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Alternative treatment of urban wastewater using electrochemical oxidation

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ABSTRACT

In recent days, the lack of water resources in many countries impels the research in finding new sources. Regeneration is one of the best choices, and electrochemical technology can be an interesting alternative to the existing technologies. A laboratory scale electrochemical experiment for the treatment of urban wastewater (UWW) has been investigated, using sodium chloride (2%) as electrolyte as alternative treatment methods. In this study, UWW was passed through an electrolytic cell using Ti/Pt as anode and Stainless Steel 304 as cathode. Due to the strong oxidizing potential of the chemicals produced (chlorine, oxygen, hydroxyl radicals and other oxidants) the organic pollutants and nutrients (NH_4-N, phosphorous) were wet oxidized to carbon dioxide, and nitrogen. Experiments were run in a continuous, laboratory-scale, pilot-plant, at 30 ± 2 °C and the efficiency of oxidation was studied in relation to pH. It was found that the implementation of electrochemical oxidation for 90 min reduce the COD up to 95% for pH 8, up to 54% for pH 7 and up to 13% for pH 6 while the TP were reduce up to 81% for pH 8, up to 43% for pH 7 and up to 12% for pH 6. For the same residence time the efficiency of electrolysis were 1.99, 8.98 and 16.47 $gCOD_r/h\text{-}A\text{-}m^2$ for pH 6, 7 and 8, respectively. The colour removal was up to 100% in less than 1 h. The results may be useful as in the near future we must develop environmental friendly technology in order to provide new sources of water, especially in countries in which the lack of water resources has become a serious problem.

Keywords: COD removal; Colour removal; Domestic wastewater; Electrochemical treatment

1. Introduction

Cyprus is situated in the north-eastern part of the Mediterranean Sea, 338 easts' and 358 north of the Equator. It is situated 75 km south of Turkey, 105 km west of Syria, 380 km north of Egypt, and 380 km east of Rhodes (Greece). The third largest Mediterranean island after Sicily and Sardinia, with a total population up to 10,00,000 citizens, it has an area of 9251 km^2, of which 1733 are forested. In the greater eastern area of Cyprus are the Municipality of Paralimni and Agia Napa. Those municipalities with permanency population almost 22,000 citizens (19,000 and 3000 respectively) consist of the main economical lung of the island due to the fact that in this area there are the largest hotel resorts. During the winter the population is estimated at 22,000 citizens but from the beginning of April since October are estimated at 75,000 with the tourist per day. The area presented with a long period of warm and high temperature conditions (>27 °C, and during summer >33 °C). A Sewage Treatment Plant (STP) is established to treat the production of domestic waste waters. One of the major challenges for the near future in the development of environmental technology is to provide new sources of water, especially in countries in which the lack of water resources has become a serious problem [11]. Wastewater treatment systems have been designed to minimize the environmental impacts of discharging untreated wastewater. Different options for wastewater treatment have different performance characteristics and also different direct impacts on the environment. Some systems have high energy usage, some use materials that have a high embodied energy (e.g., plastics) others occupy a lot of land [2]. The objective of sewage treatment is to produce a disposable effluent without causing harm or trouble to the communities and prevents pollution. Sewage treatment, or domestic wastewater treatment, is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. It includes physical, chemical, and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce a waste stream (or treated effluent) and a solid waste or sludge suitable for discharge or reuse back into the environment. Residences, institutions, and commercial and industrial establishments create sewage. Raw influent (sewage) includes household waste liquid from toilets, baths, showers, kitchens, sinks, and so forth that is disposed of via sewers [1].

Urban wastewater (UWW) is a complex mixture of suspended and dissolved materials; both categories constitute organic pollution. The strength and quality of UWW effluent is described mainly in terms of its Suspended Solids (SS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorous (TP) and Total Nitrogen (TN) content, pH, Electronic Conductivity. The primary function of STPs is to speed up the natural processes by which wastewater is purified into the environment. Centuries ago, these natural processes were enough to treat the effluents of human activity, but now it is important to help the aquatic environment to achieve this goal. A typical STP consists of a series of treatments. In the pre-treatment units, the influent wastewater is strained to remove all large objects that are discharged into the sewer pipes. The primary treatment removes the majority of the suspended organic material (particulate pollutants or suspended solids) and, occasionally, its performance is enhanced with coagulation processes, which allow transforming non-settling colloid-particles into larger suspended solids. The secondary treatment (biological reactor) is designed to substantially degrade the organic content of the sewage and to remove nutrients, especially nitrogen and phosphorus.

With industrialization and improvement in the quality of life, increasing amounts of nitrogen, phosphorous, and some organic substances from industrial wastewater, agricultural wastewater, and domestic wastewater are being discharged, polluting water resources such as rivers and lakes. Therefore, these wastewaters must be treated before being discharged. Therefore, these wastewaters must be treated before being discharged. The treatment methods include biological methods, chemical oxidation, and electrochemical methods. Generally, the biological approach is used to treat domestic wastewater or stock-raising wastewater, but a large part of the nitrogen in domestic wastewater and stock-raising wastewater is from ammonia, which is generally treated by biological nitrification-denitrification. However, nitrification requires a larger facility and longer treatment time, resulting in high treatment cost. Chemical treatment involves adding a high volume of chemicals resulting in unreacted chemicals being present in treated wastewater, which is unacceptable, [3] and secondary solution should be considered [4]. Furthermore, it is necessary to carefully regulate the dosage of chemicals.

In recent years there has been increasing interest in environmental damage and human injury by industrial pollution, and the relevant legislation is always being made harsher. In this framework electrochemical methods offer a good opportunity to prevent and remedy pollution problems due to the discharge of industrial and sewage effluents. The electrochemical technologies have attracted a great deal of attention because of their versatility, which makes the treatment of liquids, gases and solids possible and environmental compatibility. In fact, the main reagent is the electron which is a ‘‘clean reagent’’ [5,6]. Recently, an electrochemical method has gained attention because of its efficiency for removing wastewater pollutants and ease of operation. Electrochemical methods have been successfully applied for the treatment of urban waste water [7,8] for the Detoxification of synthetic industrial wastewaters [9] for the treatment of municipal solid wastes leachate [10] for the treatment of olive oil mill waste waters, [11]. Electro-chemical processes are supposed to have a wide perspective. It is considered that this technology will have a widespread usage in water and wastewater treatment due to its characteristics as less equipment requirement, shorter treatment period, no chemical matter need and less sludge formation as a result of all this [12]. Besides all these advantages, method has some disadvantages such as exchange of anodes as electrodes consume and high operation costs where electricity is expensive.

Recently, this electrolytic technology has been widely studied with both real [13–15] and synthetic industrial wastes [16–22]. The main results are that this technology allows the almost complete mineralization of the organics contained in the wastes with very high current efficiencies. The oxidation mechanisms involved in this technology have also been characterized and include direct electrooxidation, hydroxyl radical mediated oxidation, and oxidation mediated by oxidants generated during the treatment from the salts contained in the waste [23,24].

This study deals with a physicochemical approach for the treatment of UWW in the eastern region of Cyprus under warm climate condition based on the principle of oxidative degradation of all its organic compounds in an electrolysis system.

1.1. Theoretical approach

Time of oxidation depends upon the stability and concentration of compounds, concentration of NaCl used, temperature, pH of the solution, time of recirculation, size of the anode and current and voltage applied. The electrochemical reactions which take place during the electrolysis of a brine solution are complicated and not entirely known. For the time being only assumptions can be made, based on the products that can be determined (Cl_2, ClO_2, O_3, $OH^{\cdot}$, $O^{\cdot}$, H_2O_2, O_2, H_2, CO_2). A possible mechanism of electrolysis is described below. The electrolytic evolution of hydrogen in acid and alkaline solutions occurs in different ways. In acid solutions, the source of hydrogen is hydroxonium ions which are discharged at the cathode to form hydrogen gas [25,26].

$$2\,H_3O^+ + 2\,e^- \rightarrow H_2 + 2\,H_2O \tag{1}$$

For alkaline solutions it is assumed that electrons are directly added on to water molecules which then decompose to yield hydrogen and hydroxyl ions:

$$2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^- \tag{2}$$

Anodic discharge of the water takes place forming hydroxyl radicals which are absorbed on the active sites of the electrode surface M [27].

$$H_2O + M\,[\,] \rightarrow M\,[OH^-] + H^+ + e^- \tag{3}$$

It is believed that reaction (Eq. 3) may also proceed in acid solutions but at high current densities [25]. Very close to the anode area the main by-reaction during the procedure of electrochemical reaction (Eq. 2) is the oxygen formation according to the following reaction:

$$H_2O + M\,[OH^-] \rightarrow M[\,] + O_2 + 3\,H^+ + 3\,e^- \tag{4}$$

The electrochemical oxidation of aqueous solutions which contain organic matter, by the use of traditional anodes (Ti/Pt, Ti/PbO, Ti/IrO_2...) proceeds in two steps [27]. The first step is the reaction (Eq. 3). After this, the absorbed hydroxyl radicals, oxidize the organic matter:

$$R + M\,[OH^-] \rightarrow M\,[\,] + RO + H^+ + e^- \tag{5}$$

where RO represents the oxidized organic matter which can be oxidized continuously by the hydroxyl radicals which are formed continuously too, since the anodic discharge of the water goes on. The anodic discharge of chlorides take place simultaneously, forming possible chlorohydroxyl radicals which are also absorbed on the active sites of the anode surface M[ ].

$$H_2O + M[] + Cl^- \rightarrow M[ClOH^-] + H^+ + e^- \tag{6}$$

Under a pathway similar to Eqs. 4 and 5 the free chlorine and chlorides, as well as oxidized organic compounds, are formed according to the following reactions:

$$H_2O + M\,[ClOH^-] + Cl^- \rightarrow Cl_2 + M[] + O_2 + 3\,H^+ + 4\,e^- \tag{7}$$

$$M\,[ClOH^-] \rightarrow M\,[\,] + RO + H^+ + Cl^- + e^- \tag{8}$$

The free chlorine produced is under equilibrium with OCl^- ion according the following reaction: [26] :

$$Cl_2 + 2\,OH^- \rightarrow H_2O + OCl^- + Cl^- \tag{9}$$

So the products from the primary electrochemical reactions are Cl_2, O_2, OCl^- and RO. As concentrations of the above oxidants are increased in the electrolyzed solution, several other secondary electrochemical reactions take place. At high OCl^- concentrations, elevated temperature and turbulent flow conditions, the mass transport reactions that are created are the following [28]:

$$6\,OCl^- + 3\,H_2O - 6\,e^- \rightarrow 3/2\,O_2 + 6\,H^+ + 4\,Cl^- + 2\,ClO_3^- \quad \text{(10), on anode}$$

$$OCl^- + H_2O + 2\,e^- \rightarrow Cl^- + 2\,OH^- \quad \text{(11), on cathode}$$

At the same time, ozone, hydrogen peroxide and chlorine dioxide are found among the oxidants produced [29] from the Ti/Pt electrolysis of brine solutions. These oxidants are produced on the anode according to the following hypothetically electroreactions:

$$H_2O + M\,[ClOH^-] + Cl_2 \rightarrow M[\,] + ClO_2 + 3\,H^+ + 2\,Cl^- + e^- \tag{12}$$

$$O_2 + M\,[OH^-] \rightarrow M[\,] + O_3 + H^+ + e^- \tag{13}$$

$$H_2O + M\,[OH^-] \rightarrow M[\,] + H_2O_2 + H^+ + e^- \tag{14}$$

The radicals have a very short life due to their high oxidation potential and either they are decomposed to other oxidants (Cl_2, O_2, ClO_2, O_3, and H_2O_2) or they oxidise organic compounds (direct oxidation). The primary (Cl_2, O_2) and secondary (ClO_2, O_3, and H_2O_2) oxidants that are produced from the destruction of radicals have quite a long life and are diffused in to the area away from the electrodes continuing the oxidation process (indirect oxidation).

The direct electro-oxidation rate of organic pollutants depends on the catalytic activity of the anode, on the diffusion rate of organic compounds in the active points of the anode and the applied current density. The indirect electro-oxidation rate is dependent on the pH, diffusion rates of secondary oxidants into the solution.

2. Material and methods

The experimental plant consisted (Fig. 1) of the electrolytic cell, the recirculation system, the pH-correction system and the cooling system for the wastewater. The electrolytic cell consisted of the cathode, which was a Stainless Steel, and Pt/Ti of the anode. The electrodes were operated at 16 volts D.C. and 105 Amperes. The UWW feeding system included a vessel of 50 l, which contained the wastewater to be treated, and a dosing pump, which was continuously feeding the raw UWW into the electrolytic cell. The recirculation system included a reactor of 3 l (active volume), which contained the UWW to be treated, and a centrifugal pump of 35 l/min flow rate, which continuously re-circulated the reactor contents into the electrolytic cell. The pH correction system consisted of a pH Indicator-Recorder which continuously measured the pH content of the balance tank and with the help of the dosing pumps which supplied HCl 10% v/v and NaOH 1 N respectively, the pH was kept constant. The cooling system included a temperature indicator controller recorder. The cylinder wall and the cooling jacket constituted the cathode. Whenever the temperature of the water exceeded 33 ± 1 °C, cooling water was circulated in the jacket, until the temperature returned to the desired value. The change of redox potential in the reactor was continuously recorded by a redoxi indicator recorder (RIR). The samples for analysis were drawn from the overflow of the balance tank.

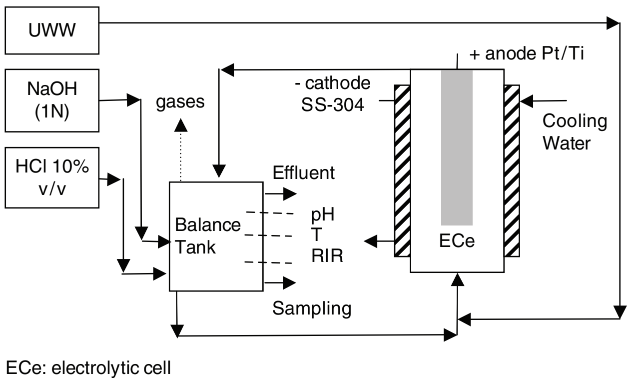

Fig. 1. Experimental laboratory pilot plant.

Sodium chloride was added to UWW so that its concentration reached 2% v/v. The efficiency of the electrolytic cell was studied in relation to pH and to the residence time of UWW into the reactor when the temperature remained constant at 30 ± 2 °C during all experiments in order to prevent the degradation of hypochlorite by anodic oxidation [6]:

$$6\,OCl^- + 3\,H_2O - 6\,e^- \rightarrow 2\,ClO_3^- + 4\,Cl^- + 6\,H^+ + 3/2O_2 \qquad (15)$$

Table 1
Composition of UWW used in experiments

Parameters	February 2009	April 2009	June 2009	August 2009	November 2009	Average influent characteristics in waster water treatment plant from 1/1/2009–31/12/2009
Temp (°C)	17.20	20.83	28.40	29.01	22.80	23.31 ± 4.70
pH	74.8	7.55	7.60	7.57	7.62	7.54 ± 0.11
SS ppm	210.60	259.17	272.40	256.00	247.80	257.12 ± 21.06
VSS ppm	172.12	188.39	199.41	184.82	174.91	192.25 ± 12.56
EC mS/cm	2.55	2.35	2.29	2.12	2.13	2.25 ± 0.19
BOD_5 ppm	282	373	323	300	289	313 ± 25
COD_{cr} ppm	573	755	748	712	575	686 ± 67
TP ppm	9.28	10.68	12.61	10.45	10.77	10.47 ± 1.40
Alkalinity mmohl/	6.92	7.07	7.00	6.80	7.04	6.87 ± 0.16
TN ppm	56.66	63.45	69.86	74.37	73.98	68.92 ± 11.2
NH4 ppm	44.26	43.73	57.42	49.97	38.90	45.84 ± 8.45

The effect of the electrochemical method on UWW treatment was examined for pH, 6, 7 and 8. Each experiment was of continuous operation and it was interrupted when steady state results were achieved. The residence time of UWW into the electrolytic system was controlled by the flow rate of the dosing feeding pump PP-3. Every half an hour samples were taken from the effluent of the reactor. COD, NH$_4$-N, TN, Total Phosphorous, Chlorides, Chlorine and Total Oxidants were calculated according to the Standard Methods for the Examination of Water and Wastewater [30]. The determination of the total oxidants except for chlorine was carried out according to Wilk et al. [29]. Five experiments under the same conditions were run for each pH value and the results presented in this work are the average of the five separate measurements. Gas nitrogen production as well as chlorates were calculated by Nitrogen and chlorine balance respectively. The colour was monitored by measuring the decrease of absorbance at 420 nm, the length of the maximum absorbance, using a spectrophotometer [6].

3. Results and discussion

The composition of the UWW that was used in all experiments is shown in Table 1. STP is presented with a yearly COD at 686 ± 67 ppm and BOD$_5$ at 313 ± 25. The yearly temperature of the area is 23.31 ± 4.70 °C. The yearly average temperature is more than 26 °C while at the same time in other European Countries is less than 20 °C [31]. EC remain in high level and is more than 2 mS/cm. High concentrations of EC for long period may create corrosion to the STP. Corrosion can result in damage to underwater metal surfaces and equipment damage. Corrosive conditions can be eliminated or controlled by the adjustment of the pH, total alkalinity and calcium hardness.

Fig. 2 presents the% removal of COD and BOD$_5$ in relation with the pH and residence time. When the pH and the residence time increase, the efficiency of the electrolytic oxidation of COD increases. Thus, while for residence time 2.5 h and pH 6, the COD was reduced from 755 to 530 mg/l, at pH 8 the COD was reduced from 755 to 2 mg/l. Similar behaviour is shown by the BOD$_5$. At pH 6 the BOD$_5$ was reduced from 373 to 328 ppm and from 373 to 1 ppm at pH 8.

Fig. 3 shows the changes in total phosphorous in relation to pH and the retention time of UWW in the reactor. In the acid and neutral region there was a partial removal of phosphates with sedimentation while in the alkaline region there was a complete precipitation of soluble phosphates. Total P efficiency is up to 18.44% at pH 6, 50.28% at pH 7 and 95.88% at pH 8. The mechanism of precipitation of phosphates is probably due to the pH shift to the alkaline region rather than to special oxidative actions. As it is shown in Fig. 4, NH$_4$-N was reduced quickly in all pH values except pH 7. Thus, for pH 6 and 8 and two hours residence time of UWW in the reactor, the NH$_4$-N was reduced by almost 100%, while at pH

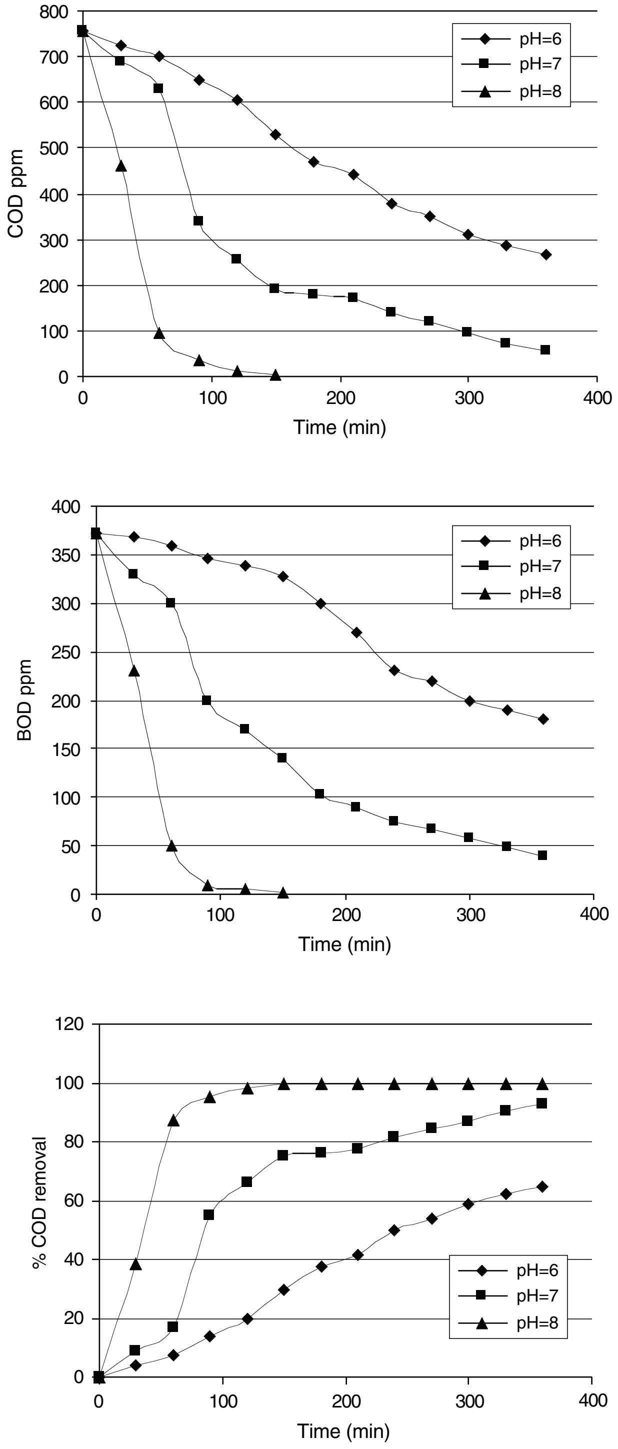

Fig. 2. Reduction of COD and BOD$_5$ in relation to pH and residence time.

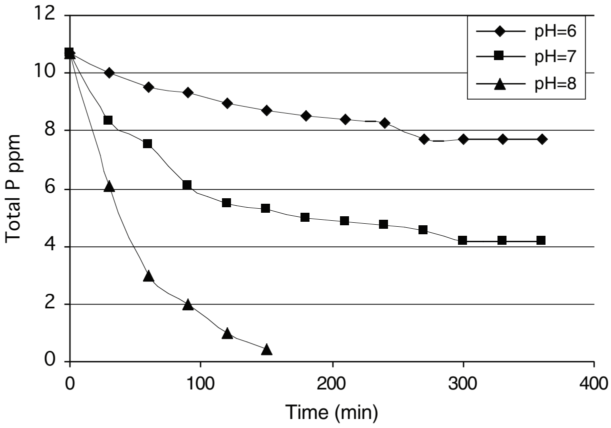

Fig. 3. TP reduction in relation to pH and residence time.

7 and the same residence time, the NH_4-N reduction was only 45.76% (from 43.73 mg/l to 23.71 mg/l). For residence time 1 h the NH_4-N reduction for pH 6, 7 and 8 were 78.9%, 13.3%, 70.2% respectively which strongly suggests that the highest rate of reduction occurs at pH 6 and that between pH 6.5–7.5 the oxidation of NH_4-N is reduced drastically. Using a graphite anode and a steel cathode full elimination of NH_4^+ was achieved at a 19.1% current efficiency when electrochemical treatment was applied as a final polishing step for biologically treated wastewaters [32]. According to Lei and Takaaki [33], the indirect oxidization of ammonia and organic carbon was mainly achieved using electro generated hypochlorous acid; therefore, the treatment efficiency was highly related to the NaCl dosage. The ammonia removal efficiency was greatly improved with the addition of NaCl but the difference between the different dosages was relatively small. These results according to Lei and Takaaki [33] indicated that a 1% NaCl dosage was almost saturated. Although better ammonia removal efficiency was achieved below the pHs 6.6 and 7.7 those below other pHs did not have a bad ammonia removal efficiency [33]. In addition, ammonia was also removed by ammonia stripping below pH 9.0 and 11.6. According to Lei and Takaaki [33], the negligible affect of initial pH on the ammonia removal, which might be caused by different anode material, wastewater etc. The nitrogen profile is shown on Fig. 4 in relation to pH and residence time in the reactor. It can be noticed that at pH 6 and 7 there was almost exact correspondence of the reduced NH_4-N, something that does not occur at pH 8. This proves that in acid environment the NH_4-N is oxidized to nitrates while in alkaline it is transformed mainly to nitrogen gas confirming the observations of Szpyrkowicz et al. [34]. The overall reaction of TKN oxidation in alkaline conditions can be expressed as follows [35,36]:

$$2\ NH_4^+ + 2\ HOCl \rightarrow N_2 + 3\ H_2O + 5H^+ + 3Cl^- \qquad (16)$$

Fig. 5 presents the production of chloramines. The higher production of chloramines happens at pH 6, where for retention time 360 min the chloramines concentration reached its peak, that is 24.7 mg/l For pH 7 and 8 the chloramines concentrations reached their highest values at 210 and 180 min at 5.01 and 1.31 mg/l respectively. This shows that in acid environment the rate of chloramines production is much higher compared to alkaline and ordinary environmental conditions. The production of chloramines ceases when all organic nitrogen has been oxidized. At pH 7 and 8 there was a slow reduction of chloramines due to their oxidation with the increase retention time of UWW in the reactor. Free chlorine is defined as the concentration of residual chlorine in water present as dissolved gas (Cl_2), HClO, and/or hypochlorous acid ions (OCl_-). Three forms of free chlorine exist together in equilibrium. Their relative proportions are determined by the pH value and temperature; free chlorine is the most effective at pH of 5–7 where HClO is the predominant form [37,38]. Fig. 6 shows the concentration

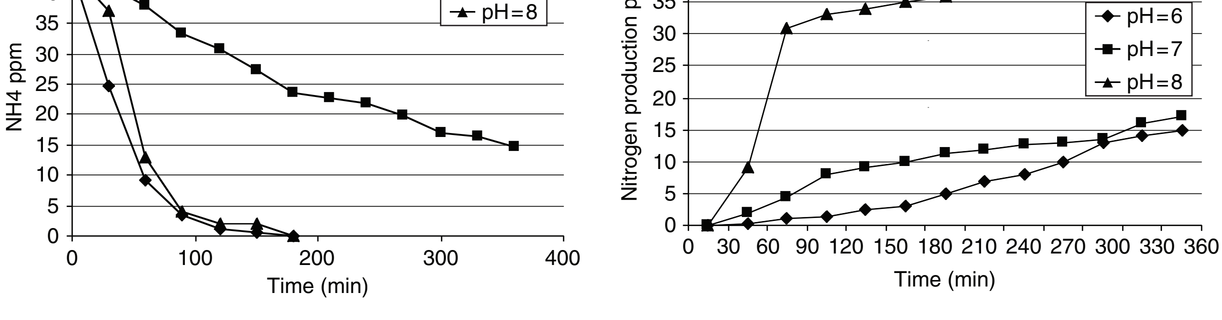

Fig. 4. NH_4^+ reduction and nitrogen production in relation to pH and residence time.

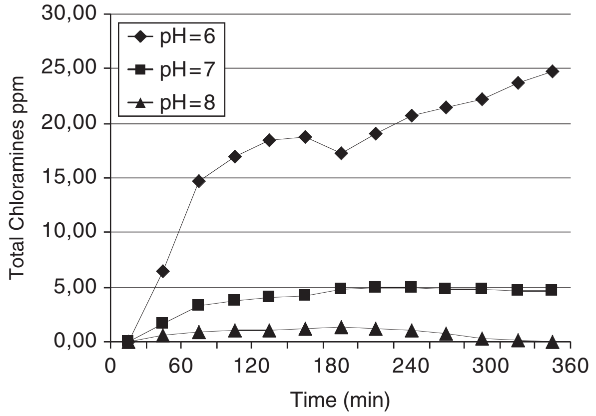

Fig. 5. Total chloramines production.

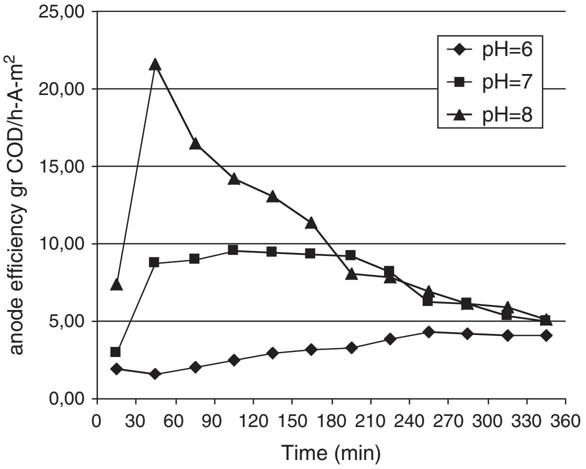

Fig. 7. Anode efficiency.

of chlorides, free chlorine, hypochlorides, chlorates and other oxidants at pH 8 and to the residence time of UWW in the reactor. The concentration of chlorides at pH 8 was reduced from 3890 to 1354 ppm in 360 min. Chlorates were detected only at pH 8. Other Oxidants (like H_2O_2, O_3) and hypochlorides were increased continuously as residence time was increasing. The addition of sodium chloride to the solution resulted in an increase in the organic oxidation rate due to the participation of electro generated hypochlorite ions in the process [6].

The anode efficiency is presented in Fig. 7 in relation to pH and residence time of UWW in the reactor measured in Kg COD removed per hour per sq.m. of anode surface and per Ampere applied (kg CODr h^{-1} $(sq.m)^{-1}$ A^{-1}). For 90 min residence time the anode efficiency is 1.99, 8.98 and 16.47 for pH 6, 7, 8 respectively. The gradual decrease of electrode efficiency indicates the increasing difficulty for oxidation of residual organics and inorganic in the waste and this is happen when the time of electrolysis was increased.

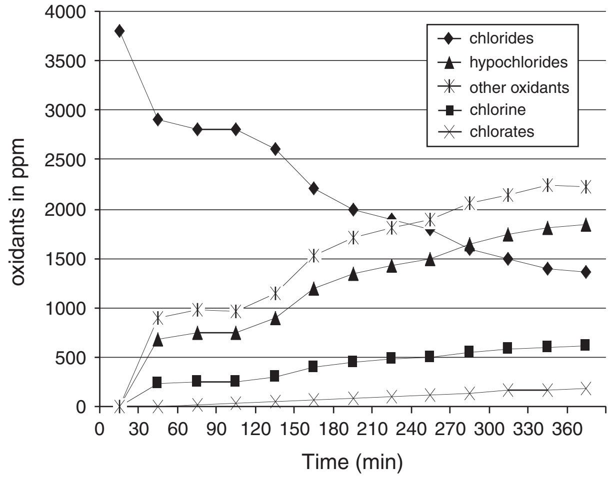

Fig. 6. Oxidants production at pH 8.

Commonly employed methods for colour removal are: adsorption [38] coagulation [39] chemical oxidation with ozone [40] or Fenton's reagent [41], and advanced oxidation processes [42,43]. However, these processes are quite expensive and involve several operational problems. For these reasons, there has been increasing interest in the use of new methods such as electrochemical oxidation [44,45]. The colour in this study was reduced to zero in less than 60 min for all the experiments due to the presents of H^+. Marco Panizza and Giacomo Cerisola [44] report that, the colour removal by an electrolysis system of Pt/Ti is up to 94% from wastewaters.

4. Discussion

Many industrial processes generate flow streams that contain small concentrations of organic compounds. The removal of these materials is required prior to discharge or reuse of the waste flow. In appropriate circumstances, the organic compounds contained in these wastes can be economically recovered, but usually the best method to treat these streams is the destruction of the organics by different oxidation techniques, including incineration, biological oxidation, and chemical oxidation or, in some cases, Advanced Oxidation Processes (AOPs) and electrochemical oxidation. The oxidation mechanisms involved in this technology (electrochemical oxidation) have also been characterized and include direct electro oxidation, hydroxyl radical mediated oxidation, and oxidation mediated by oxidants generated during the treatment from the salts contained in the waste [23]. Comparison of the utility and treatment costs associated with different technologies is a subject of major importance. However, it is very difficult to compare technologies, as the cost analyses are often based on different assumptions [47] and, consequently, they can lead to very different treatment costs. For example, literature data concerning the cost associated with Fenton treatment are in the range 0.2–17.7 V m^{-3}. This huge range does not mean that estimations are incorrect, but simply that very different assumptions are made in the cost analysis. The same trend is observed for other AOPs such as electrochemical oxidation, ozonation, etc, [48–50]. Therefore, several items must be considered in order to estimate the cost of a wastewater treatment process, the most important of which are equipment amortization cost, raw materials cost, energy cost and labour cost [24]. Canizares et al. [24] report that the price of the electrode is often negligible in comparison to the price of the cell, and this is sometimes included in the budget for the cell. However, diamond electrodes are an exception due to their known high price. The price of electrodes is presently around 8000–18,000 € /m^2 although this is expected to decrease in the near future to values in the range 4000–10,000 €/m^2. However, in this work a conservative estimate of 10,000 €/m^2 was used. The costs associated with the equipment required to run the electrochemical process must also take account of the price of the power supplied during the process. This can be calculated as a function of the power supplied, assuming a value of 0.30 €/W. Nowadays, electrochemical technologies have reached such a state that they are not only comparable with other technologies in terms of cost but also are more efficient and more compact. For some situations, electrochemical technologies may be the indispensable step in treating wastewaters containing refractory pollutants [51]. Concluding it can be said that electrochemical processes are presented with several attractive advantages which are generally

- Flexibility: direct or indirect oxidation and reduction, phase separation, concentration or dilution, biocide functionality, applicability to a variety of media and pollutants in gases, liquids, and solids, and treatment of small to large volumes from microlitres up to millions of litres.
- Energy efficiency: electrochemical processes generally have lower temperature requirements than their equivalent non-electrochemical counterparts, e.g., thermal incineration. Electrodes and cells can be designed to minimise power losses caused by inhomogeneous current distribution, voltage drop and side reactions.
- Amenability to automation: the system inherent variables of electrochemical processes, e.g., electrode potential and cell current, are particularly suitable for facilitating process automation.
- Cost effectiveness: cell constructions and peripheral equipment are generally simple and, if properly designed, also inexpensive.

5. Conclusions

This study deals with a physicochemical approach for the treatment of UWW in the eastern region of Cyprus under warm climate condition based on the principle of oxidative degradation of all its organic compounds in an electrolysis system. Biological waste treatment is currently the most widely used method for removing organic pollutants and nutrients from UWW. The obtained results may be useful as in the near future we must develop environmental friendly technology in order to provide new sources of water, especially in countries in which the lack of water resources has become a serious problem. The electrochemical treatment of UWW seems to be favoured for small communities by the sea. The electrochemical oxidation seems to be an integrated and effective method for the treatment of UWW because it can reduce all pollutants (COD, NH_4–N, phosphorus, colour) almost at 99%.

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