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Short communication

Dairy wastewater polluting load and treatment performances of an industrial three-cascade-reactor plant

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ABSTRACT

An industrial three-cascade-reactor plant treating 45 $m^3\,d^{-1}$ of dairy wastewater (DW) was monitored for approx. one year to investigate the effect of variable daily influent loads. It removed more than 85% COD, NH_4-N and non-ionic and anionic surfactants from DW within the loads 7–24, 0.4–2.3, 0.4–0.7 and 0.1–0.5 kg d^{-1}, respectively; NH_4-N removal, in particular, was almost quantitative. Although the degradation of the above parameters below the lower load thresholds declined to 78.7, 87.5, 50.2 and 64.7%, respectively, their residual concentrations met effluent discharge standards. The biomass settling properties, assessed as sludge volume index (SVI), were satisfactory (generally lower than 150 ml g^{-1}) regardless of the organic load of the influent. The depletion of the pollutant load took mainly place in the first reactor albeit a significant contribution to the removal of the slowly degradable organic matter fraction was given by the two subsequent reactors.

1. Introduction

The dairy industry is one of the largest sources of agro-industrial wastewaters worldwide. In a typical manufacturing plant, the effluent is primarily generated by cleaning and washing operations and its volume generally ranges between 2- and 3-fold the volume of processed milk depending on the plant typology [1,2].

The dairy wastewater (DW) is characterized by high biological (BOD) and chemical oxygen demand (COD) and generally contains fats, nutrients, lactose, as well as detergents and sanitizing agents [1,3]. Serious environmental problems can, thus, arise if the DW is discharged either untreated or partially treated. To meet stringent effluent discharge criteria, aerobic biological treatments relying on conventional activated sludge plants are generally employed [3].

The intrinsic chemical characteristics of DW, including a high C:N ratio, phosphorus limitation and the presence of highly soluble and degradable organic substances, often referred to as rapidly biodegradable COD (rb-COD), might result in poor sludge settling (*i.e.*, bulking phenomena) which, in turn, negatively affects the efficiency of these plants [4]. To overcome these problems, the use of reactors in series, often referred to as cascade reactors, has been proposed since, at the same total working volume, they may enable greater treatment efficiency than conventional activated sludge plants [5]. To date, however, little information is available on the treatment performances of this plant typology at the industrial level and, above all, it is limited to either municipal wastewaters [5,6] or paper mill effluents [7]. An industrial three-cascade-reactor plant with a treatment capacity of 45 m^3 DW d^{-1} was operated under varying aeration conditions, obtained by means of on/off cycles of the blower, and highest treatment performances were obtained with a 45/15 min on/off aeration regime providing 45.4 kg O_2 d^{-1} [8]; in the same study, however, the plant performances were not investigated as a function of the pollutant load of the feeding wastewater and thus the process robustness was not assessed. An additional finding of that previous study was that the removal of organic load was highly and significantly correlated with both richness and Shannon–Weaver index of protozoa rather than with those of bacteria [8].

Objective of this study was to assess the effect of markedly different loads, under the aforementioned optimal aeration regime, on DW treatment performances in a three-cascade-reactor plant. Effluent quality was inferred from removals of conventional organic and inorganic pollutants (COD, BOD_5, total nitrogen, NH_4-N and PO_4-P). An additional aim was to assess the impact of the treatment process on anionic (Methylene Blue Active Substances, MBAS) and non-ionic (Bismuth Active Substances, BiAS) surfactants, the fate of which, despite their common presence in DW, is often neglected in treatment studies of this effluent.

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2. Materials and methods

2.1. Dairy wastewater (DW)

The DW came from the cheese factory "Buona Tavola Sini" (Monterosi, Viterbo, Italy) which processes 15–20 m^3 of milk daily and produces about 45 m^3 d^{-1} of wastewaters; whey was disposed of separately. The DW characteristics expressed in terms of mean values and standard deviations during the one-year monitoring were (mg l^{-1}): TOC, 320.4 ± 145.2; COD, 898.1 ± 399.7; BOD_5, 514.4 ± 187.3; N_{tot}, 26.3 ± 16.8; NH_4-N, 24.1 ± 14.9; NO_2-N, 0.1 ± 0.9; NO_3-N, 2.3 ± 3.0; PO_4-P, 12.5 ± 13.5; MBAS, 4.1 ± 3.3; BiAS, 1.5 ± 1.8; Chloride (Cl^-), 3131.0 ± 2396.1; suspended solids, 335.9 ± 219.0; pH, 6.4 ± 0.7. Sampling was made on a weekly basis.

2.2. Wastewater treatment plant, operative conditions and sampling procedures

The treatment plant of "Buona Tavola Sini" factory was designed and manufactured in glass fiber tanks by the Manzi Aurelio Srl (Montefiascone, VT, Italy) and consisted of a primary sedimentation section (200 m^3), also acting as an equalization basin, three aerated cascade reactors (R1, R2 and R3) (18 m^3 capacity each) and a secondary sedimentation section (18 m^3) [8]. A digestion section (18 m^3), connected with three drying beds, collected the excess sludge (approx. 3 m^3 d^{-1}); the recirculation ratio was kept constant at 150%, while the average sludge age was 11.7 days. Aeration regime was maintained for the whole experimentation at 45/15 min (on/off cycle of the blower) [8]. During the study, the plant worked at a hydraulic load of about 45 m^3 d^{-1} with a hydraulic retention time of roughly 10 h for each aerated reactor. Samples of wastewater influent, mixed liquor of the three aerated reactors, liquid effluent and recirculation sludge were taken every week in duplicate and subjected to physico-chemical and biological analyses. Due to the large volume of the equalization basin, the ensuing variations of influent loads were attenuated. At each influent load, measurements were done under operational steady-state conditions, which were assumed to be reached after approx. 10 reactor volumes of treated DW.

2.3. Physico-chemical analyses

Dissolved oxygen (DO), temperature, redox potential (ORP) and pH were measured directly on-site [8]. The samples were analyzed for TOC, COD, BOD_5, NH_4-N, NO_2-N, NO_3-N, N_{tot} (Kjeldahl), PO_4-P, BiAS, MBAS, suspended solids, mixed liquor suspended solids (MLSS), sludge volume index (SVI) and chloride ions (Cl^-) using procedures accordingly to the Standard Methods [9].

In order to quantify the whole treatment performance of the cascade reactors, removal efficiencies (*RE%*) were calculated for the chemical parameters (COD, NH_4-N, PO_4-P, BiAS and MBAS) using the following equation:

$$RE\,(\%) = \frac{C_{in} - C_{eff}}{C_{in}} \times 100$$

where C_{in} and C_{eff} are the concentrations in the influent (IN) and in the effluent (after settling) out of reactor R3, respectively. Data from the two sets of samples were averaged.

2.4. Statistical analysis

For each sampling time, duplicate samples were taken and two replicates were done for each parameter in each sample (4 total replicates). Data were analyzed by one-way ANOVA and multiple pair-wise comparisons were performed by the Tukey test ($P \le 0.05$) using the Sigmastat 3.5 software (Jandel Corp, San Rafael, CA).

3. Results and discussion

Dairy wastewater (DW) was treated in an industrial plant equipped with three cascade reactors and the treatment process was followed for approximately one year. To best show efficacy and flexibility of this plant in treating DW, typically characterized by large variability in both composition and load, the experimental results have been grouped in classes based on specific load ranges.

3.1. Removal of organic load

COD removal was higher in the first reactor (R1) than in the other ones (R2 and R3), regardless of the TOC load range: in fact, the differences between the COD load of the influent wastewater (IN) and the residual one after treatment in R1 were always significant ($P \le 0.01$) (Fig. 1). Throughout the whole experimentation, the residual pollutant content of the final effluent was almost always low with average residual COD and BOD_5 of 80.3 and 24.4 mg l^{-1}, respectively. Best COD removal performances (between 92.7 and

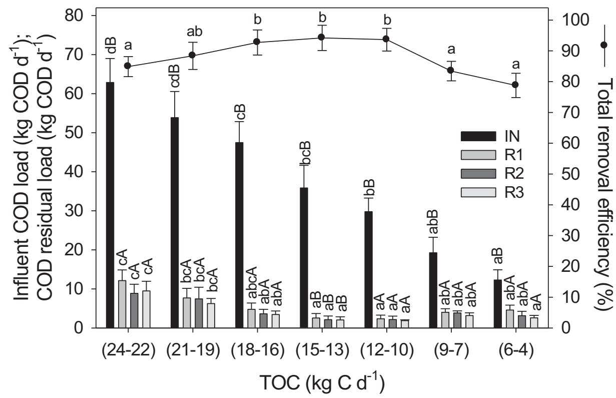

Fig. 1. Influent (IN) and COD residual loads in the cascade reactors (R1, R2 and R3) at different ranges of TOC loads and related total efficiencies, calculated between IN and out of R3. Data are the means of 4 replicates and error bars indicate standard deviations. Pairwise comparisons were performed by the Tukey test ($P \le 0.05$): for each parameter, same lowercase or uppercase letters denote absence of statistically significant differences within the same group (*i.e.*, IN, R1, R2, R3 and Total removal efficiency) at different TOC load ranges or between different groups at the same TOC load range, respectively.

94.2%) were recorded when the influent TOC was in the range 10–18 kg d^{-1}. Conversely, TOC loads lower than 10 kg d^{-1} led to reduced performances (< 84%) probably due to reduction of the food/microorganisms ratio (F/M, kg BOD_5 kg $MLSS^{-1}$ d^{-1}), that were lower than 0.46, 0.09 and 0.09 d^{-1} in R1, R2 and R3, respectively, and the possible occurrence of concomitant predation phenomena [10,11]. The distribution of the activated sludge biomass (MLSS) in the three reactors (Fig. 2A) was greatly influenced by the daily influent organic load consistently decreasing with its decrease. On the other hand, no differences in sludge biomass were observed among the three reactors, likely consequence of the free passage of the sludge from the first to the following reactors which were connected in series. The biomass settling properties, assessed as sludge volume index (SVI), were satisfactory regardless of the organic load of the influent: SVI values were generally lower than 150 ml g^{-1} (Fig. 2B) value that was suggested to be the boundary between bulking and non-bulking conditions [4].

The highest substrate removal rate (SSRR, kg BOD_5 kg $MLSS^{-1}$ d^{-1}) was observed in R1 since the large majority of the readily degradable organic matter fraction was depleted therein (Fig. 2C) in agreement with other studies [5,12]. In particular, the average SSRR steeply decreased from 0.0217 in R1 to 0.0014 and 0.0006 d^{-1} in R2 and R3, respectively. Nevertheless, R2 and R3 were of fundamental importance ensuring the metabolization of the recalcitrant and/or the slowly degradable organic fraction, mainly made up of fats, proteins and detergents [13,14].

The highest metabolic activity was observed in R1 as indicated by respirometric data (Fig. 2D). Indeed, both dissolved oxygen (DO) and redox potential (ORP) were always lower in this reactor than in R2 and R3, consistently with the fast degradation rate of the organic matter shown in Fig. 2C [15,16]. Particularly, loads higher than 20 kg BOD_5 d^{-1} in R1 led to marked declines in both ORP and DO reaching levels as low as −130 mV and 0.2 mg l^{-1}, respectively (Fig. 2C), thus determining a typical anoxic environment [8,17]. After the depletion of the readily degradable substrate in R1, DO and ORP increased in R2 and R3. This was probably due to two concomitant factors, namely, a lower oxygen requirement in processes acting on the residual organic matter fraction [13,15] and the occurrence of starvation conditions in R2 and R3 as indicated by the respective F/M mean values (0.18 and 0.16 d^{-1}, respectively) [18]. Moreover, it is worth noting that the starvation conditions which