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Study of the adaptation of an MBR system to double the wastewater purification capacity of the Barranco Seco II treatment plant

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ABSTRACT

This paper considers the problem of an urban wastewater treatment plant which has no land available for expansion but whose capacity needs to be increased from its current 52,000 m^3/d. To increase capacity, adaptation to the purification process was proposed of a membrane bioreactor (MBR) system with ultrafiltration (UF) membranes submerged in the biological reactor. The experimental study gave biomass concentrations of between 15,000 and 20,000 mg/L. Mass load was chosen as operating and control parameter of the MBR system, which ranged between 0.02 and 0.16 (kg BOD_5/d/kg of mixed liquor volatile suspended solids) with an optimum value between 0.12 and 0.13. This study shows that MBR systems are able to process wastewaters at biomass concentration levels as claimed by the manufacturer, operating in conditions similar to those of prolonged-aeration-type activated sludge systems, with a high quality water product. The feasibility is shown of doubling plant capacity with the MBR system as it is possible to work with biomass concentrations between 5,000 and 6,000 mg/L compared with the 2,500–3,000 mg/L of the biological reactor without the proposed MBR system.

Keywords: MBR; Wastewater purification; Activated sludge; MLVSS; UF

1. Introduction

The "Barranco Seco II" wastewater treatment plant (WWTP) began operating between the end of 2005 and the start of 2006. It had an initial wastewater purification capacity of around 52,000 m^3/d, with most of the wastewater coming from the city of Las Palmas de Gran Canaria (Canary Islands, Spain). The plant, run by the local water company EMALSA (Empresa Mixta de Aguas de Las Palmas S.A.), is located on the outskirts of Las Palmas de Gran Canaria at a height of approximately 65 m above the main sewage discharge point of the city.

Virtually no land is available for expansion of the WWTP facilities. In 2005, the LP3 desalination plant supplied Las Palmas de Gran Canaria with approximately 50,000 m^3/d of potable water. Today it supplies about 80,000 m^3/d, and the wastewater generated in the city now considerably exceeds the purification capacity of the WWTP. This problem has been partly alleviated by improvements made to other smaller plants situated some distance away and by dumping

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pre-treated wastewater into the sea despite the negative environmental drawbacks.

In view of the above, a proposal was made to EMALSA, the water company which runs the WWTP, to undertake a research study on the analysis and possible adaptation of a membrane bioreactor (MBR) system with ultrafiltration (UF) membranes submerged in the wastewater. The aim was to increase the wastewater purification capacity of the plant without the need for civil engineering works (construction of new reactors, separating tanks, etc.). The WWTP in question uses type A-B activated sludge technology. In reactor A, the concentration of volatile suspended solids (VSS) in the mixed liquor (MLVSS) is around 1,000–1,500 mg VSS/L, and in Reactor B, around 2,500–3,000 mg VSS/L.

The experimental procedure was tested at an MBR pilot module, equipped with hollow fibre UF membranes submerged in the wastewater subject to purification. This MBR pilot module was kindly provided by the Canary Island Technological Institute (Spanish initials: ITC) as part of a research contract between the University of Las Palmas de Gran Canaria and EMALSA, with the former supplying the pilot module and research team and the latter logistic support (transportation, technical assistance and use of the EMALSA laboratory).

2. Aims of the research project

The main aim of the research study was to analyse and evaluate the possibility of incorporating UF membranes in the biological activated sludge system at the plant. This would enable it to operate as an MBR system, doubling or tripling the bacterial population (MLVSS) in the biological reactor and thus increasing the purification capacity of the WWTP to above 52,000 m^3/d.

Before considering this main aim, it was necessary to achieve the following partial aims:

2.1. Determination of maximum MLVSS

It was first decided to confirm whether the MBR technology for processing the wastewater was in fact able to operate as claimed by the manufacturer and as described in the corresponding technical literature, particularly in reference to the maximum amounts of biomass MLVSS (concentration of microorganisms in the biological reactor), indicated at between 8 and 30 g/L. Such concentrations should result in high rates of elimination of BOD_5 from the wastewater [1,2], a minimum production of biological sludge [3–5], and high rates of nitrification [6]. Likewise, it was necessary to determine whether, with respect to the filtrate water product, the MBR systems were able to achieve COD elimination rates of above 98%, 100% removal of suspended solids, as well as the complete elimination of faecal coliforms (natural disinfection without the use of biocides) [7]. If this were the case, the quality of the wastewater purified with these MBR systems would be far higher than the effluent from activated sludge systems, which in addition include a complete tertiary physico-chemical treatment (coagulation–flocculation, sedimentation and filtration). Such wastewater would also be much more suitable for re-use in, for example, agriculture.

2.2. Study of operating conditions

A study was also necessary of the operating conditions in which this MBR technology would be able to purify the wastewater processed in the WWTP (medium load) as, according to the technical literature, these MBR systems operate in conditions similar to those of prolonged aeration-type activated sludge systems (treating only wastewater of low BOD_5 organic contamination and so low mass load (ML). If feasible, incorporation of the MBR system would allow a doubling or even tripling of the WWTP purification capacity, proportionally increasing the concentration of microorganisms in the biological reactor (MLVSS) and increasing the wastewater flow rate to the biological reactor "B". In this way, the purification capacity (m^3/d) of the Barranco Seco WWTP could be increased without the need for civil engineering works or the use of more land for such purposes.

2.3. Identification of a design and control parameter of the purification process

It was decided that the mass load (ML) would be a suitable design parameter of the MBR system with which the Barranco Seco WWTP would work. The ML would also serve as a control parameter of the MBR system, once it had been adapted to the purification process of the wastewater processed in the plant's biological reactor "B", provided aims 2.1 and 2.2 had been correctly attained [8].

3. Experimental procedure

3.1. Material

The experimental procedure was undertaken using a Zenon ZeeWeed@ 10 pilot unit (Fig. 1). The ZeeWeed demonstration unit is designed to operate in wastewater applications [9]. Installation and Operation Manual, Zeeweed-10 (ZW-10) demonstration unit. The system is used to demonstrate the capacities of ZeeWeed@ submerged membrane technology in a wide variety of applications and is comprised of:

- A membrane module for demonstration purposes with an active membrane area of 0.9 m^2
- A feed tank of 190 L – complete with feed valve, drainage valve, temperature indicator and overflow
- Diffuser of 7.1 m^3/h – with air flow indicator
- A reversible permeate pump and its motor
- A backflush tank of 19 L – complete with drainage valve and permeate discharge overflow
- A reject discharge pump
- Solenoid valves to control the process
- A central control panel
- A stainless steel stack

3.2. Methodology

The wastewater processed in the biological reactor "B" of the Barranco Seco WWTP was collected at three different points and fed to the MBR pilot module in order to evaluate the degree of adaptation of the MBR system to the

Fig. 1. Membrane bioreactor pilot module.

purification of wastewater processed in the plant [10]. The experimental procedure was carried out in three stages, as described below.

3.2.1. First stage: adaptation of the MBR module to the WWTP process

Personnel were given training in MBR technology and its application in wastewater purification, operating conditions, and design and operating parameters and their determination techniques.

The MBR pilot module equipped with hollow fibre UF membranes (ZeeWeed@ 10) had been taken out of service, disassembled and stored in the ITC warehouse for more than 2 years. The module had to be transported, adapted to the requirements of the research study, reassembled and put back into service. Adapting the MBR module to the project requirements meant more than 3 months of additional work.

3.2.2. Second stage: determination of the maximum attainable biomass

The aim was to establish the maximum concentrations of biomass (microorganisms) or $MLVSS_{max}$ which could be attained during the purification process of the Barranco Seco wastewater [11]. For this purpose, the pilot module was set up in parallel with the "B" reactor of the WWTP, processing the wastewater fed to the "B" reactor. Three collection points in the "B" reactor of the wastewater fed to the MBR pilot module (batch processing) were evaluated [12]. These points in reactor "B" were as follows:

- Inlet of the "B" anoxic chamber
- Mid-region section of reactor "B"
- Reactor "B" outlet

3.2.3. Third stage: confirmation of previous results and determination of maximum ML

The purpose of this stage was to confirm the previous results, namely the maximum biomass value (MLVSS) [11], and to determine the maximum ML, which is the organic load ratio or food-to-microorganism ratio, *F*/*M* (kg of BOD_5/d/kg of MLVSS in the reactor), that could be attained in the MBR pilot module during the processing of the wastewater which was processed in parallel in the "B" reactor of the Barranco Seco WWTP. For this purpose, it was necessary:

- To determine the most suitable collection point for feeding of the MBR module (closest point) to allow the pilot system to stop batch processing and operate continuously (with the help of the WWTP personnel working in shifts). To confirm the results of the second experimental stage and select the operating parameter to be evaluated (it was decided to use the ML).
- To evaluate the selected operating parameter (ML), to identify the parameters required to obtain it (V30 and MLVSS, etc.), and to purchase new UF membranes to ensure the reliability of the results in the third stage [13].
- To collect data of the selected parameters (V30, MLVSS, COD, BOD_5, etc.) and evaluate the selected operating parameter (ML = *F*/*M*, organic load fed to the bioreactor/population of microorganisms in the bioreactor), establishing the maximum corresponding $(ML = F/M)_{max}$ value. This was performed with the new membranes acquired for this purpose.

4. Experimental results and analysis

4.1. First stage

The first step was to determine the maximum concentrations of biomass MLVSS which could be attained with the MBR system, processing the wastewater which the Barranco Seco WWTP purifies. For this purpose, the MBR pilot module which processed by batch was fed with wastewater from reactor "B". Experimental data were obtained from three wastewater collection points (in the "B" reactor") which were used to feed the MBR pilot module (equipped with hollow fibre UF membranes). The results are shown in Figs. 2–4.

4.2. Second stage: confirmation of first stage results

The test results corresponding to this second stage are shown in Figs. 5, 6, 7 and 8. They correspond to the pretest stage and to periods between washes of the MBR pilot module. After each wash the reactor was loaded with new wastewater (batch processing).

4.2.1. Evaluation of ML (process design and control parameter)

In this stage, the V30 was measured for concentrated sludge and the corresponding value was then used to determine the sludge volume index (SVI). As our pilot module was batch operating, the ML was calculated based on the volume of the biological reactor and the SVI was then plotted

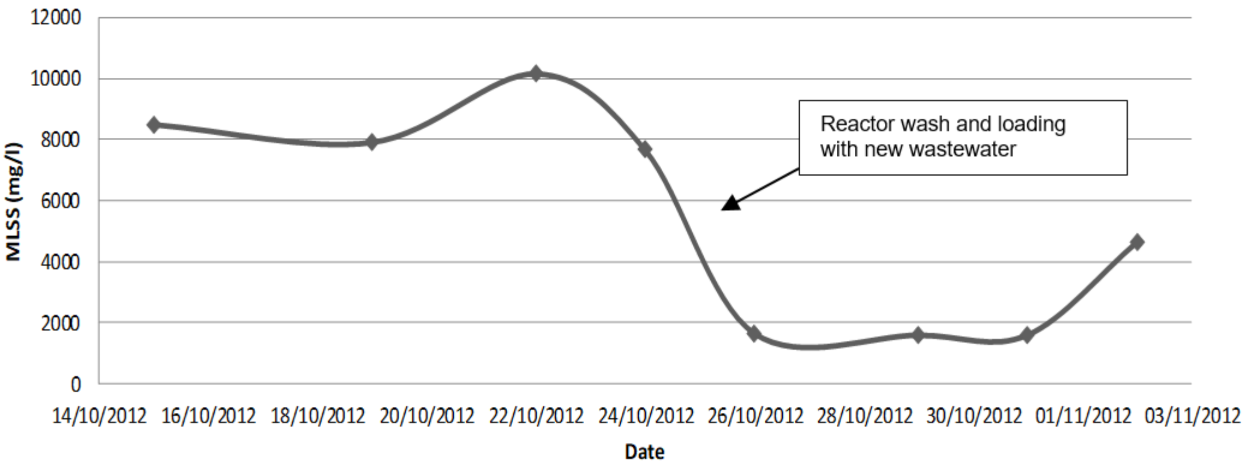

Fig. 2. First collection point: Reactor "B" anoxic chamber inlet. Zone 1.

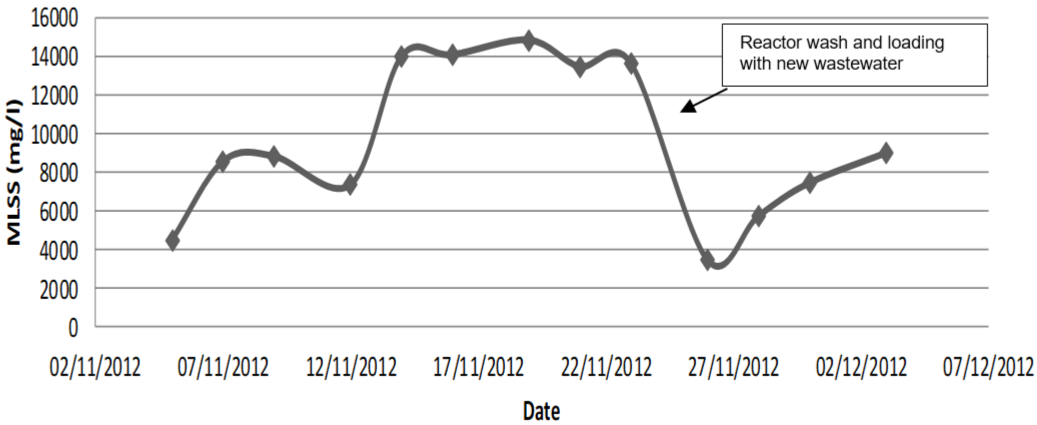

Fig. 3. Second collection point: mid-region of reactor "B". Zone 2.

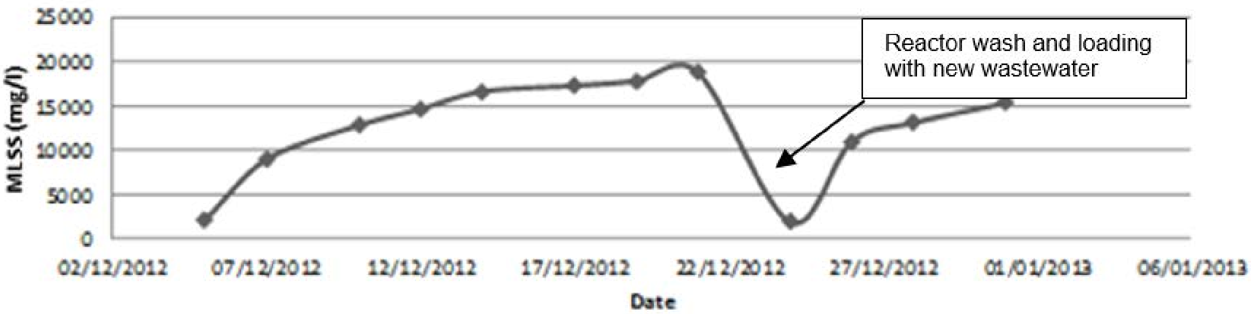

Fig. 4. Third collection point: "B" outlet. Zone 3.

against ML to finally determine the maximum ML. Figs. 9 and 10 show this procedure.

4.2.2. *Quality of the MBR effluent wastewater (filtrate)*

Analysis of the quality of the filtrate of the MBR pilot module equipped with hollow fibre UF membranes was only performed during the first stage. With the assistance of EMALSA laboratory staff, the COD, BOD_5 and faecal coliform values were analysed. These test results are shown in Figs. 11–13.

5. Discussion of test results by aims

Following is an analysis of the test results in accordance with the aims set out in sections 2.1, 2.2 and 2.3. This

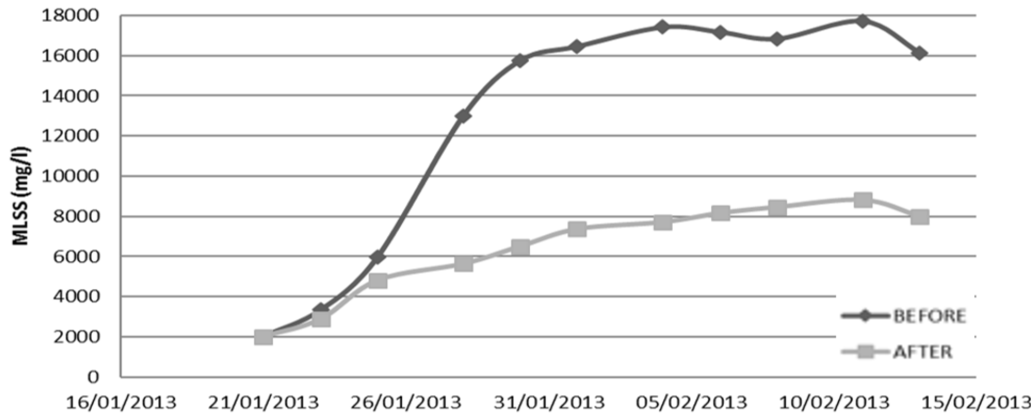

Fig. 5. Pre-test.

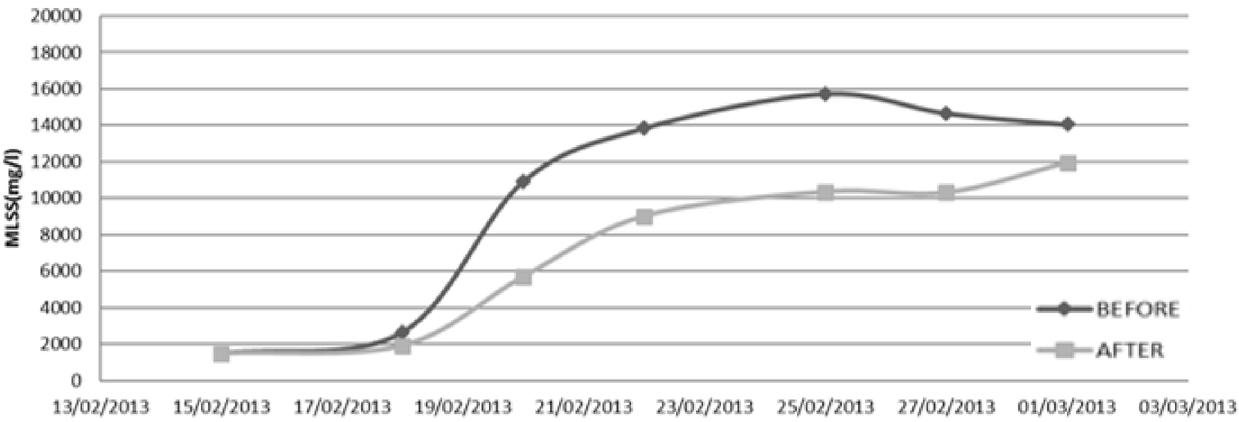

Fig. 6. Test 1.

analysis is based on the results represented in Figs. 2–14 in section 4:

5.1. First aim: determination of $MLVSS_{max}$

As can be seen in Figs. 2–4, which correspond to the first stage, the $MLVSS_{max}$ depends on the characteristics of the wastewater fed to the MBR pilot. The characteristics of BOD, biomass concentration and degree of aeration differ according to the collection point from which the biological reactor of the MBR pilot module is fed. The following results were obtained:

- For the collection point at the reactor "B" anoxic chamber inlet of wastewater fed to the reactor of the MBR pilot module, and as can be seen in Fig. 2, $MLVSS_{max}$ ≈ 10,000 mg/L (10 g/L)
- For the collection point at the aerated mid-region point of reactor "B" of wastewater fed to the reactor of the MBR pilot module, and as can be seen in Fig. 3, $MLVSS_{max}$ ≈ 15,000 mg/L (15 g/L)
- For the collection point at the reactor "B" outlet of wastewater fed to the reactor of the MBR pilot module, and as can be seen in Fig. 4, $MLVSS_{max}$ ≈ 20,000 mg/L (20 g/L).

The maximum value was confirmed in the second stage. Having acquired a better understanding of the operation of the MBR pilot module, wastewater fed to the reactor of the MBR pilot module was only collected from the aerated mid-region of the "B" reactor. As can be seen in Figs. 5–8, the biomass concentrations ranged mostly between 15,000 and 20,000 mg/L. It can, therefore, be stated that using MBR systems equipped with hollow fibre UF membranes to purify wastewater processed by the Barranco Seco WWTP, an $MLVSS_{max}$ of approximately 20,000 mg/L (20 g/L) can be obtained.

5.2. Second aim: analysis of operating conditions

This subsection explains the conclusions of the study of the operating conditions of the MBR pilot system used to purify the wastewater processed by the Barranco Seco WWTP. A study was made of the most useful design parameter for the WWTP. This parameter would also serve as operating and control parameter for a purification process adapted to this type of system. For this purpose, in addition to observing the evolution of MLVSS in the MBR pilot module, as well as pH and temperature, an evaluation was also made of the V30 and, subsequently the SVI. The parameter chosen was the mass load factor (ML), namely the ratio between the organic load (BOD_5 in kg/d) which is fed to a biological reactor and the active biomass or microorganisms

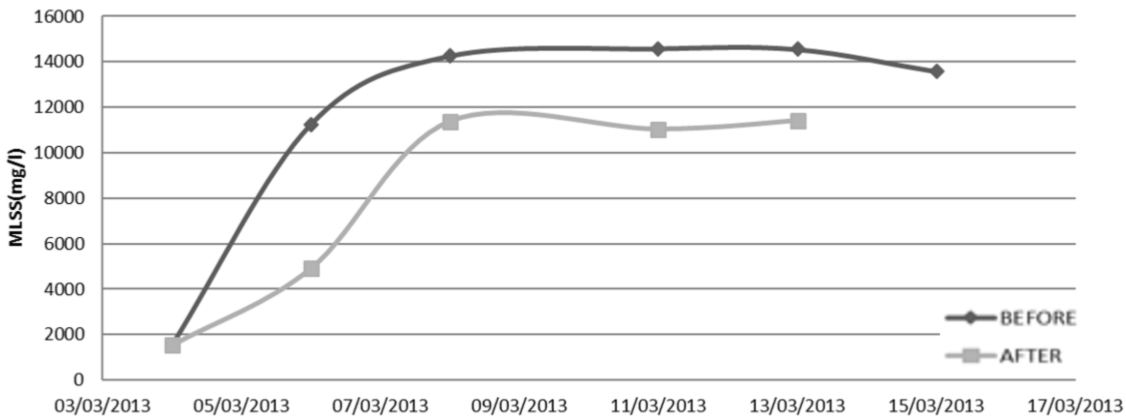

Fig. 7. Test 2.

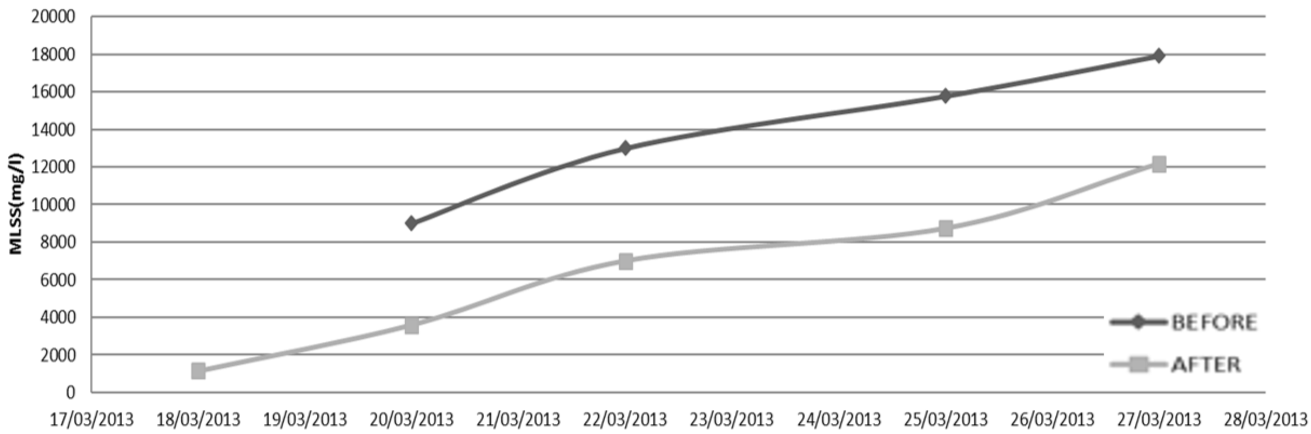

Fig. 8. Test 3.

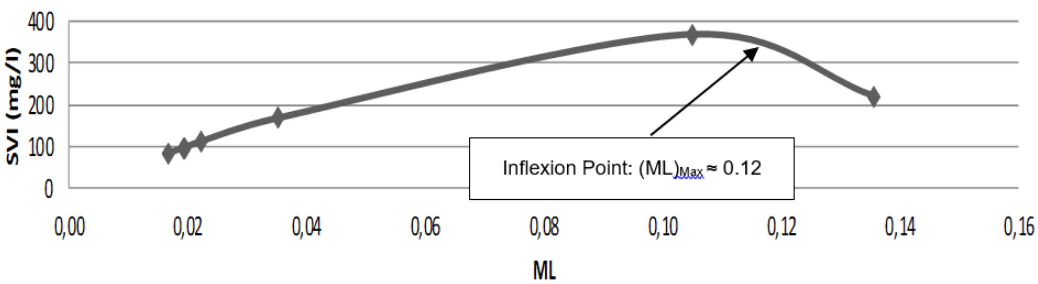

Fig. 9. Sludge volume index vs. mass load. Test 1.

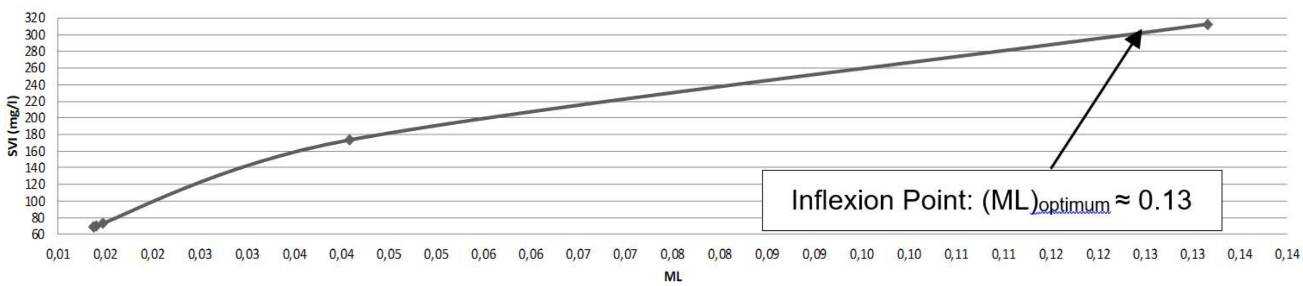

Fig. 10. Sludge volume index vs. mass load. Test 2.

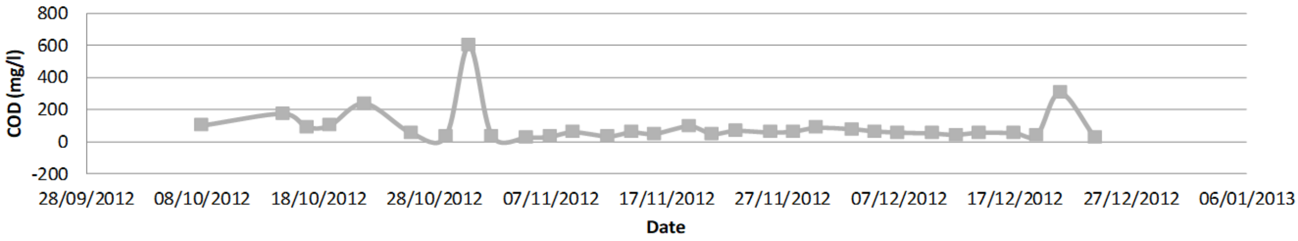

Fig. 11. Filtrate chemical oxygen demand (mg/L) evolution.

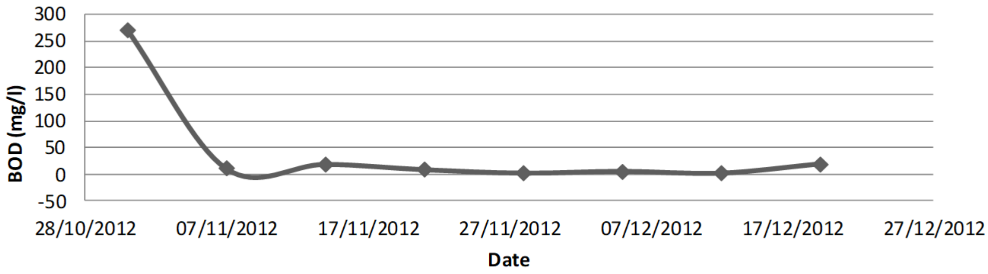

Fig. 12. Filtrate biochemical oxygen demand (mg/L) evolution.

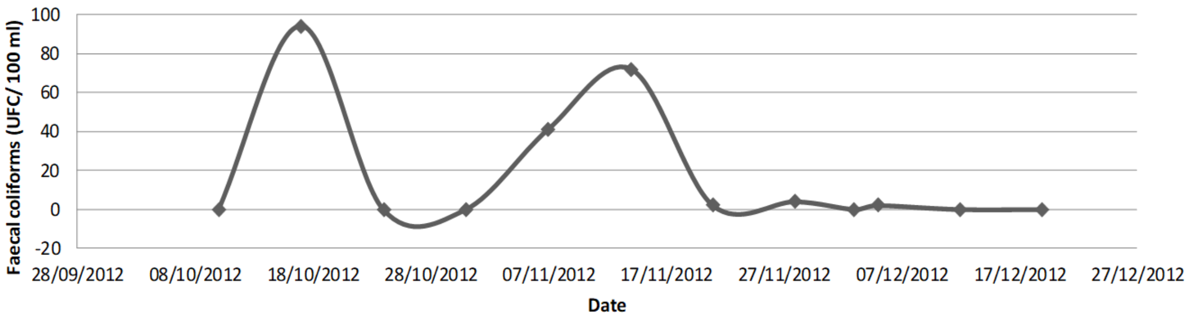

Fig. 13. Filtrate faecal coliforms (UFC/100 mL) evolution.

(kg of MLVSS in the reactor), which should be maintained in the biological reactor to reduce the BOD_5 to the legally permissible values for any corresponding wastewater reuse. It can be concluded from the results shown in Figs. 9 and 10 that the ML during the purification process varies between approximately 0.02 and 0.16 (kg of BOD_5/d/kg of MLVSS). This can be most clearly observed in Fig. 9 and is concordant with MBR systems operating under conditions similar to those of a prolonged aeration activated sludge system which works with an ML range of between 0.05 and 0.15. It was, therefore, concluded that the ML values obtained in the present study were correct.

5.3. Third aim: determination of maximum ML

After analysing the data shown in Figs. 9 and 10 and taking into consideration the inflexion points of the curve (which are associated with the point of change of the cellular synthesis process to endogenous respiration), it can be concluded that the maximum ML at which the MBR system can work processing the Barranco Seco II wastewater lies between 0.12 and 0.13 (kg of BOD_5/d/kg of MLVSS). To determine this value with greater precision, it would be necessary to evaluate this parameter with the MBR module working continuously and with samples taken at least three times a day.

5.4. Quality of the filtrate water of the MBR pilot module equipped with hollow fibre UF membranes

The quality of the wastewater effluent of the MBR pilot module is good when compared with that of a settling tank in an activated sludge system, and even better than the quality obtained if the wastewater is subjected to a complete physical–chemical tertiary treatment (coagulation, flocculation and filtration). This can be observed in the most stable areas of Figs. 11–13, where it can be seen that:

- MBR pilot module COD effluent levels oscillate around 50 mg/L
- MBR pilot module BOD_5 effluent levels oscillate around 10 mg/L
- MBR pilot module faecal coliform effluent levels are around 0 UFC/100 mL

It should be noted that the appearance of faecal coliforms in the effluent (filtrate) was due to the fact this this filtrate was collected in a small tank used for membrane backwashing. Initially, no consideration was given to the resulting contamination of the water and formation of biomass inside the tank. Once this situation was realised, the tank was washed with greater frequency and in the final month, as can be seen in Fig. 13, the faecal coliform curve tends to zero.

6. Conclusions

In view of the results obtained and analysed in this research study, the following conclusions may be drawn:

- The feasibility can be confirmed of using an MBR system to purify the wastewater processed in the Barranco Seco WWTP, with a much better water quality than that obtained presently [14].
- The estimated maximum ML between 0.12 and 0.13 (kg of BOD_5/d/kg of MLVSS) indicates that it is possible to work with a maximum biomass or MLVSS in the order of around 15,000 mg/L (15 g/L) [11].
- Bearing in mind that reactor "B" of the Barranco Seco WWTP operates with a biomass or MLVSS of around 2,500 to 3,000 mg/L, the theoretical possibility exists of increasing plant capacity by a maximum factor of between 3 and 6. However, this is clearly not necessary and would entail a much more complex plant operation. Therefore, in terms of present and future demands (basically a doubling of the current purification capacity of the Barranco Seco WWTP plant) [15], working with MLVSS in the order of 5,000 to 6,000 mg/L would suffice in a worst case scenario. This would guarantee that plant demands are met and would only require an easily operable MBR system as aeration becomes less efficient as the MLVSS increases, as was observed in the study when this concentration rose above 15 g/L.

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