High Efficiency in Nitrogen Removal and Energy Saving by Small WWTPs Upgrade from Extended to Alternated Aeration Process

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Abstract

This work presents the results obtained, in terms of nitrogen removal and energy saving, when alternating cycles of aeration/non-aeration, based on a patented automatic remote control system, were applied to full-scale wastewater treatment plants (WWTPs). Two existing small plants (denoted WWTP1 and WWTP2) with different structural parameters and influent macropollutant concentrations were used to test the process. The experimentation was carried out throughout one year in each plant and the data processed showed a high efficiency both in nitrogen removal and energy saving. In fact, a comparison with previous data from both plants showed an average decrease of NO_3-N effluent of about 65% in WWTP1 and 92% in WWTP2 and lower energy consumption, usually <100 Wh $PE^{-1}d^{-1}$. The selected plants, which are representatives of the standard small WWTPs in southern Spain, along with the higher performance of the automatic alternating systems, could be adapted to upgrade the general situation of nutrient removal in order to gain benefits in terms of less energy consumption.

Introduction

The region of Extremadura presents an atypical situation compared with other areas of Spain. Small villages are far away one from the others, what generates a diffused contamination which arrives to large reservoirs. This implies a lot of very small wastewater plants with a low level of automation. These plants are the targets of this work.

This fact was driven by Government regulations on wastewater treatments, which have generated a huge increase in the amount of wastewater to be treated. According to the EC Directive 91/271/CEE, 2005 was the deadline to carry out the secondary treatment of wastewaters for discharges over 10.000 population equivalents (PE) and over 2000 PE if wastewater is discharged into estuaries or rivers. Furthermore the Spanish laws stated 15 mg of Total Nitrogen (TN) per litre as a standard for effluent quality for nitrogen compounds.

A recent survey carried out by the University of Extremadura and funded by the Regional Government of Extremadura described the state of municipal wastewater treatment plants, in terms of characteristic, management systems and performance of the nutrient removal processes. It showed that there were about 100 WWTPs in Extremadura, most of them with a design treatment capacity between 10.000 and 100.000 PE. Thirty representative plants were studied and 90% of them showed management problems related to some operational conditions such as overloading, under loading, over aeration and under aeration. Their effects were reflected on settling characteristics and performance of nutrients and micropollutans removal. In many cases they were out of the limits established in the aforementioned EC Directive.

From those data the research team of the University of Extremadura studied the application of alternating cycles (AC) as a valid system to guarantee a proper treatment of domestics influents, providing a patented control system to WWTPs which changes the original control philosophy applied to complete mixed tanks (Universidad de Extremadura, 2009). In order to satisfy the legal TN limits in the effluent, an alternating cycle (AC) process based on ORP and DO measurements was implemented on several WWTPs. So a continuous process of automatic alternating oxic and anoxic phases was carried out in the stirred reactor itself. Many author have used the bending points of ORP, pH and DO curves to control the alternating cycles process (Battistoni, et al., 2003) (Fatone, et al., 2005) (Nardelli,et al., 2009), but in this work, an intelligent strategy was put into practice, aerating the reactor tank until DO had reached 2 mg/l, a reference that has been proved to be enough to ensure the transformation of ammonia into nitrate allowing the accumulation of a fraction of carbonaceous matter in the basin (Serralta, et al., 2002) (Martins, et al., 2003). Once that point is reached, the control works out an organic load estimation (OLE), based on ORP and DO profiles, that is used to decide the duration of the aerobic phase, or the start of an anoxic one according to several rules programmed to work according to three priority levels. First: COD elimination, second: nitrogen removal and third: phosphorous removal. In a non aerated-phase, the control system extended its duration if the OLE was low to get a high denitrification performance and energy saving (it was usually on the night period); in other case, the anoxic phase was short because a high load influent was estimated. This work describes the results of two full-scale WWTPs in which an AC process based on a patented control device was applied. A comparison in terms of nutrients removal and energy saving is reported.

Methods

Full-Scale Plants. The study was carried out in two wastewater treatment plants denoted WWTP1 and WWTP2. The design capacity and flow rate for each plant are summarized in Table 1. Upgrading of the plants was achieved by installing on-line dissolved oxygen (D) and ORP probes for process control, put in each biological reactor. $N-NO^3$ and pH probes to check the control strategy, and $N-NH^4$, SAK 254 nm and SST probes to characterize the incoming raw wastewater were also used.

Influent Characterization: The variations in the wastewater flows observed in the treatment plants tend to follow a very marked diurnal pattern, as shown on Fig. 1. Minimum flows occur during the early morning hours when water consumptions is lower and when the base flow consists of infiltration and small quantities of sanitary water. This case, known as **LOW LOAD**, was characterized by low concentrations of Total Suspended Solid (SST), Ammonium and Dissolved Organic Carbon (measurement as Spectral Absorption Coefficient SAC 254 nm). In this period, the patented control device carried out an anoxic stage long enough to ensure a complete denitrification, avoiding over-aeration (Fig 2. (a)). The first and highest flow peak usually appears at the late morning when the wastewater from the peak morning water used, reaches the treatment plant. This fact is known as **HIGH LOAD** and was characterized by a sudden peak in the ammonium influent and a rise in the SST and SAC profiles. The strategy of control under HIGH LOAD was based on an increase of the aeration stage to ensure the oxidization of organic matter in spite of an increase in the nitrate generation by excessive nitrification (Fig 2 (c)). A second flow peak usually appears at the early evening, between 6 and 9 p.m., when the ammonium profile was rather constant and the trend of SST and SAC decrease. This situation is known as **MEDIUM LOAD**. In this case, in order to allow a complete nitrification and avoid generating a lot of nitrate, the control system carried out two cycles of aeration, i.e., when a value of 2 mg/l of OD was reached the blower was switched off, and when DO decrease to 0.1 mg/l, the blower was switched on again. In this situation there was not an anoxic period (Fig 2 (b)). The time the peak happens and its amplitude vary with the size of the community and the length of the collection system. As the community size increases, the variations between the high and low flows decrease due to the increased storage in the collection system of large communities that tends to equalize flow rate.

	design capacity (PE)	Average influent flow rate ($m^3 day^{-1}$)	Specific Reactor Volume ($L\ PE^{-1}$)
WWTP1	12000	2844	250
WWTP2	4000	600	300

Table 1. Design Treatment Capacity and Influent Flow Rate

Results and discussion

Nitrogen Mass Balance: The nitrogen removal performance of two plants depended on the length of the aerobic and anoxic phases. In both cases the nitrogen mass balance for WWTP1 and WWTP2 highlighted optimal removal efficiencies for the alternating cycles compared with the conventional process, as shown in Table 2.

	WWTP1		WWTP2	
	pre-AC	AC	Pre-AC	AC
E_{NT} (%)	35	85	41	90
E_{COD} (%)	87	90	92	95
E_{PT} (%)	13	55	10	60

Table 2. Nutrient removal and organic matter efficiency

Electric energy consumptions: In the AC process the alternation of aerobic and anoxic phases in the same continuously fed reactor allows for the best exploitation of nitrogen-bound oxygen for COD oxidation, as consequence it is possible to reach an effective decrease of energy consumptions (Nardelli, P, et al., 2008). For these reason, energy saving of 26 % for WWTP1 and 47 % for WWTP2 can be observed.

Conclusions

A test study with two full-scale small WWTPs was carried out to test a new control strategy based on alternating phases of aeration and non-aeration to get high performance on nitrogen compound removal. The plants studied were representative of the whole small WWTPs in southern Spain. In parallel with the increase in the nitrogen removal performance a proportional energy saving, in the range 30-50%, was achieved.

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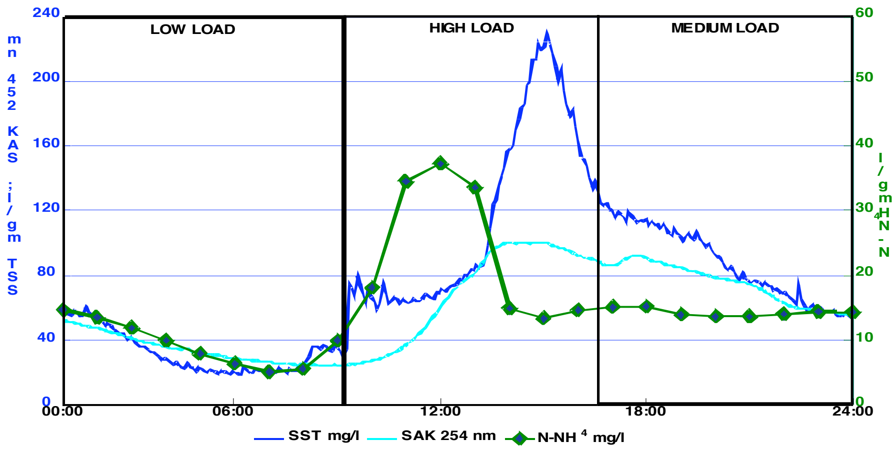

Figure 1. Typical daily fluctuation on Domestic Raw Wastewater Influent

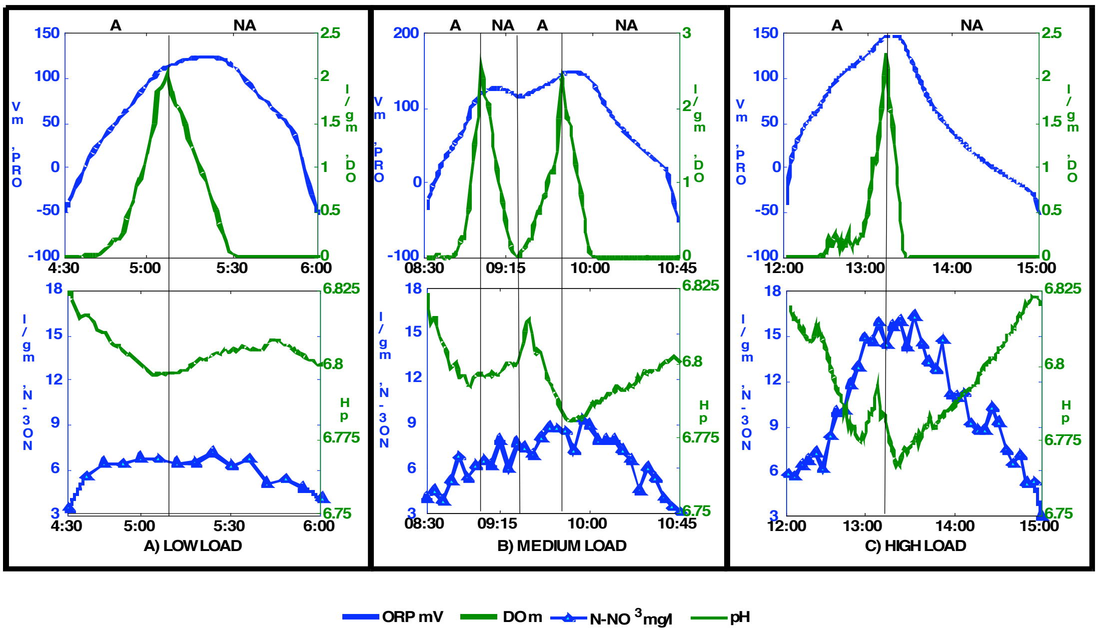

Figure 2. Variation of oxidization-reduction potencial (ORP), OD , pH and N-NO³ during three typical load rate per day