REDUCTION OF CARBON EMISSIONS IN A MEDITERRANEAN URBAN WASTEWATER TREATMENT PLANT

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ABSTRACT
In the last few decades, with the rapid growth of population, and more than half of them living in cities, the urban wastewater treatment has become a big challenge that consumes many resources, namely energy. In a climate change scenario, the Mediterranean region is facing more frequent water scarcity periods, and urban water reuse can be a solution, at least for supplying some non-potable water uses. In this context, the performance of urban wastewater treatment plants (WWTP) is of utter importance, to produce environmentally safe treated water while reducing energy consumption and carbon emissions (CE). Activated sludge is the biological process most widely used in wastewater treatment and requires aeration systems in order to promote the oxidation of organic matter and ammonia. It is known that the energy consumed in the aeration processes is of major importance for the global WWTP CE. This study was carried out in a WWTP in southern Portugal, wherein an aeration control system that responds in real time to ammonia and nitrate concentrations was tested. The system is set to optimize the duration of the aerated and non-aerated periods, for nitrification and denitrification. During the experimental period, BOD, COD, *Escherichia coli*, TN and TP were monitored in the treated effluent, in order to verify the quality standards that allow its reuse. The aeration control system contributed to a decrease of about 13% of the specific energy consumption, when compared with the corresponding period in previous years, representing a CE reduction of about 1.2 t CO_2 eq, during the experimental period. The treated effluent maintained its high quality standards and can be used, for example, in agricultural irrigation of local crops. Aeration control systems reacting in real time can have an important role to decrease CE of urban WWTPs; however, further research is needed, including more WWTPs and analyzing seasonal variations in energy consumption over the year.
Keywords: urban wastewater treatment, aeration control, energy, carbon emissions, water reuse.

1 INTRODUCTION

Although wastewater treatment plants (WWTP) are of utmost importance to environment and public health, they consume resources, and release emissions with negative environmental impact and contribute to global warming [1]–[3]. To produce environmentally safe treated water, WWTP have appropriate treatment technology including a set of equipment that execute different processes, with high energetic costs [1], [4]–[7], e.g. a lot of energy is required to pump, treat and deliver water. About 20% of the total energy consumption for public utilities by the municipalities is for wastewater treatment [3], [8], [9], and energetic costs correspond to the WWTP main operation cost [2], [4], [5].

The activated sludge process (ASP) is very common for urban wastewater treatment, despite the large amount of oxygen it requires for the oxidation of organic matter and ammonia in the biological tanks [5], [9]. The requirements in terms of dissolved oxygen to biological processes are closely related to the effluent criteria, defined by legal requirements. Over time, some studies aimed to optimize the ASP related to aeration control, selecting more

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efficient aerators or using more efficient aeration processes, in order to decrease the energetic consumption [9]–[11], while meeting the quality requirements of the treated effluent.

In order to improve the sustainability of the urban water cycle, the waste water treatment technologies and the water reuse are of paramount importance [12]. The global carbon emissions (CE) of a WWTP are closely related to greenhouse gas emissions (GHG) associated with material consumptions and energy, namely from all treatment processes, e.g. carbon dioxide emission from electric power consumption in the ASP [13]. According to the Portuguese supplier of electricity [14], during 2016 in Portugal 79.6% of electricity comes from renewable sources (wind, water, renewable cogeneration, urban solid waste and others) and 20.4% from non-renewable (coal, natural gas, fossil fuel, nuclear, and municipal solid waste).

The urban wastewater is a resource suitable for the recovery of valuable materials (e.g. nutrients for agriculture) and clean water, and its reuse is a common practice in several countries [12]–[15]. The water reuse is an important measure to address water scarcity reducing the pressure on natural water resources, in a climate emergency scenario, as we are facing in Mediterranean. Several studies demonstrated that water reuse can save chemicals and electricity needed to pump, treat and distribute water from natural sources [12], [13], [16], however the WWTP flow rate availability, effluent quality (e.g. salinity) and the distance between WWTP location and places of application of reused water influence the magnitude of application [13]. In addition, the water reuse can contribute to the implementation of circular economy practices in water sector, decreasing the corresponding CE.

This study was carried in an urban WWTP in the Mediterranean area and aimed to quantify the impact on CE, of installing an aeration control system (RTC-N/DN System®) adjusted to minimize energy consumption and comply with the quality requirements for water reuse.

2 METHODOLOGY

This study was performed between December 2015 and April 2016 in the Ferreiras WWTP, Albufeira (Algarve, south Portugal), built in 1990 and improved in 2002 to serve 22,160 equivalent inhabitants. This WWTP (Fig. 1) has a preliminary treatment with an automatic screening system (6 mm), and oil and grease removal by mechanical separation. The secondary treatment is composed of two biological treatment lines by ASP, each line consisting of an anoxic tank (140 m^3), two aerobic tanks (total volume 2.153 m^3) with aeration in sequence, and a circular decanter. After secondary sedimentation, the disinfection is carried out through a UV disinfection system and before the discharge into the Albufeira Stream, the effluent passes through a final maturation lagoon to additional UV disinfection and where some nutrients removal also takes place. In the ASP tested line the aeration in the biological treatment is ensured by 2 turbines (Europelet) with 20.45 kW of power and 1.9 kg O_2/kWh of oxygenation capacity. The RTC-N/DN System® was installed to optimize the length of the aerated and non-aerated periods, for nitrification and denitrification, responding directly to ammonia and nitrate concentrations in the ASP. During the experimental period, the aeration time was adjusted to minimize energy consumption, complying with the requirements defined for Biochemical Oxygen Demand (BOD, mg/L·O_2), Chemical Oxygen Demand (COD, mg/L·O_2), *E. Coli* (MPN/100 mL), Total Nitrogen (mg/L·N) and Total Phosphorous (mg/L·P), in the treated effluent. All these parameters were quantified weekly, in laboratory according to Standard Methods for the Examination of Water and Wastewater [17]. In real time, continuously we measured the influent flow (m^3/h), temperature (°C) with

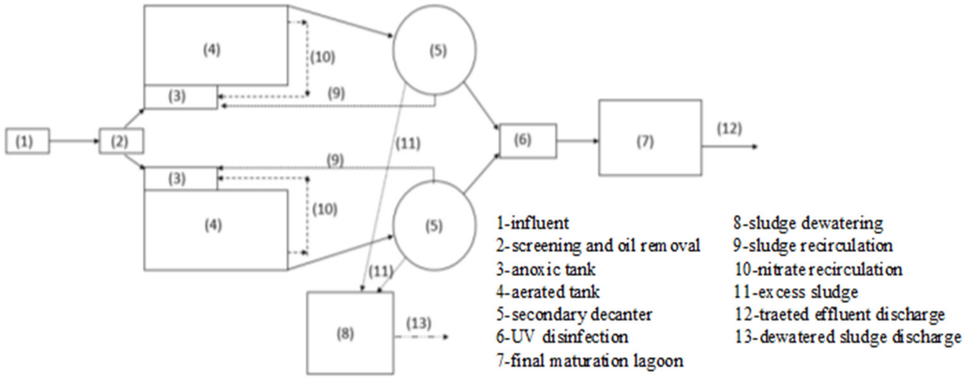

Figure 1: Linear diagram of the Ferreiras WWTP.

the EasyLog EL-USB 2, Dissolved Oxygen (mg/L) with the Hach LDO sensor, and Ammonia (mg/L·N) and Nitrate (mg/L·N) with the combined sensor Hach AN-ISE. All information was saved in a data logger SC 1000. The relationship between parameters was assessed using Pearson correlation (r). The supplier company measured the total energy consumption of the WWTP using an Itrón ACE 6000 meter. It was measured the energy consumption of the turbines during aeration with a mains analyzer Fluke 435 Serie 2.

There are wo types of GHG related to WWTPs, the direct emissions from all processes in the plant, such as CO_2 emission from de ASP, and the indirect GHG emissions associated with the energy consumption [18]. This study focused on indirect GHC emissions related to energy consumption on ASP aeration. The aeration periods were converted into energy consumption (kWh) and CE (kg CO_2 eq), considering 381 g CO_2 eq/kWh [14]. The results of BOD and faecal coliforms in the treated effluent, were compared with the water reuse requirements for agricultural irrigation (Portuguese Law 119/2019).

3 RESULTS AND DISCUSSION

During the experimental period (December 2015 to April 2016), the influent flow ranged between 1,190 m^3/day in February and 1,412 m^3/day in December, with an average value of 1,286 m^3/day. The change evolution (Fig. 2) reflected the pattern of domestic water consumption, with peaks in the early morning and the end of the day, as described in previous works for municipal WWTP [19]. The mean temperature of the influent changed between 17.9°C (at 10:00 h in February.) and 19.1°C (at 18:00 h in April). Two ammonia and nitrate setpoints were tested in the biological reactor in order to evaluate the operation of the control system and the reliability of the probes. On December 2015, at the beginning of the experimental period, the RTC-N/DN System was programmed to start aeration at ammonia concentration of 10 mg·N/L and nitrate concentration of 10 mg·N/L. From February 24 until the end of the experiment (April 30), the target concentrations changed to 5 mg·N/L of ammonia and 5 mg·N/L of nitrate. Fig. 2 shows the change throughout the day during the different months (average and standard deviation) of the influent flow rate, temperature, aeration duration, dissolved oxygen, ammonia and nitrate concentrations. The aeration time throughout the day showed a strong correlation with dissolved oxygen (r = 0.93) and temperature (r = 0.75), while the correlations with ammonia and nitrate concentrations were lower (respectively, r = 0.67 and r = 0.68). Ammonia and temperature showed similar patterns

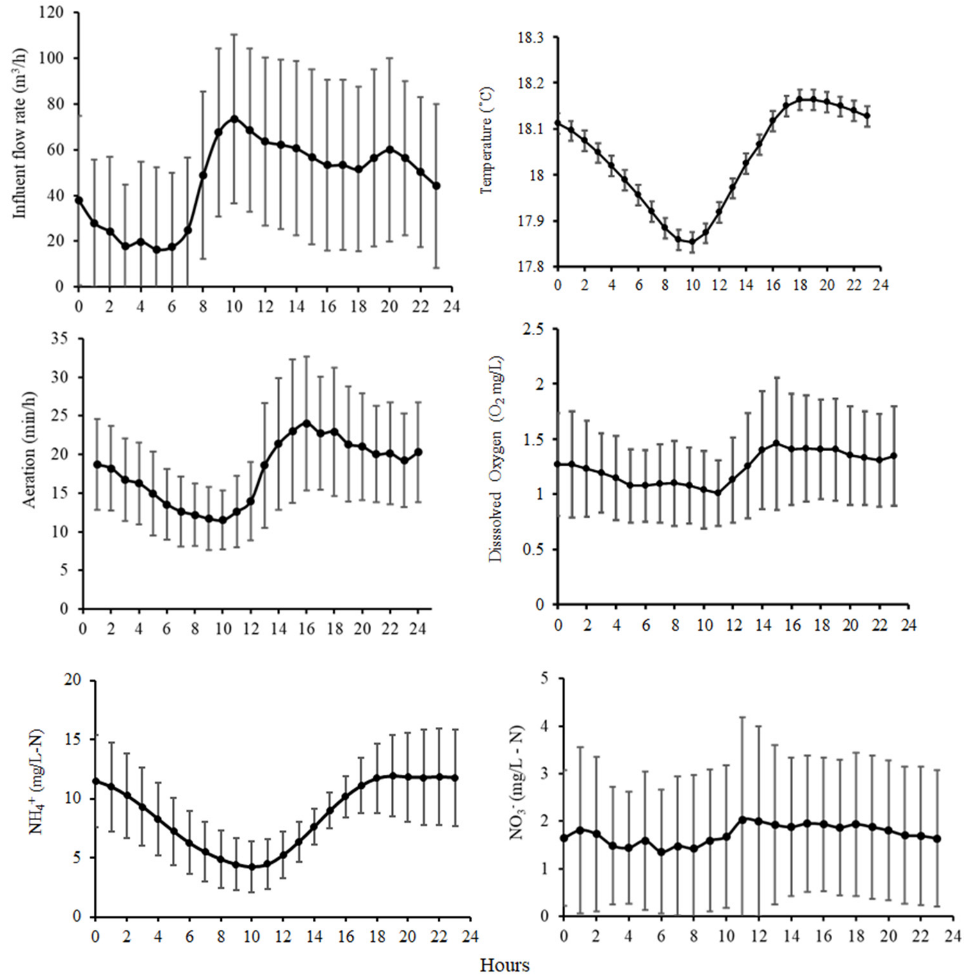

Figure 2: Daily changes in monitored parameters during the experimental period (average ± standard deviation).

(r = 0.99), related to the influent flow fluctuation and subsequent oxidation of organic matter, and to the typical variation of the ambient temperature throughout the day.

The results of BOD, COD, and faecal coliforms in the treated effluent (Table 1) met the limits defined in the WWTP Discharge Permit, and the requirements defined for irrigation of crops consumed raw, which grow above the ground, and where the consumable part does not contact water, such as fruit orchards. The water reuse on local fruit tree crops irrigation, such as citrus tree, can function as an important contribution to the water resource´s protection in region, where the water scarcity is a usual problem. Despite the BOD <10 mg/L·O_2, it is expected that treated effluent presents higher organic matter contents than the groundwater usually used for crops irrigation, suggesting that the water reuse can have a positive effect on soils organic carbon and thus on water retention capacity [20]–[22]. Furthermore, the

Table 1: Analytical characterization of the treated effluent in the experimental period, December 2015 to April 2016.

Parameter	Minimum	Average	Maximum	Discharge permit	Water reuse[(1)]
BOD mg/L·O_2	<10 (QL)	<10 (QL)	<10 (QL)	25	<25
COD mg/L·O_2	21	33	42	125	ND
E. coli MPN/100 mL	42	144	370	2,000	≤1,000
Total nitrogen mg/L·N	3.6	7.1	13.0	ND	ND
Total phosphorus mg/L·P	0.5	1.3	3.6	ND	ND

QL: Quantification limit; ND: Not defined; (1): Portuguese Law 119/2019.

nitrogen and phosphorous contents in the treated effluent, instead of being discharged into the environment promoting eutrophication phenomena, can supply part of plants' nutritional requirements, representing a significant reduction in application of synthetic fertilizers, as reported before in other studies [22].

Regarding the energy consumed in the WWTP, during the experimental period, the aeration consumption represented two thirds of the total energy, ranging from 67% in December to 76% in February (Fig. 3), confirming some previous results obtained for municipal WWTPs with similar treatment technology [9], [23], [24], but higher than reported by other authors [25]. The comparison with the same months on previous years (from 2012 to 2014), shows that during the experimental period, the specific energy consumption in aeration decreased in December, January and February, respectively 40, 10 and 21%, and increased slightly in March (more 8%) and April (more 9%), as shown in Fig. 4. This is due

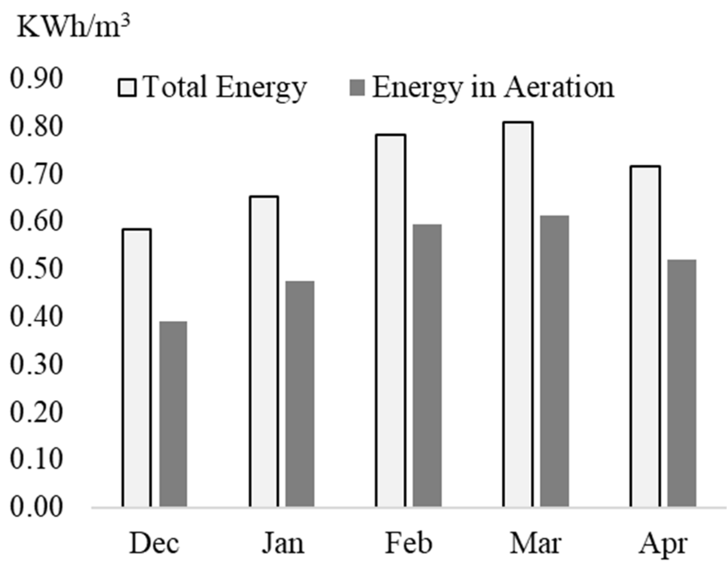

Figure 3: WWTP energy consumption by cubic meter of treated effluent, during the experimental period, December 15 to April 16.

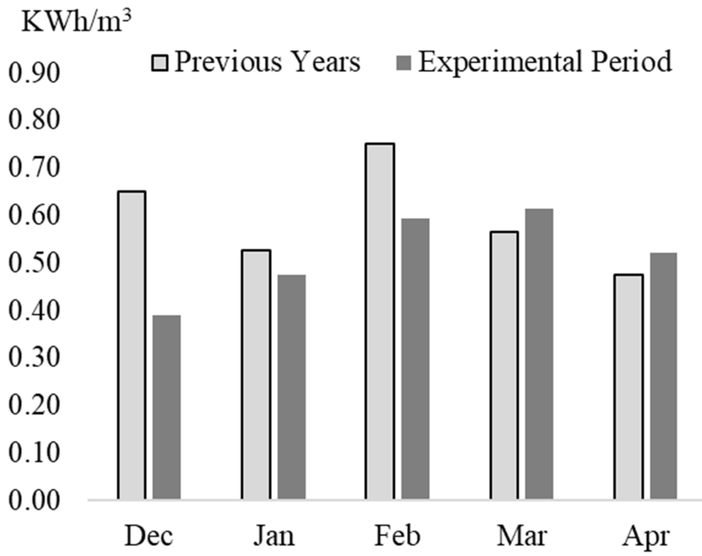

Figure 4: WWTP energy consumption in aeration, by cubic meter of treated effluent in the period 2012–2014.

to the occurrence of a more complete nitrification as the ammonia setpoint in the biological reactor decreased from 10 to 5 mg/L·N, which means more aeration and thus an increase on energy consumption. In average the specific energy consumption in the aeration stage decreased about 13% with the installation of the RTC-N/DN System®. In the experimental period, the specific energy consumption in the aeration stage was 0.52 ± 0.09 kWh/m^3 (average ± standard deviation), which are in line with previous studies for municipal WWTPs from USA and Japan, using conventional ASP [26]. The installation of the RTC-N/DN System® ensured enough oxygen for organic matter oxidation, decreasing the specific CO_2 emissions from 226 to 198 g CO_2 eq/m^3 (Table 2), a reduction of about 13%.

Table 2: Carbon emissions related to energy consumption on ASP aeration.

	Previous years g CO_2 eq/m^3	Experimental period g CO_2 eq/m^3
December	248	148
January	200	181
February	286	226
March	215	234
April	181	198
Average ± standard deviation	226 ± 42	198 ± 35

4 CONCLUSIONS

The WWTPs strongly contribute to the CE of the urban water cycle. The present work showed how energy consumption in a urban WWTP can be optimized, reducing CE, and keeping the quality standards of treated effluent. During the experimental period, the installation of the RTC-N/DN System® saved monthly about 13% of WWTP total electrical energy consumption, which mean a reduction of about 1.2 t CO_2 eq on CE. This reduction is foreseen to be greater in the summer, due to the increase of influent flow related to seasonal tourism in Algarve. The decrease in energy consumption did not affect the treated effluent quality, which can be used for non-potables purposes, as in agricultural irrigation, saving the fertilizer application and reducing the water abstraction from aquatic ecosystems, in accordance to circular economy principles. To improve the sustainability of urban water cycle, regarding the CE related to effluent treatment, further research is needed to optimize the control of the aeration systems, during all the year and including several WWTPs with different technologies.

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