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Evaluation of the operation performance of a municipal activated sludge unit

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ABSTRACT

The objective of this work was the evaluation of the operation of a municipal activated sludge unit and the assessment of potential correlations between the operating parameters that might affect the process performance. Samples were collected from various points of a plant receiving about 40,000 m^3 day^{-1} and were analyzed for the determination of a number of parameters. The assessment of the effluent parameters and the statistical evaluation of the values during an one year monitoring period proved an efficient operation of the plant, resulting to an effluent of low organic loading and nitrogen concentration. COD average values did not exceed 60 mg l^{-1}, while maximum values remained always lower than 95 mg l^{-1}. These parameters remained almost constant during the monitoring period, and were not affected by potential variations of influent characteristics. The assessment of the activated sludge process took place by the measurement of the mixed liquor suspended solids and the sludge volume index; MLSS content varied between 2,000 and 6,000 mg l^{-1}, and SVI showed a similar trend by the time. The examination of the operation parameters of the anaerobic digesters included the measurement of the solids content, volatile acids and total alkalinity; suspended solids and volatile solids presented similar behaviour with a ratio of VSS/SS about 60%. The statistical analysis of various parameters revealed a positive linearity between suspended solids and sludge volume index and suspended solids and volatile suspended solids in the homogenizer and the digesters; this analysis could be used for the assessment of the efficient performance of a treatment plant and the early identification of potential problems.

Keywords: Municipal wastewater; Operation parameters; Wastewater treatment plant performance; Sludge volume index; Anaerobic digester; Sludge suspended solids

1. Introduction

A wastewater treatment plant (WWTP) is a combination of separate treatment processes or units, designed to produce an effluent of specified quality from a wastewater (influent) of known composition and flow rate. The treatment plant is also, usually, required to process the separated solids to a suitable condition for disposal. By a suitable combination of these unit processes it is possible to produce a specified final effluent quality from virtually any type of influent wastewater. The amount of treatment required depends largely on the water quality objectives of the receiving water and also the dilution capacity available [1,2].

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The proper operation and control of wastewater treatment plants (WWTP) is receiving increasing attention because of the rising concern about environmental issues [3,4]. Improper operation of a WWTP may bring about serious environmental and public health problems, as deduced by a number of reports on eco-toxicity of treated effluents or reclaimed waters used in various applications [5,6,7]. In addition, efficient operation may result to the production of a high quality effluent, increasing thus the wastewater reuse potential than discharging to a water body. An increase in the rate of reuse can be achieved by maintaining a good quality of the treated effluent, which could help to convince local farmers for the utilization of effluents in irrigation. Thus, the need for systematic controls of effluent quality is demonstrated, achieved mainly by the proper evaluation of the treatment plant performance and by performing the necessary changes in order to improve its efficiency. Furthermore, it has been suggested that routine monitoring and specific research studies to be beneficial in solving specific problems arising during the operation of large wastewater reclamation systems [8,9].

However, like other biotechnological processes, real-time control of a WWTP constitutes a quite complex problem due to the lack of reliable on-line instrumentation and simplicity of the models used to describe the microbiological processes that take place in the bioreactor [10,11]. In addition, it presents some specific problems like the great variability of the input (both in quantity and quality), the very complex interactions between the different microorganism populations present in the system and to the combination of physical, biological and chemical processes involved in wastewater treatment process [12,13].

In this context, the present study deals with the evaluation of the performance of a full scale municipal wastewater treatment plant of Larissa city (Greece), and retails the influence of multiple factors on its characteristics. The aim of this study was the examination of the quality of the wastewater treatment unit, the evaluation of the performance of the facility and the determination of the correlation of different operating parameters in order to develop effective indicators for the assessment and optimization of an activated sludge unit; potential correlations between operating parameters have been proved important for a number of factors such as the early identification of system failures, the redesign of an existing activated sludge system, the evaluation of the stabilization rate of excess sludge etc. [10,14].

2. Materials and methods

The collection of samples from the sewage treatment unit and the analysis for the determination of their physicochemical characteristics took place over a 1 y period and included samples from the aeration tank, where the suspended solids (SS) content and the sludge volume index (SVI) were estimated, from the effluent stream where ammonia nitrogen ($N–NH_4^+$), nitrate nitrogen ($N–NO_3$), phosphates ($P–PO_4^-$) and Chemical Oxygen Demand (COD) concentration were determined, from the thickener and homogenizer where suspended solids (SS), volatile suspended solids (VSS) and pH were measured, and from the digester where suspended solids (SS), volatile suspended solids (VSS), volatile acids (VA), total alkalinity (TA) and pH were calculated. The methods used to determine these parameters were based on standard analysis techniques used for the examination of water and wastewater samples [15]. The objective of this work was the analysis and the identification of the principal factors affecting the plant performance. Thus, analysis of the experimental data was performed using the MiniTab12 statistical software package.

The wastewater treatment plant of Larisa city is located in the Region of Thessaly, in Greece; the plant started its operation in 1989 for the treatment of about 20,000 m^3 day^{-1} of influent corresponding to about 115,000 population equivalents. Initially, the plant consisted in a screening system, a grit chamber, two primary sedimentation basins, two aeration activated sludge reactors with anoxic compartments for denitrification, two secondary clarifiers, a sludge thickener, two anaerobic digesters and two sludge filter presses. After the upgrade and the expansion of the plant, the treatment capacity was doubled to about 40,000 m^3 day^{-1}, with the ability to treat wastewaters from 230,000 inhabitants.

3. Results and discussion

3.1. Effluent quality

The wastewater treatment plant of Larisa city receives both municipal wastewaters and wastewaters from septic tanks. The daily flow rate is 42,000 m^3 day^{-1}, with the following average characteristics: BOD_5 = 325 mg l^{-1}; SS = 350 mg l^{-1}; total nitrogen 62.5 mg l^{-1}; total phosphorous 15 mg l^{-1}. The biological process is taking place into four aeration tanks, each one has a total volume of about 4,400 m^3. The average hydraulic retention time is estimated to 8.5 h, while the organic loading rate varies between 0.17 and 0.53 kg day^{-1}.

The quality of the treated effluent is shown in Fig. 1, where the organic matter (COD) content, ammonia–nitrogen, nitrate–nitrogen and phosphates concentrations are presented as a function of time, as deduced by the measurements performed on samples collected on a daily basis. In addition, the corresponding monthly average and standard deviation for each parameter are

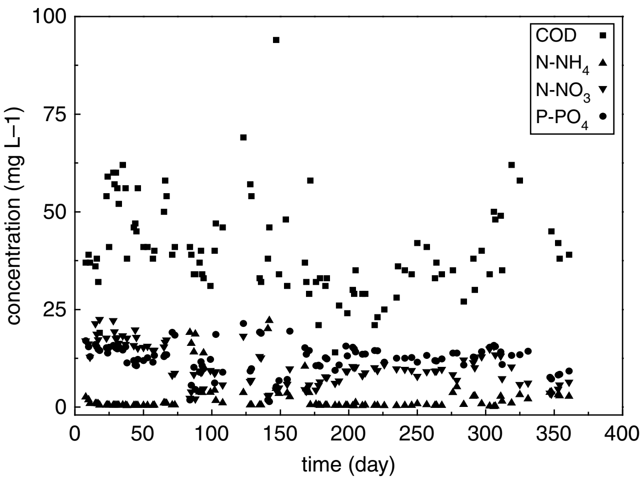

Fig. 1. Larisa wastewater treatment plant effluent parameters as a function of time.

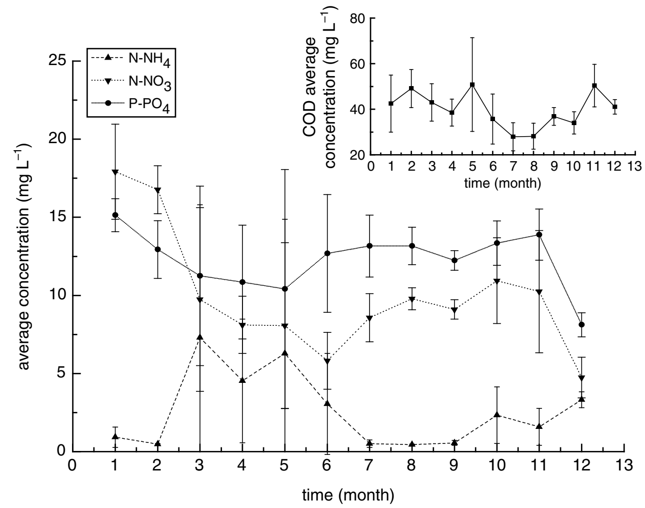

Fig. 2. Monthly average and standard deviation of N–NH_4 (*up triangle*), N–NO_3 (*down triangle*), P–PO_4 (*circle*) and COD (*inset*, *square*) from the Larisa city municipal wastewater treatment plant.

presented in Fig. 2, while the minimum and maximum values are given in Table 1 monthly values are given in order to evaluate potential seasonal correlations and/or trends.

As shown, an effluent with low organic content was produced; COD values ranged between 15 and 60 mg l^{-1}, while during the one year period monitoring, a high COD value reaching 95 mg l^{-1} was observed only once and could be attributed to randomized effects. The variation of effluent COD values by the time, as shown in Fig. 1, showed that there was not a significant correlation to the operation time, although the higher values were observed during the winter period, while the lower values were measured during the summer and autumn periods. The upper limit for the disposal of treated effluent to Pinios river, the final receiver as determined by the Environmental Permission Legislation and the 91/271 EC directive, is 125 mg l^{-1}, and not only the average values but the maximum daily value of the effluent COD did not exceed the permissible limits. In addition to organic loading, low nitrogen content was measured in the effluent. Average ammonia-nitrogen

Table 1
Minimum and maximum values of organic matter (COD) content, ammonia–nitrogen, nitrate–nitrogen and phosphates concentrations

Month	COD (mg l^{-1})		N–NH_4 (mg l^{-1})		N–NO_3 (mg l^{-1})		PO_4 (mg l^{-1})	
	Min	max	min	max	min	max	min	max
1	19.00	60.00	0.48	2.57	12.80	22.50	12.90	17.00
2	38.00	62.00	0.41	0.54	14.58	19.80	10.60	15.40
3	34.00	58.00	0.51	19.10	2.10	17.20	1.80	19.10
4	31.00	47.00	1.09	13.90	4.70	9.40	6.20	18.60
5	32.00	94.00	0.54	22.20	2.90	18.20	1.40	21.40
6	21.00	58.00	0.42	10.50	4.10	9.80	7.10	19.40
7	14.00	35.00	0.37	1.17	6.10	10.40	9.40	15.60
8	21.00	36.00	0.39	0.50	8.80	10.90	11.50	14.50
9	33.00	42.00	0.46	0.86	7.90	9.70	11.50	13.20
10	27.00	40.00	0.28	5.20	6.90	14.90	10.80	15.30
11	35.00	62.00	0.17	3.20	5.80	15.60	10.90	15.80
12	38.00	45.00	2.80	3.90	3.40	6.40	7.20	9.20

concentration varied from 0.5 to 7.3 mg l^{-1}, while average nitrate–nitrogen values ranged from 4.7 up to 17.9 mg l^{-1}; maximum nitrate values did not exceed 23 mg l^{-1}, indicating an efficient nitrification—denitrification process taking place in the aeration and anoxic parts of the unit. The lowest nitrate–nitrogen values were observed during the high temperature periods, while high concentrations were measured during the winter period, where the low temperature affected the nitrogen removal bioprocess. However, phosphates content was slightly increased and average values ranged from 8.1 up to 15.1 mg l^{-1}, attributed to the increased phosphates content in the influent, as the city is located in an agricultural area and various agro-chemicals may be drained to the sewage system.

3.2. Plant performance efficiency

The assessment of the efficiency of the municipal wastewater treatment plant included the evaluation of the performance of the plant by the examination of the operation parameters in two groups of processes: the aeration tanks and the processes used for the excess sludge treatment. The evaluation of the aeration process was studied by the examination of the variation of mixed liquor suspended solids content (MLSS) and the sludge volume index (SVI) corresponding to the sedimentation capacity of the mixed liquor. The results from both parameters are presented in Fig. 3, for samples collected on an almost daily basis, while the analysis of potential correlation of the two parameters is presented in the scatter plot in Fig. 4. As shown, the concentration of the suspended solids in the aeration tanks ranged between 2,000 and 6,000 mg l^{-1}, depending upon the season and the influent loading; the lowest values were observed during the autumn months, especially from the end of August up to October and were attributed to the low organic content fed to the plant, the temperature reduction that took place during this period and an increased sludge wastage. Nevertheless, MLSS content was similar in both tanks, as a result of the balanced operation of the plant. Furthermore, the sedimentation capacity of the mixed liquor remained satisfactory, and the sludge volume index varied from 70 up to 200 ml l^{-1}; the lower values were associated to the lower MLSS concentrations, as shown in Fig. 3.

The scatter plot of MLSS and SVI, presented in Fig. 4, and potential correlation of the parameters was evaluated by the estimation of the Pearson correlation factor, *r*, for $p < 0.05$; for the examined parameters, a correlation factor of 0.664 was estimated, indicating a statistically significant positive correlation between the two parameters; according to the results presented in this figure, the higher the MLSS content the higher the SVI. It should be noticed that the SVI results were always ranging between acceptable limits, and mostly remained lower than 180 ml l^{-1}. However, Pearson correlation factor was lower than unit and data did not show a strong linearity.

The assessment of the operation of the digestion plant took place by the measurement of the content of suspended solids (SS), volatile suspended solids (VSS), volatile acids (VA), total alkalinity (TA) and pH. The variation of the suspended and volatile suspended solids as a function of operation time is given in Fig. 5 while the corresponding results for volatile acids and total alkalinity are presented in Fig. 6; the corresponding scatter plot for the determination of potential statistical correlation of solid concentration is given in Fig. 7.

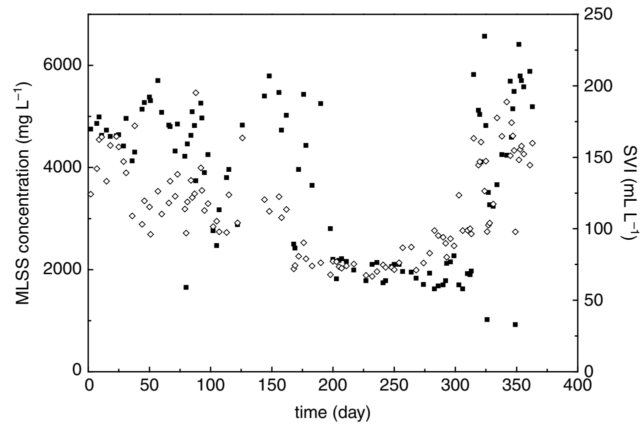

Fig. 3. MLSS content (*square*) in the aeration tank and sludge volume index (*diamond*) of mixed liquor during the one year operation period.

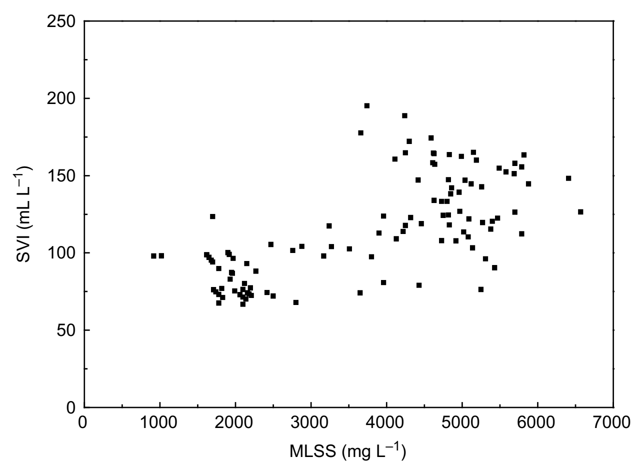

Fig. 4. Scatter plot of MLSS and SVI in samples from the aeration tanks (Pearson correlation factor $r = 0.664$, $r_{op} = r_{0.05(2),(n-2)} = 0.134$, $n = 216$).

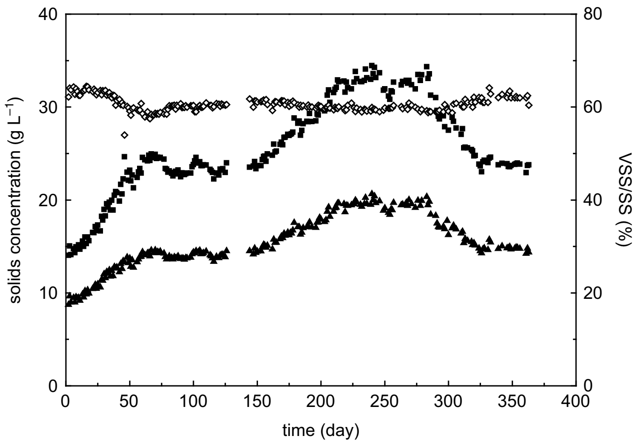

Fig. 5. The variation of suspended solids (*square*) and volatile suspended solids (*triangle*) content and ratio of VSS/SS (*diamond*) in the digester system as a function of operation time.

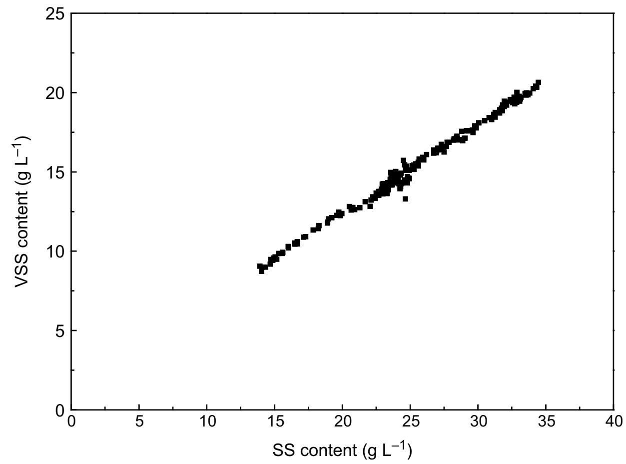

Fig. 7. Scatter plot of suspended solids and volatile suspended solids in the digester ($n = 218$, $r = 0.996 > r_{op} = r_{0.05(2),(n-2)} = 0.133$).

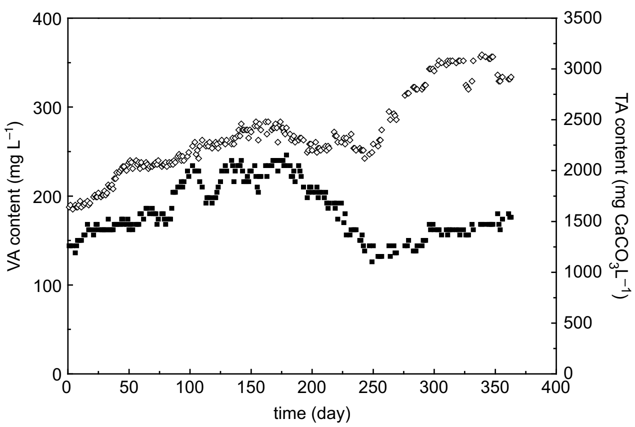

Fig. 6. The variation of volatile acids (*square*) and total alkalinity (*diamond*) in the digester system as a function of operation time.

As presented in Fig. 5, suspended solids concentration in the digester increased from low values in the winter months of about 15–35 g l^{-1}, followed by a decrease after a one year period to about 20 g l^{-1}. Volatile suspended solids presented a similar trend over the operation time, with a ratio of VSS/SS remaining almost constant to about 60%. In addition, the measurement of volatile acids content revealed a similar behaviour: the concentration of acids increased up to a high value and then decreased during the winter months. On the other hand, a strong linearity was observed between the suspended solids and the volatile solids content in the digester, as deduced by the scatter plot of these parameters shown in Fig. 7, Pearson correlation factor was close to unit, indicating the significant correlation of these data; however, such a correlation was not observed in the content of the units before the digestion process: a weaker correlation of these parameters was observed in the content of the homogenizer tank ($r = 0.76$), while no correlation was found in the thickener ($r = 0.142$). Furthermore, the examination of the scatter plots revealed a statistically significant correlation between suspended solids and total alkalinity ($r = 0.47$) and between volatile suspended solids and total alkalinity ($r = 0.5$), although the values of the correlation coefficient were much lower than unit, indicating a poor linearity. The corresponding suspended solids and volatile suspended solids concentration in the digesters located in the Larisa wastewater treatment plant, indicated a rather satisfactory operation of the sludge treatment unit and a high potential for the utilization of the sludge energy content through the production of biogas during anaerobic digestion: the ratio of volatile suspended solids to suspended solids was typical for municipal wastewater treatment plants, and it appears that the presence of dissolved phosphorous, as indicated by the effluent analysis, and neutral pH values enhanced the anaerobic degradation process.

The evaluation of the operation of the excess sludge treatment process was performed by the examination of the operation of the anaerobic digestion unit. This process consists in two twin digesters, each one having an active volume of about 1,600 m^3, operating at 35 ± 1°C, and treating about 210 m^3 day^{-1} of thickened sludge with a residence time of about 15 d; average organic loading rate is estimated to about 1.6 kg VS/m^3 day^{-1}. The appropriate and efficient operation of this system is important for the operation of the overall plant, as it results to the production of about 2,800 m^3 day^{-1} of biogas, corresponding to a biogas yield of 0.6 m^3/kg removed VS day^{-1}, with a thermal content of about

23 MJ N m^{-3}; the energy content of the produced biogas is utilized for production of thermal energy (water heating in a boiler) and for production of electric energy in corresponding generators. The total energy production by the biogas is about 64 × 10^3 MJ day^{-1}, which covers about 15% of the overall plant power consumption.

The improvement of energy efficiency and the reduction of energy consumption represent a multidisciplinary task in wastewater treatment plants; an effective preventive maintenance program can improve the energy performance in a plant, enhancement of system reliability, cost reduction etc. The development of an energy management program in a wastewater treatment plant may include several measures such as electric motors control; pumps adjustment; staging of treatment capacity; optimization of aeration devices; improvement of sludge properties [16]. Especially, in the case of anaerobic digesters, as in the studied wastewater treatment plant, energy improvements may include the following:

- Enhancement of biosolids mixing in the digester, aiming to achieve a higher level of volatile solids destruction rate
- Optimization of digester performance by optimizing process temperature; sludge pretreatment; implementation of co-digestion of other types of organic wastes such as restaurant grease, vegetable waste, municipal solid organic waste
- The use of combined heat and power production process (CHP) aiming to increase the energy content utilization of biogas through reciprocating engines, microturbines or fuel cells

The adoption of such measures would be beneficial to the performance of the Larisa treatment plant resulting thus, to the simultaneous increase of energy recovery from biogas and the reduction of plant energy demand.

4. Conclusions

The aim of this study was the evaluation of the operation of a municipal wastewater treatment plant, the examination of the effluent characteristics over time, the determination of the potential correlation between various operation parameters and the assessment of its energy utilization rate. Samples were collected from the effluent and from the content of the different basins of the plant and were analyzed for the measurement of organic content, nitrogen and phosphorous concentration, suspended solids and volatile suspended solids and total alkalinity. The assessment of the effluent parameters and the statistical evaluation of values during the 1 y monitoring period proved an efficient operation of the plat, resulting to an effluent of low organic loading and nitrogen concentration. These parameters remained almost constant during the monitoring period, and were not affected by potential variations of influent characteristics. Evaluation of the biological process carried out by the measurement of the mixed liquor suspended solids and the sludge volume index; MLSS content varied between 2,000 and 6,000 mg l^{-1}, and SVI showed a similar trend by the time, representing a statistically significant linearity although of poor quality. Low MLSS values were measured during the period of temperature decrease and low organics content in the influent. The examination of the operation parameters of the anaerobic digesters showed that suspended solids and volatile solids presented a linear relation, although a similar correlation was not observed for the thickeners and the homogenizer. The successful operation of the anaerobic digestion was attributed to the neutral pH values and the presence of dissolved phosphorous in the aqueous phase. This statistical analysis, although simple, could be applied for an assessment of the operation of a municipal wastewater treatment plant. Biogass produced by the anaerobic digesters, is about 2,800 m^3 day^{-1}, and is currently used for partially covering the thermal needs of the plant; however, additional measures could be applied, aiming to an improved energy management plan of the unit.

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