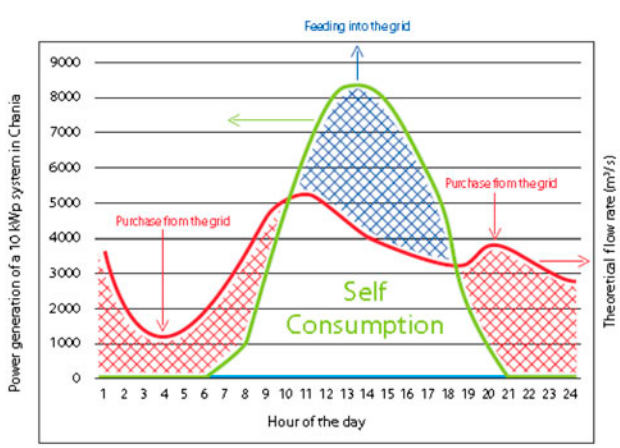


Fig. 5. Schematic presentation of a waste water plant using photovoltaics for self-consumption (power generation data are from a photovoltaic plant in a typical May day, Chania).

## 3. Novel low-energy requirements wastewater treatment system

### 3.1. Overview

As aeration process is by far the greatest energy consuming process in conventional activated sludge wastewater treatment, our aim is to replace part of the biological process with physical and physicochemical processes. The later processes typically require less energy and are much faster (thus, they require smaller footprint). Primary treatment will also be altered by replacing primary clarification by micro-sieving (a low energy cost requiring minimal space). Finally, the energy requirements for biosolids management will be also reduced, as the dewatering process will be altered. The process is graphically outlined in Fig. 6, while the proprietary processes are described in detail below. The proposed process consists of three distinct parts: (a) Solids removal (which consists of micro-sieving followed by sand filtration); (b) Removal of soluble BOD (which consists of a biofilter with option for liquid recirculation and clarifier); and (c) Polishing (sand filter). Disinfection is by UV radiation, but sodium hypochlorite or ozone may be used instead. It is worth mentioning that the wastewater exiting the primary sand filter is almost devoted of suspended solids. A flocculent, such as PAC may be used to enhance sand filtration.

### 3.2. Micro-sieving

The M2 Renewables, Inc., USA, MicroScreen™ utilizes a proprietary continuous belt screen filter that separates solids from the raw wastewater (Fig. 7). Wastewater is pumped right downstream from the headworks (i.e. bar screen and grit chamber) to the MicroScreen, where it is filtered through a rotary belt screen made of polyester material. Solids are captured and accumulated on the screen and deposited into a separate collection trough. An auger screw in the trough moves the solids to a compression and dewatering section to produce a 30–45% dry solid cake (depending on fibre content of the solids) [22]. The belt screen can be installed with different size openings depending on the specifications and individual requirements for each installation. Typically, belts with mesh sizes between 100 and 300 μm are used for municipal wastewater applications. The speed of the belt is regulated by a control system based on the level of water in the influent side of the belt. The automation has been designed to speed up the belt as the level of water increases. MicroScreens operate at low pressure gradients (below 4 kPa), as compared to MF or UF (which operate between 40 and 60 kPa). Depending on wastewater characteristics, belt mesh size, and belt rotation speed, the MicroScreen can achieve TSS removal between 30 and 70% [22,23].

### 3.3. Continuous backwash upflow media filter

The continuous backwash upflow media filter (CBUMF) (Fig. 8) uses sand as the filtration media. Filtration efficiency is enhanced by the controlled injection of coagulant—typically, polyaluminum chloride (PAC). The coagulant addition effectively creates a

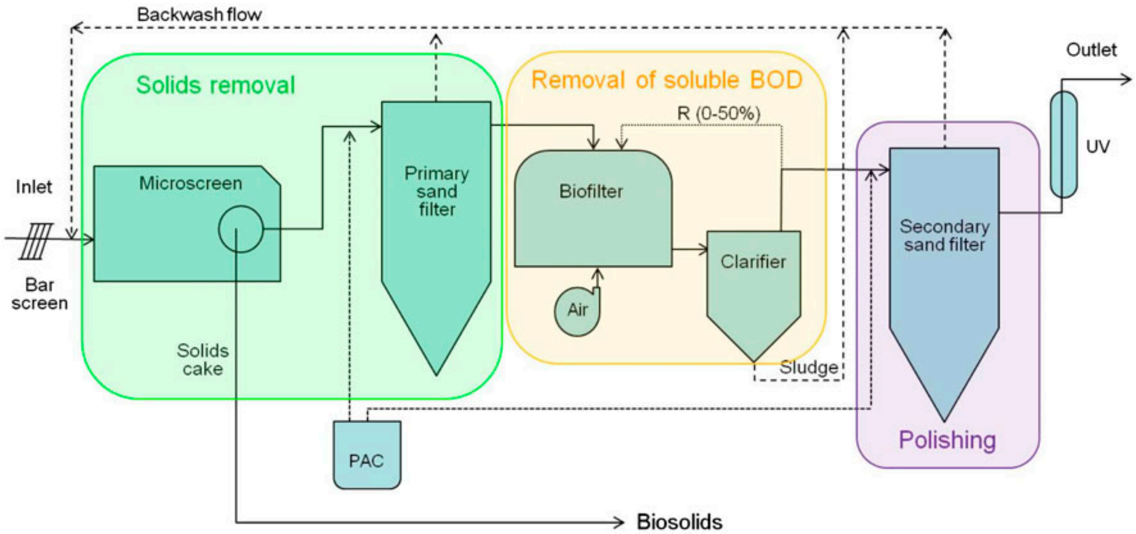


Fig. 6. Flow diagram of the wastewater treatment process proposed for the Greek Islands.

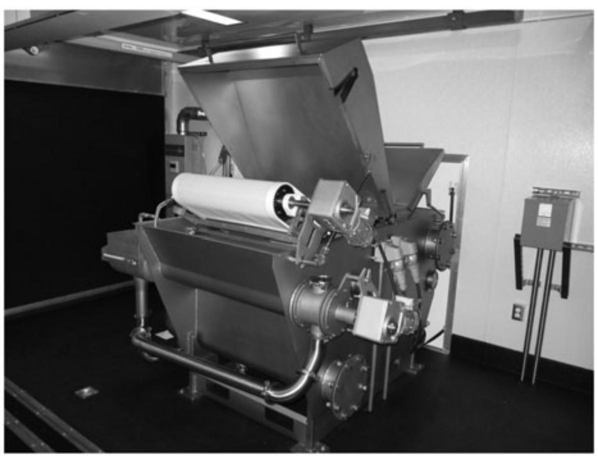

Fig. 7. Photo of rotary fabric belt MicroScreen$^{TM}$, with open housing, to reveal the fabric belt.

"coagulant-rich" layer within the sand media. As water flows upwards through the coagulant layer and into the sand, suspended solids and BOD associated with organic particulate matter are destabilized and coagulated. Destabilized solids and sand are removed from the bottom part of the filtration vessel by the action of an air lift. Compressed air moves the dirty media from the bottom of the filter up to the media washer at the top of the filter, where the sand is scoured and cleaned. The clean sand is deposited from the media washer downward on top of the filter bed. The rate of air flow for media washing is adjusted to allow for solids build-up at the bottom of the filter, as this solids layer aids in contaminant removal; however, the latter automation feature was not enabled during the present trials. The rate at which sand is recycled varies with influent flow and

Fig. 8. Photo of two continuous backwash upflow media filters (CBUMF), for advanced solids removal (right) and for wastewater polishing (left).

turbidity to maintain a headloss set point within the filter. All filter media are washed and recycled within 6–8 h. The M2 Renewables, Inc., USA, CBUMF uses headloss differential and flowrate measurements to automatically control the sand movement; however, the present trials were carried out at manual mode (without the patented solids loading control) [23].

Raw municipal wastewater treated with the above process (MicroScreening followed by CBUMF), results to about 80–90% reduction in TSS and 60–70% reduction in $BOD_5$. Moreover, the vast fraction of BOD left is in soluble form and thus readily biodegradable. An attached growth biofilter with natural draft aeration is used to remove the remaining BOD (mostly dissolved BOD), with parallel ammonia nitrification. All biosolids are conveyed to the MicroScreen, where they are removed and dewatered collectively with primary solids (to about 40% solids), using an auger screw. There are several options available for biosolids management, such as: (a) anaerobic digestion for the production of biogas, (b) gasification for the production of synthesis gas, (c) combustion, and (d) sanitization and disposal. Promising experiments have been carried out to exploit the energy of this type of biosolids using gasification [24,25]. However, the management of biosolids is beyond the scope of the present article.

### 3.4. Energy wise analysis

As can be seen from Fig. 6, almost all the settable and suspended solids are removed by the microscreen CBUMF system; thus, the wastewater entering the biofilter contains almost exclusively dissolved BOD. The later can be easily assimilated by micro-organisms, with minimal aeration requirements. The microscreen requires a motor to rotate the cloth filter, while the CBUMF requires an air compressor to move the sand bed. A pump may also be required, if the CBUMF is elevated, with respect to microscreen outlet point. The biofilter requires a centrifugal pump for the recirculation of the wastewater and an air blower, for aeration. Alternatively, naturally ventilated biofilters may be used if intense aeration is not needed. The polishing CBMFU, if required, demands also a compressor for the movement of the sand bed. Finally, electric energy will be needed for the UV radiator. The size of the motors and exact power requirements are a function of wastewater quality and flowrate.

Energy consumption data for conventional activated sludge wastewater treatment plants have been collected from the plants of Patras and Volos, in Greece. Both wastewater treatment plants utilize the activated sludge process with nutrients removal. The hydraulic flow in each plant is about 12–14 $Mm^3/y$, and the electrical power between 610 and 640 kW. The electric energy requirement for complete treatment has been calculated between 1.4 and 1.7 $MJ/m^3$ (personal communication with the plants managers). For smaller conventional wastewater treatment plants, it is likely that the above energy requirement may be higher even by a factor of 2 [6]. On the other hand, it has been calculated that the electrical power requirements for a novel-type wastewater treatment plant with the same hydraulic capacity (about 1.5 $MJ/m^3$), as described above, is about 250 kW. Thus, for wastewater flowrate of 1,000 $m^3/d$, the energy requirements for conventional treatment are about 25 $MJ/m^3$, while they are reduced to about 10 $MJ/m^3$, for the novel system that has been proposed. As a result, the energy requirements of the novel wastewater treatment approach are about 40% of a conventional activated sludge process.

## 4. Conclusions

The solar radiation pattern in the Greek islands is ideal for the usage of photovoltaic electrical energy to supply wastewater treatment plants. As conventional wastewater treatment plants utilize a significant amount of electrical energy, a novel wastewater treatment system with low-energy requirements and low carbon footprint has been proposed. The system primarily utilizes physical and physicochemical process in place of extended aeration. Biological treatment is used only for the removal of soluble BOD and ammonia nitrification. It has been calculated that the operation of the novel plant will require about 40% of the energy required by conventional activated sludge wastewater treatment plants; thus, it is ideal to be used in the Greek Islands.

## References

[1] E. Means, Water and Wastewater Industry Energy Efficiency: A Research Roadmap, AWWA Research Foundation, Denver, CO, 2004.

[2] G. Tchobanoglous, F.L. Burton, D.H. Stensel, Metcalf and Eddy: Wastewater Engineering, Treatment and Reuse, fourth ed., McGraw Hill, New York, NY, 2003.

[3] E. Maria, T. Tsoutsos, The sustainable management of renewable energy sources installations: Legal aspects of their environmental impact in small Greek islands, Energy Convers. Manage. 45(5) (2004) 631–638.

[4] A. Ataei, Wastewater treatment: Energy-conservation opportunities: Consider these options to improve energy efficiency and reduce the cost of treating wastewater, Chem. Engin. 17(1) (2010) 34–41.

[5] E.A. Müller, F. Schmid, B. Kobel, Activity Energy in WWTPs, 10 Years of Experience in Switzerland, Korrespondenz Abwasser, 53(8) (2006) 793-797 (in German).

[6] S.A. Channiwala, On biomass gasification process and technology development—Some analytical and experimental investigations, Ph.D. Thesis, IIT Bombay, Mumbai, 1992.
[7] I. Shizas, D.M. Bagley, Experimental determination of energy content of unknown organics in municipal wastewater streams, J. Energy Eng. 130(2) (2004) 45–53.
[8] D. Fytili, A. Zabaniotou, Utilization of sewage sludge in EU application of old and new methods—A review, Renew. Sust. Energ. Rev. 12 (2008) 116–140.
[9] B. Wett, K. Buchauer, C. Fimml, Energy self-sufficiency as a feasible concept for wastewater treatment systems, in: Proceedings of IWA Leading Edge Technology Conference, Asian Water, Singapore, 21–24 September 2007.
[10] M.E. Arnold, E.S. Merta, Towards energy self-sufficiency in wastewater treatment by optimized sludge treatment, Water Pract. Technol. 6(4) (2011). Article No. 7.
[11] W. Mo, Q. Zhang, Can municipal wastewater treatment systems be carbon neutral? J. Environ. Manage. 112 (2012) 360–367.
[12] P. Gikas, K. Stedman, Novel wastewater treatment configuration for zero energy requirements wastewater treatment plants, in: Third Asian Conference on Sustainability, Energy and the Environment, Osaka, 6–9 June 2013.
[13] P. Gikas, Wastewater treatment plants as net energy production factories, in: International Conference on Environmental and Hazardous Substance Management towards a Green Economy, Bangkok, 21–23 May 2013.
[14] Boulder, Wastewater Treatment Facility Solar Electric System, City of Boulder, CO, 2010. Available from: https://bouldercolorado.gov/water/wastewater-treatment-facility-solar-electric-system (Accessed 11 August 2013).
[15] Mammoth, Water is Future, Mammoth Community Water District, CA, 2012. Available from: http://www.mcwd.dst.ca.us/Solar%20Page/MCWDSolar.htm (Accessed 11 August 2013).
[16] Browning, Wind Power for the Wastewater Treatment Plant, Town of Browning, MT, 1999. Available from: http://www.browningmontana.com/wind.html (Accessed 11 August 2013).
[17] F.L. Burton, Water and Wastewater Industries: Characteristics and Energy Management Opportunities, CR-10961, Electric Power Research Industries, St. Louis, MO, 1996.
[18] ENRI, Energy Audit Manual for Wastewater Treatment Facilities, Electric Power Research Institute, St. Louis, MO, 1994.
[19] J.B. Zhou, M.M. Jiang, B. Chen, G.Q. Chen, Emergy evaluations for constructed wetland and conventional wastewater treatments, Communic. Nonlin. Scie. Numer. Simulat. 14 (2009) 1781–1789.
[20] J.K. Kaldellis, D. Zafirakis, E. Kondili, Energy pay-back period analysis of stand-alone photovoltaic systems, Renew. Energ. 35 (2010) 1444–1454.
[21] G.P. Giatrakos, T.D. Tsoutsos, P.G. Mouchtaropoulos, G.D. Naxakis, G. Stavrakakis, Sustainable energy planning based on a stand-alone hybrid renewableenergy/hydrogen power system: Application in Karpathos island, Greece, Renew. Energ. 34 (2009) 2562–2570.
[22] G. Koliopoulos, P. Gikas, Fine mesh sieving of raw municipal wastewater for TSS and COD removal, in: Thirteenth International Conference on Environmental Science and Technology, 5–7 September 2013, Athens.
[23] A. Franchi, K. Stedman, P. Gikas, Enhanced primary solids removal from municipal wastewater by two steps filtration, in: IWA Regional Conference on Wastewater Purification and Reuse, 28–30 March 2012, Heraklion.
[24] P. Gikas, S.A. Noll, K. Stedman, Gasification of primary fine screenings for energy production, in: Proceedings of First Eurasia Waste Management Symposium, 14–16 November 2011, Istanbul.
[25] P. Gikas, S.A. Noll, K. Stedman, G. Tchobanoglous, The characterization and testing of wastewater fine screen fresh solids for suitability as a gasification feedstock, in: Proceedings of Second International Conference on Hazardous and Industrial Waste Management, 5–8 October 2010, Chania.