Desalination and Water Treatment
www.deswater.com
1944-3994/1944-3986
doi: 10/5004/dwt.2012.3360

39(2012)248–255
February

Taylor & Francis
Taylor & Francis Group

Evaluation of the treatment efficiency of the central treatment unit (CTU) of the industrial area of Larisa(Greece)

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Received 27 August 2010 Accepted revised 23 March 2011

ABSTRACT

The aim of the present study was the evaluation of the treatment performance of the central treatment unit (CTU) of the industrial area of Larissa, located at central Greece (Thessaly region). The operation of CTU was monitored continuously during the period December 2008–February 2010 through periodic sampling from the inlet and the outlet of the treatment plant. The routine chemical analysis conducted in the inlet and outlet samples included pH, conductivity, chemical oxygen demand (COD), biological oxygen demand (BOD_5), total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) determinations. In selected samples several other measurements were conducted, such as oils and fats determination, color, chlorides content, total nitrogen (TN), ammonium nitrogen, nitrates, phosphorus content (as o-phosphates), SAR index and boron content. The evaluation of the treatment performance was conducted by comparing the characteristics of the outlet samples with the characteristics of the inlet samples and with the respective legislation limits regarding the disposal of treated wastewater in Larisa prefecture. From the results, it was revealed that significant improvement of all physicochemical properties of the wastewater occurs after the treatment. However, the treatment performance cannot be assigned as satisfactory. Several of the measured parameters were found higher than the respective legislation limits in the majority of the tested samples, including COD, BOD_5, Cl^-, TSS, whereas conductivity was much higher than the respective limit in all the tested samples. The stricter supervision of the individual industries in order them to comply with the regulatory guidelines and the conduction of necessary modifications (upgrading) of selected sub-units in the facility of CTU are thought to be the key factors for the further improvement of CTU performance. It should be mentioned that most of the proposed changes, regarding the CTU facility, have been nowadays fulfilled and moreover, most of the individual industries have complied with the respective legislation limits after the continuous control of their wastewater characteristics, resulting in substantial improvement of the obtained results.

Keywords: Industrial wastewater treatment; Disposal; central treatment unit; Industrial areas; Treatment performance; Wastewater's quality monitoring

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3[rd] International Conference on Small and Decentralized Water and Wastewater Treatment Plants (SWAT-III), Skiathos, Greece, 14–16 May 2010

1. Introduction

There is an increasing tendency the last two decades for better organization and essential control of the industrial areas in Greece. The main aim of these efforts is the reduction of the negative environmental impacts due to uncontrolled wastewater discharge, created during the several industrial processes. In a second step, the reuse of treated wastewater is desirable as well, for example for urban applications (irrigation of public parks or landscaped areas, toilet flushing, fire protection, construction, vehicles washing, etc.), industrial applications (cooling systems, boiler feed waters, industrial processes), ground water recharge (usually to augment aquifers, to establish salt water intrusion barriers in coastal aquifers), and agricultural applications (restricted or unrestricted irrigation). Specific quality criteria have been established for each of the aforementioned reuse applications, as well as special considerations, necessary when traditional sources of water are being substituted with reclaimed water [1]. It should be mentioned that the reuse of treated wastewater for irrigation is undergoing fast expansion in areas with water scarcity (e.g. Mediterranean countries), providing an important alternative water source [2]. It is of primary concern in such areas and especially in Greece, where water scarcity is particularly noticeable during the summer time, denoting the importance of the aforementioned efforts.

Nowadays, almost every prefecture in Greece (where an industrial area is present) has established discharge criteria for treated industrial wastewater, which vary according to the specific receiver, the region, the possible existence of ecologically sensitive areas, etc. These criteria are further verified by the Greek state through ministerial decrees (KYA). Responsible for the observance in the majority of the industrial areas in Greece is a joint-stock corporation (with 35% participation of the Greek State), ETVA VI.PE. S.A., which was established in 2003 and is responsible for the management and operation of 32 distinct industrial areas.

Among them is the industrial area of Larissa (IAL), which is located at about 15 km north-east to the city of Larissa at central Greece (Fig. 1). It covers 2,415.713 ha of flat land, is very close to the national road network and along its borders (west side) is the national railroad. The installation of industries in IAL began at 1981 and is still continuing. Nowadays, 50 individual industries are located at IAL covering a total area of 479.4 ha. Thirty-eight of these industries were settled in the area or expanded their facilities during the period 2000–2004. About 1,296 ha are still available for industrial use (sum: 73.5% of the total area of IAL is intended for industrial use), 170.5 ha (7.1%) are for communal use and 469.7 ha (19.4%) are covered with streets, green and pipes network [3,4].

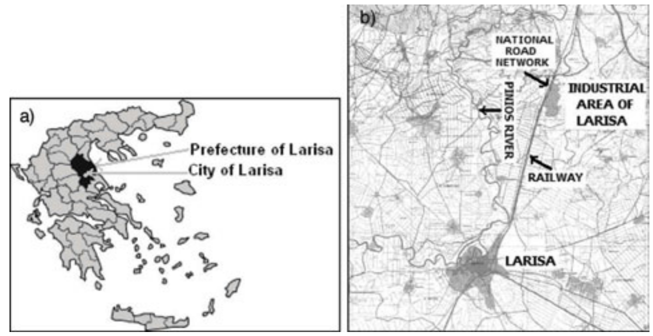

Fig. 1. (a) Map of Greece, showing the location of Larissa, (b) location of IAL.

The types of industrial facilities located at IAL cover the most important manufacture sections, including food processing, constructions and constructions materials, chemicals, wood processing, clothes, plastics etc. The infrastructure of IAL includes a water supply network, rainwater network, a central treatment unit (CTU), industrial wastewater network, pipes network for the disposal of the treated wastewater and the internal road network.

The aim of the present study was the evaluation of the treatment performance of the central treatment unit (CTU) of the industrial area of Larissa, the detection of possible problems affecting its operation and the suggestion of feasible solutions for the further improvement of its efficiency.

2. Experimental

The CTU of IAL is operating since 2001 and is receiving and treating a variety of industrial liquid wastes, which are transferred to CTU through the dingily network from all the installed industries. In general, the wastewater treatment in CTU includes biological treatment (secondary treatment), physicochemical treatment (tertiary treatment) and chlorination before discharge. In Fig. 2 the general layout of CTU is presented [4,5].

According to the initial design criteria, CTU was designed for full-time operation (24 h/day) and for the treatment of 3,500 m^3/day of wastewater (mean flow), or 145.8 m^3/h of wastewater (maximum wastes flow 371.9 m^3/h). In practice, CTU is capable to treat 2,000 m^3/day of wastewater, but if it is necessary its facilities can be further expanded (for the treatment of 3,500 m^3/day of wastewater) [4]. Moreover, the incoming wastewater should have the characteristics presented in Table 1 for efficient treatment to take place. Therefore, all industries are obligated to treat their wastewaters (pre-treatment) in order to meet these criteria. However, several of the industries don't treat their wastewaters sufficiently (or

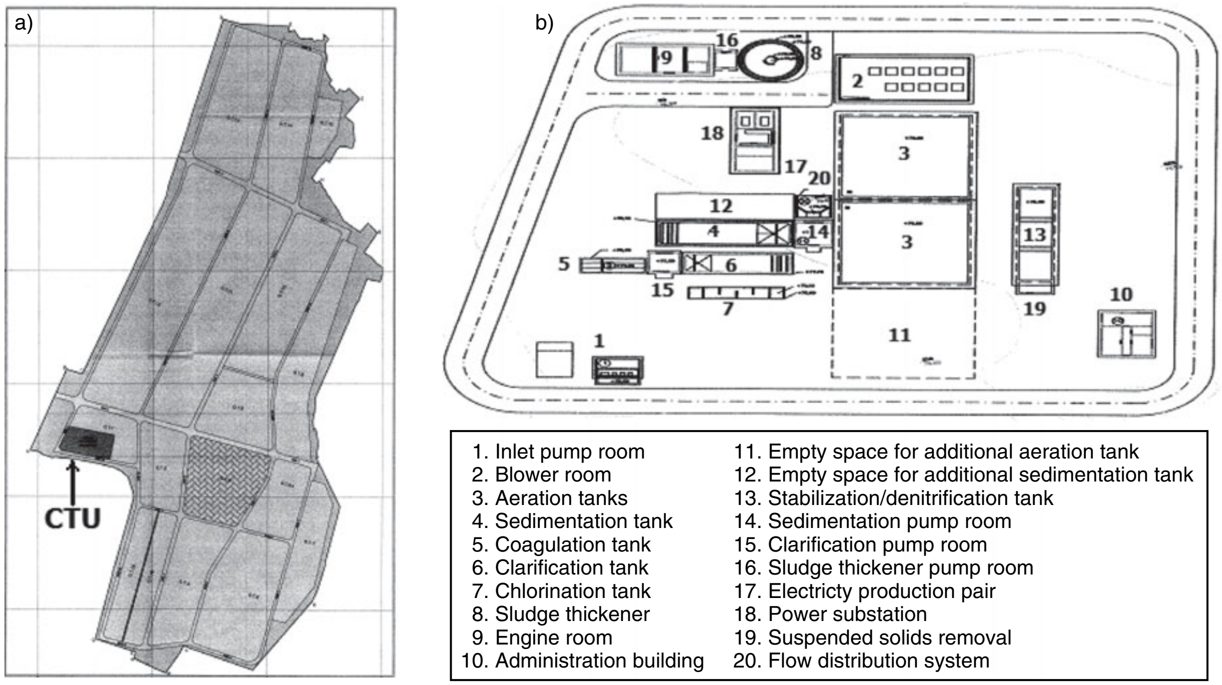

Fig. 2. (a) View of IAL, (b) general layout of CTU.

not at all), thus creating problems of increasing pollutants loading in the inlet of the CTU. Among them are a slaughterhouse products treatment facility, an egg separation and pasteurization facility, an agriculture products processing and packaging facility, a metallurgy facility, etc. In several cases in the wastewaters of those facilities very high COD values (up to 56,000 mg/l), BOD values (up to 3,000 mg/l) and TSS concentrations (up to 8,000 mg/l) were observed, resulting in the dramatic increase of the values of these parameters in the inlet of the CTU and creating problems regarding its treatment efficiency. However, it should be mentioned that several of the aforementioned industries have nowadays complied with the respective legislation limits and particularly after the continuous control of their wastewater characteristics (during the last 1.5 y) and the enforcement of penalties. ETVA VI.PE. S.A. in cooperation with AUTH (Department of Chemistry) is running a monitoring program, regarding the quality control of rain and wastewaters in 10 industrial areas of Central and North Greece.

After the treatment in CTU, the treated wastewater is transferred through a closed pipe network in the receiver, the Pinios river. The discharge limits regarding the disposal of treated wastewater in Pinios river are presented in Table 1. Today, CTU is receiving about 1,500–2,000 m^3/day of wastewater, included domestic sewage from the activities of the personnel of IAL. Its treatment performance is continuously monitored during the last 1.5 y, through periodic sampling from the inlet and outlet of the facility. The examined parameters include pH, conductivity, COD, BOD_5, total solids (TS), suspended solids (TSS) and dissolved solids (TDS) determinations. In selected samples several other measurements are conducted, such as oils and fats determination, chlorides content, total nitrogen (TN), ammonium nitrogen (NH_4–N), nitrates (NO_3–N), phosphorus content (as o-phosphates), SAR index, boron content and several toxic metals (Cr, Cu, Zn, Pb, Ni, Cd). All the above parameters are determined according to AWWA Standard Methods for the Examination of Water and Wastewater [6].

3. Results and discussion

3.1. Raw wastewater (influent) and treated wastewater (effluent) quality

Fig. 3 illustrates the results for the majority of the examined parameters of the influent and the effluent samples of CTU. From Fig. 3a it can be seen that the pH value of influent samples varies between 6.0 and 8.0. Only in one sample (sampling day 263) the pH value was found extremely high (pH = 11.5). Regarding the pH value of the effluent, generally it varies between 7.2 and 8.1 and is within the respective legislation limits range. Only in one sample the pH value was lower than the lower legislation limit (sampling day 399, pH = 6.65).

Table 1
Legislation limits regarding the quality of the influent in CTU and the treated wastewater (effluent) before disposal in Pinios river (prefecture of Larisa)

Parameter	Influent restrictive limit values[a]	State regulatory discharge guidelines[b]
pH	–	6.9–9.5
Biochemical oxygen demand (BOD_5)	500 mg/l	40 mg/l
Chemical oxygen demand (COD)	1,200 mg/l	120 mg/l
Total suspended solids (TSS)	500 mg/l	50 mg/l
Dissolved oxygen (DO)	–	3 mg/l
Fats and oils (FOG)	50 mg/l	10 mg/l
Temperature	–	28°C
Chlorides (Cl^-)	–	120 mg/l
Conductivity	–	750 μS/cm (20°C)
Boron	–	3 mg/l
SAR index	–	18
N total	50 mg/l	–
$N\text{-}NH_3$	37.5 mg/l	–
P total	12 mg/l	–

[a]Corresponding to the required quality of the pre-treated wastewater from the individual industries.
[b]Prefecture of Larisa.

Greater variation was observed in the conductivity values, both in effluent and effluent samples (Fig. 3b). Particularly, the influent conductivity varies between 1.91 and 7.16 mS/cm, whereas the effluent conductivity varies between 2.8 and 5.52 mS/cm and is always higher than the respective legislation limit. Moreover, in the majority of the cases the effluent conductivity is higher than the influent conductivity, a fact than can be attributed to the addition of chemical reagents during the physicochemical treatment process.

Fig. 3c shows the influent and effluent COD concentrations and the percent (%) COD removal. The influent COD values range between 252 and 6,870 mg/l and in 5 of the total 16 samplings (31% of samplings) the influent COD value is greater than the limit of 1,200 mg/l (regarding influent quality), indicating that CTU was susceptible to pollutant loading shocks several times due to insufficient wastewater pre-treatment in the individual industrial plants. The COD removal efficiency varies between 62% and 94% and the COD concentration in the effluent samples ranges between 51 and 1,250 mg/l. For the majority of the samplings (nine samplings, 56% of total samplings) the COD value exceeded the respective legislation limit. The highest COD value of 1,250 mg/l was observed at sampling day 399. In the respective sampling day, the highest influent COD value (6,870 mg/l) was observed as well.

Regarding BOD removal, from Fig. 3d it can be observed that the respective removal rates are slightly higher than the COD removal rates, ranging from 59% to 96%. The influent BOD generally ranges between 116 and 810 mg/l and in one sample (sampling day 399) extremely high BOD concentration was observed (2,540 mg/l). Moreover, in five samplings the initial BOD values exceed the influent limit of 500 mg/l. The effluent BOD varies between 31 and 515 mg/l and exceeds the respective legislation limit in nine samples. The BOD/COD ratio in the influent ranges between 0.27 and 0.55, whereas in the effluent BOD/COD ratio ranges between 0.27 and 0.58. The relatively high values of BOD/COD ratio in the outlet of the treatment plant can be attributed to insufficient biological treatment and/or to the presence of recalcitrant materials, which are not easily biodegradable. Their presence is probably due to insufficient pre-treatment (individual plants).

Suspended solids removal rates show great variation, ranging generally from 67% up to 99% (Fig. 3e). In several cases however, very low TSS removal was observed (e.g. sampling day 321, Re = 3.3%) or no removal at all (e.g. sampling days 399 and 413, Re = 0%). The influent TSS concentrations vary between 86 and 2,115 mg/l, whereas the effluent TSS concentrations range from 17 up to 314 mg/l. In the majority of the effluent samples TSS conc. exceeds the respective limit value, that is in 13 of the total 16 samples (81%) TSS concentration is higher than 50 mg/l. In the influent samples, TSS concentration is higher than the respective limit of 500 mg/l in five samples.

Fig. 3f illustrates chlorides and boron concentrations in six selected effluent samples. Chlorides concentration ranges from 1,009 up to 2,610 mg/l and in all the examined samples exceeds the respective limit value. On the other hand, boron concentration is relatively low in the effluent (0.06–0.25 mg/l) and much lower than the legislation limit of 3.0 mg/l. Boron is thought to be an important toxicity factor to crops and its removal is of primary importance, when reclaimed wastewater is going to be used for irrigation [7].

Table 2 displays the results for several additional parameters, which were determined only in few selected samples. Regarding oils and fats, their concentration is

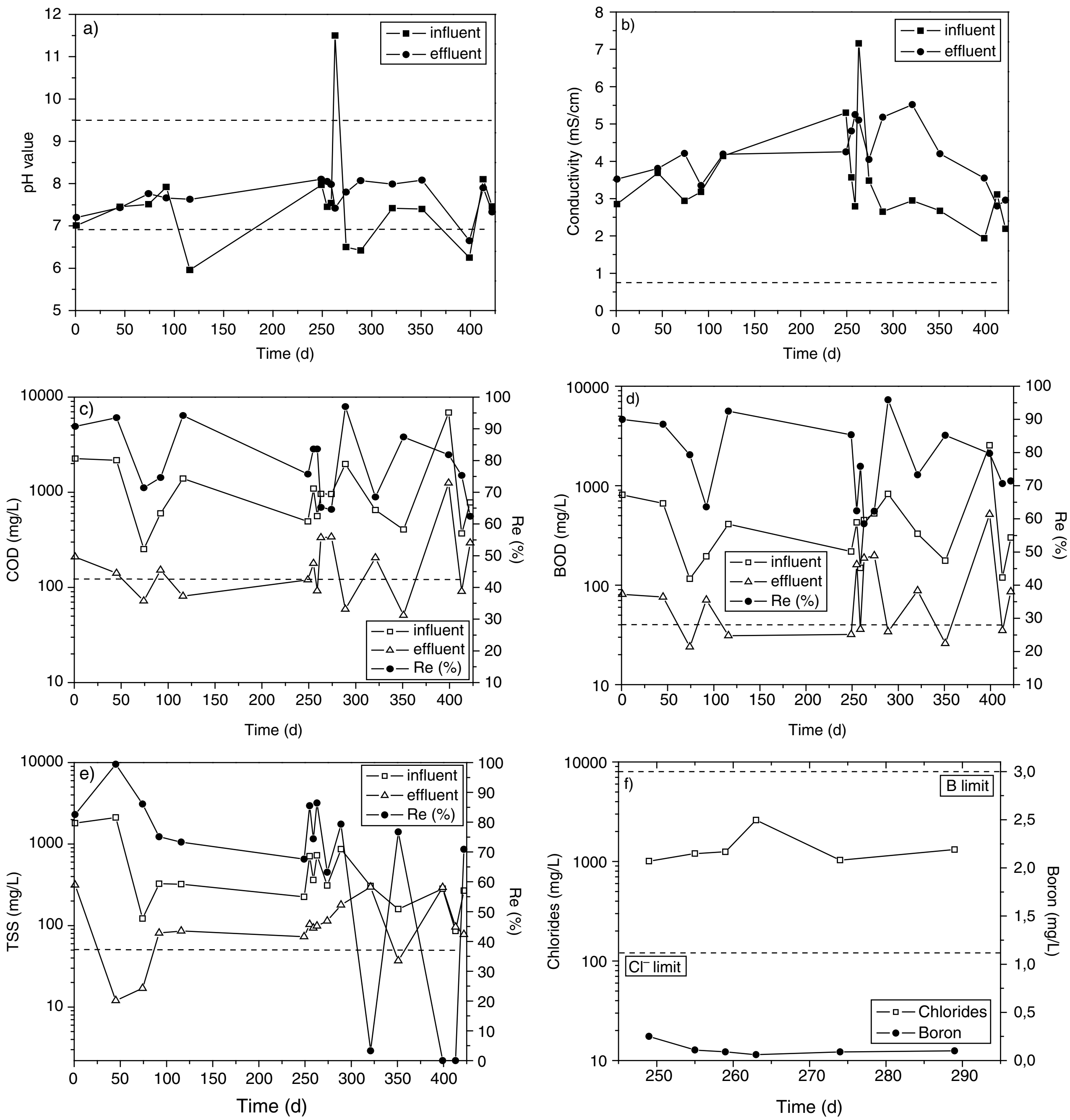

Fig. 3. Results for the majority of the examined parameters in the influent and effluent samples from CTU. (a) pH, (b), conductivity, (c) COD, (d) BOD_5, (e) TSS, (f) chlorides and boron (only effluent), versus time (d) (the *dashed lines* represent the respective disposal legislation limits).

relatively low in both the influent and effluent samples. SAR index (sodium adsorption ratio) is one of the most important factors, which designate whether water is suitable to be used for irrigation [7]. In the three examined effluent samples, only in one case SAR index exceeded the legislation limit (sample day 15, SAR = 24). In the two other samples, SAR index was significantly lower than the respective legislation limit. o-Phosphates were determined in one influent and one effluent sample (same sampling say) and their concentration was found relatively low in both samples. Additionally, from Table 2 it can be seen that total nitrogen and ammonia do not exceed the respective limits in the influent samples. Regarding the effluent samples, there is no relevant

Table 2
Additional quality parameters of several influent and effluent samples of CTU

Sample type	Sampling day	NH_4–N (mg/l)	NO_3–N (mg/l)	TN (mg/l)	o-P (mg/l)	Oils–fats (mg/l)	SAR index
Influent	1	–	–	–	–	2.0	–
	11	–	–	–	–	2.1	–
	103	14.9	1.45	38.5	–	–	–
	174	0.85	0.47	41.3	2.32	–	–
Effluent	1	–	–	–	–	<1	–
	11	–	–	–	–	<1	–
	15	–	–	–	–	<1	24
	26	–	–	–	–	–	9.1
	41	–	–	–	–	–	12
	103	0.045	7.52	20.2	–	–	–
	174	0.331	1.15	7.71	0.7	–	–

legislation limits, but from authors experience and by taking into consideration the respective limits of other industrial areas, the concentrations of ammonia and total nitrogen can be characterized as relatively low. Ammonia removal seems to be efficient (e.g. sampling day 103), indicating sufficient nitrification process. However, the increased concentrations of nitrates in the effluent compared with the influent concentrations are indicative of insufficient denitrification process [8].

3.2. Evaluation of CTU operation—proposals for further improvement

It is evident that after treatment in CTU, significant improvement of major physicochemical properties of the industrial wastewater occurs. COD and BOD removal rates can reach up to 94% and 96% respectively, pH is always in the desired pH range, TSS removal rate can reach up to 99%, boron concentration is much lower than the respective limit and the concentrations of nitrogen compounds, o-phosphates and oils and fats can be characterized as relatively low. However, the treatment procedure conducted in CTU cannot be assigned as completely satisfactory, as in the majority of the examined effluent samples high COD, BOD and TSS concentrations were noticed (higher than the limits), conductivity is always higher than the respective legislation limit and chlorides concentration exceeds the respective legislation limit in all the examined samples as well.

Two main reasons are responsible for the insufficient treatment in CTU; the insufficient pre-treatment conducted in several individual industries and the need for immediate maintenance (or even upgrading) of the facility. The insufficient pre-treatment causes increasing pollutants loading in the inlet of the CTU, thus suppressing the system, which is not designed to correspond well to sudden pollutant loading shocks. In Table 2, several cases of heavy polluted wastewaters from individual industries are presented, detected after sudden and unexpected inspections of the facilities of the specific industries, conducted by ETVA VI.PE. and AUTH research teams. As it can be seen, COD, BOD, TSS and oils–fats concentrations are much higher than the respective limits (Table 2), thus causing implications on the treatment performance of CTU. Moreover, several extreme pH and conductivity values detected in the wastewaters of those industries are also mentioned. Despite the fact that legislation limits haven't been established for the specific parameters, they can also affect the CTU treatment performance and therefore they are mentioned. The cases of Table 3 represent just few examples of legislation limits violations in IAL and therefore the supervision of the individual industries and the enforcement of penalties should be stricter.

Regarding the maintenance of CTU, the most important remarks after careful inspection of its facilities are the following: The relatively high COD and BOD values in the effluent samples clearly state that the biological treatment is insufficient. One of the main reasons detected is a problem in the aeration system. Specifically, it was observed that in the aeration tanks the tubes providing air are subjected to corrosion. As a result, significant air loses were noticed and the aeration of wastewater provided by airlifts is clearly insufficient (verified also by dissolved oxygen measurements). Therefore, the replacement of the tubes providing air in the aeration tanks (in total 12 tubes) is thought to be of primary concern, and specifically the new tubes should be made of stainless steel.

Table 3
Quality of the wastewaters

Type of industry	pH	Conductivity (mS/cm)	COD (mg/l)	BOD (mg/l)	TSS (mg/l)	Oils–fats (mg/l)
Egg separation and pasteurization facility	11.77	5.16	56,525	32,310	8,270	–
Slaughterhouse products treatment facility	11.35	6.54	6,820	1,636	2,972	–
Agriculture products processing and packaging facility	5.03	–	6,023	1,538	670	–
Metallurgy facility	–	–	4,307	2,468	1,712	626

Additionally, the tubing of the six airlifts should be replaced by new, made of stainless steel tubing, as well.

Furthermore, it was observed that the coagulation process (applied after biological treatment) is also insufficient. The problem is due to insufficient agitation speed, which inhibits the efficient mixing and dispersion of the chemicals added (i.e. coagulant and flocculant aid), and therefore new reduction gear should be placed. The insufficient coagulation process has two main side effects, poor sedimentation and therefore high TSS concentration in the effluent and can also contribute in increasing conductivity, due to residual concentration of coagulation reagents in the treated wastewater.

Other implications detected include the insufficient operation of the electricity production pair due to inappropriate maintenance and several problems in the system of automation and control of the operation of CTU (SCADA system). Particularly, the hardware and software should be replaced, as they are old and unreliable, thus presenting problems during operation. New PLC should be installed in the existing control panels and new SCADA system as well. The installation of a GSM modem for malfunctions notification during the whole day is thought to be essential for the appropriate operation of CTU. Finally, it was observed that the facility of CTU lacks of an adjustment and control system of dissolved oxygen concentration in the aeration tanks and therefore it should be installed.

It should be mentioned that most of the proposed changes, regarding the CTU facility, have been nowadays fulfilled and moreover, most of the individual industries have complied with the respective legislation limits after the continuous control of their wastewater characteristics, resulting in substantial improvement of the obtained results.

4. Conclusions

The aim of this study was the evaluation of the treatment performance of the central treatment unit (CTU) of the Industrial Area of Larissa in relation with the influent quality. After continuous monitoring of several parameters in influent and effluent samples for over a year time period, it was found that the efficiency of CTU was initially not satisfactory. Despite the fact that significant improvement of major physicochemical properties of the industrial wastewater occurs after treatment, COD, BOD and TSS concentrations were found higher than the respective legislation limits in the majority of the examined effluent samples, whereas chlorides and conductivity exceeded the respective limits in all the examined samples. The deficiency of CTU can be attributed mainly to two reasons; the insufficient pre-treatment conducted in several individual industries and the need for immediate maintenance (or upgrading) of the facility, which has been nowadays mostly already performed. The stricter supervision of the individual industries in order them to comply with the regulatory guidelines and the conduction of necessary modifications in the facility of CTU are thought to be the key factors for the further improvement of CTU performance. The monitoring program conducted by ETVA VI.PE. S.A. and AUTH regarding the quality control of rainwater and industrial wastewaters is continuing and is regarded as a substantial tool for the achievement of this improvement.

Acknowledgements

This study is part of the common project between AUTH (Division of Chemical Technology, Department of Chemistry) and ETVA VI.PE. S.A. regarding the monitoring of the quality of untreated and treated wastewaters in several industrial areas of Greece. The project is fully financed by ETVA VI.PE. S.A.

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