International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 6, (Series-VIII) June 2020, pp. 41-48

RESEARCH ARTICLE OPEN ACCESS

The Utilization of Electrokinetics for the Treatment of Industrial Wastewater-Industrial Size Experimental Study-

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ABSTRACT
Environmental policy in China is compelling industries to treat their wastewater to a level that can be released into the domestic sewer system or even for reuse. However, many industrial branches are lacking space for traditional wastewater plant. Hence, electrokinetics wastewater treatment is a viable alternative as it is fast and does not require large apace. Thus, a prototype of electrokinetic wastewater treatment industrial-size device has been designed, constructed and tested under real conditions. In this paper the device is described and the results obtained from the operation of the device are presented and discussed.
Keywords:wastewater treatment; electrocoagulation; Electrokinetics, industrial wastewater

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Date of Submission: 13-06-2020 Date of Acceptance: 29-06-2020

I. INTRODUCTION

It is well known that electrical current can trigger in an electrolyte such as wastewater or sludge the following processes:Electrocoagulation, Electrooxidation, Electro-floatation, Electro-disinfection, Electroosmosis, Electromigration, Electrophorese, Electro-filtration, etc. These processes allow to utilize the electric power to treat wastewater according to the triggered mechanisms. E.g. electrocoagulation can be used to aggregate suspended matter in wastewater, so it can settle or it can be removed by floatation or filtration. To oxidize chemical compound such as organics, electrooxidation can be helpful. For dewatering of sludge, electroosmosis and electrophorese can be applied to enhance the efficiency.

Other successful field applications have been reported in the field of soil improvement and stabilization (LO et al., 1991; CHAPPEL & BURTON, 1975; BJERRUM et al., 1967). Electrokinetic is used to drainage the clayey soil and to improve foundation soil properties (AZZAM et al., 1997). In recent years, the research on electrokinetics has been intensified and new research fields established such as geo-environmental engineering applications such as dewatering and consolidation of soil covers and mine tailings (SHANG, 1997a; LOCKHART, 1983a-c), electrokinetic barriers to contaminant transport through compacted landfill liners (AZZAM, 1997), electrokinetic barriers for contaminated sites (LAGEMANN, 1990), and wastewater treatment and dewatering of sludge (AZZAM, 2001). The utilization of electrokinetics to support the remediation of groundwater with the funnel and gate concept is introduced by CZURDA & WEISS (1998). AZZAM and KLAPPERICH (2006) introduced the utilization of the technique for in-situ soil remediation of contaminated fine-grained soil.In situ methods have advantages in avoiding high costs and health risks of excavation.

Electromigration causes the transport of charged ions such as heavy metals in the electric field.Uncharged species like organic contaminants can only be transported by electroosmosis. Once the fluid with the contaminants reaches the electrode wells, it can be easily pumped out and treated.When the contaminant is immobile, it is necessary to create suitable chemical conditions in the soil to mobilize it. Several researchers were reporting about successful applications of the method to remove heavy metals (among others OEY & AZZAM, 1999a; ACAR et al., 1995; ACAR et al., 1994; HAMED et al. 1991), and organic contaminants from clayey soil in laboratory tests (among others ACAR et al., 1992, BRUELL et al., 1992).ACAR& ALSHAWABKEH (1993) showed that for the transport of ions in the electric field, electromigration is much more significant than electroosmosis. This means that electrokinetics can also be used to remove ionic contaminants from coarse-grained soils (RUNNELS & WAHLI, 1993).

In this paper the treatment of contaminated wastewater is addressed. An industrial size treatment unit has been developed and tested. The unit contains of two different reactors operated by three mechanisms, electrocoagulation, electrooxidation and electrofloatation.

In the electrocoagulation process metal ions are produced due to electrical current from the electrode material. In the case where the electrodes are made of iron, ferric ions are produced, in accordance with Faraday's Law, due todischarge of electrons:

$$Fe - 2e^{-} \Rightarrow Fe^{2+} \quad (1)$$

The iron ions react with the water and produce ferric-hydroxide and the hydrogen ion concentration increases:

$$Fe^{2+} + 2H_2O \rightarrow Fe(OH)_2 + 2H^{+} \quad (2)$$

Due to the presence of free oxygen, the ferric-hydroxide is transformed to ferric-hydrate:

$$Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \quad (3)$$

The same reaction happens if the electrodes are made of aluminium (s. also Fig. 1).

$$Al \longleftrightarrow Al^{3+} + 3e \text{ (anode)} \quad (4)$$

$$3H_2O + 3e \longleftrightarrow 3/2H_2 + 3OH^{-} \text{ (cathode)} \quad (5)$$

The Al^{3+} and OH^{-} ions generated at the electrodes react in the wastewater suspension and form aluminum hydroxide:

$$Al^{3+} + 3OH^{-} \longleftrightarrow Al(OH)_3 \quad (6)$$

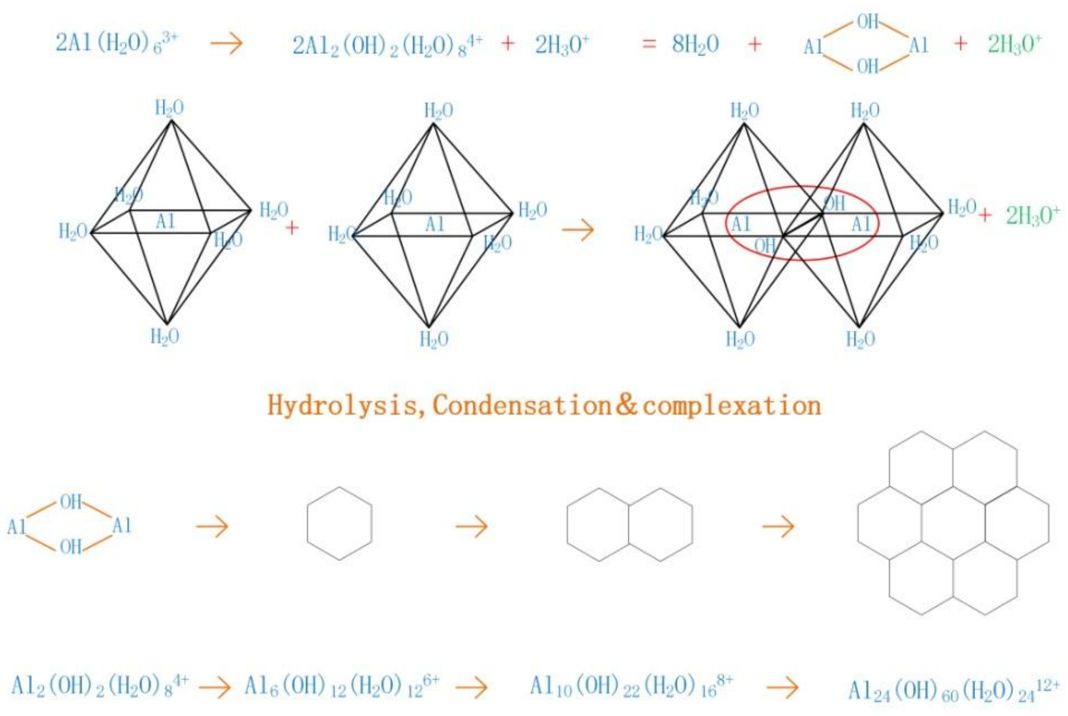

Fig.1 Proposedmechanism of electrogoagulation

The metal ions tend to form metal hydroxides followed by a process of hydrolysis, condensation and complexation that electromechanically attract to the contaminants that have been destabilized. The mechanism of absorption of pollutants is shown in Fig. 2. The process results in forming colloidal particles that attract other particles in the suspension, which can be separated easily from the suspension. Fig. 3 shows the wastewater before and after treatment by electrokinetics.

Also, the treatment causes precipitation of all suspended particle in very short time. This process occurs even though the particles are so small that gravimetrical precipitation is not possible.

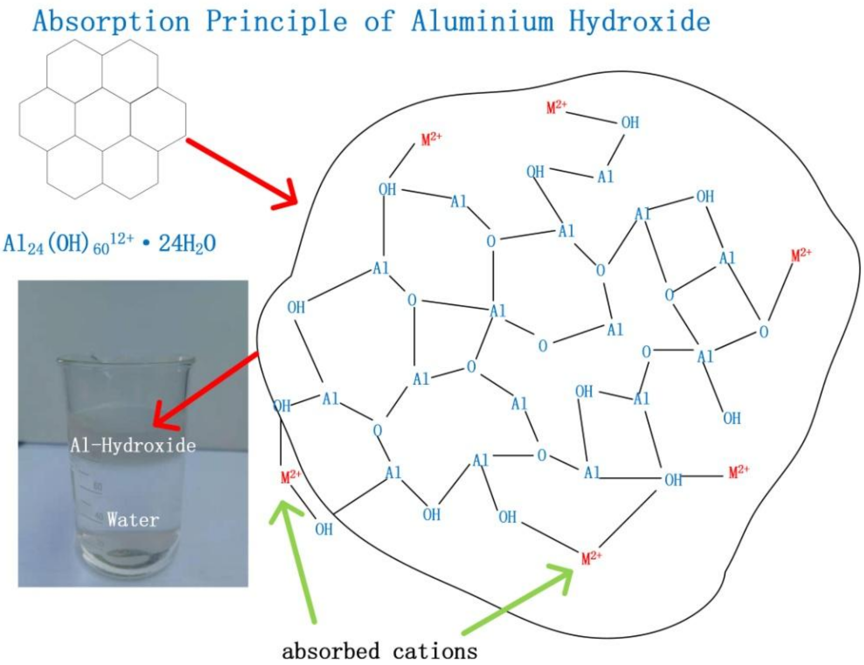

Fig.2 Absorption principle of metal hydroxide

Fig. 3 Wastewater before and after treatment with electrokinetics

Electrooxidation processcan destroy organic and toxic pollutants that are dissolved in wastewater by direct or indirect oxidation. The direct oxidation process occurs on the anode as it first absorbed the pollutants on the surface and then an anodic electron transfer reaction happens. Due to electrolysis strong oxidants such as hypochlorite/chlorine, ozone or hydrogen peroxide can be generated by the electrochemical reactions. The pollutants in wastewater are then destroyed by the strong oxidants by chemical reaction in the solution. Many scientists have reported about successful electrooxidation with regard to many specific pollutants, such as ammonia, hazardous dye, etc., but also the general reduction of COD. The electrooxidation process does not need a sacrificed anode, it is rather important to use a stable anode with catalyst material that favors the oxidation of the specific pollutant. Most applications utilize Titanium oxide with catalysts such as Ru/Ir/Sn among others as an anode.

The electrochemical oxygen transfer reactionat the anode surface causes discharge of the water molecules thus hydroxyl radicals are formed:

$$MO_X + H_2O \rightarrow MO_X\,(^{\bullet}OH)\,H^+ + e^- \quad (7)$$

In Equation (7)MO_Xrepresents the metal oxide anode.

The intensity of electrooxidation depends on the type of electrode material, which can be classified into active and non-active anodes. The active anode can cause higher oxidation and may interact stronger with the hydroxyl radicals forming higher oxides:

$MO_X(^{\bullet}OH) \rightarrow MO_{X+1} \quad + H^{+} + e^{-}$ (8)

The surface redox couple MO_{X+1}/MO_X is often denoted chemisorbed active oxygen and can act as mediator in the conversion or partial oxidation of organics on active anodes (J. Muff, 2010):

$MO_{X+1} + R \rightarrow MO_X + RO$ (9)

The non-active electrodes interact with hydroxyl radical weakly forming physically-sorbed active oxygen (hydroxy radicals) that can help in the mineralization process of the organics to carbon dioxide:

$MO_X\ (^{\bullet}OH) + R \rightarrow MO_X + CO_2 + H_2O + H^{+} + e^{-}$(10)

Electrofloatationoccurs as a result of the oxygen formation due to the dissociation of water during the dialysis. It can be considered as a byproduct of the electrocoagulation or electrooxidation. It helps however to carry the suspended matter to the surface of the water, where it can be skimmed off and separated.

The system has been used for the treatment of wastewater in a half-industrial scale.

II. DEVICES AND RESULTS

To be able to optimize the processes of wastewater treatment in an industrial scale, a laboratory test set up has been installed and tested. The testing device (cell) was constructed in a modular way, so that different metals for the electrodes can be tested. The electrical device has been designed flexible so that various types of half-waves at different frequencies can be adjusted. Also, the current or the voltage are adjustable. In this case the optimum treatment conditions for certain chemical compounds can be established. During the testing process important parameters such as pH, temperature, treatment period, power consumption, etc. were registered and, if necessary, controlled. The effect of the treatment is then controlled by chemical analyses with regard to coagulation and precipitation of the colloidal particles and with regard to extraction of the targeted chemical compounds.

The laboratory testing cell was operated in batch system, so that the treatment time is established. The industrial size wastewater treatment system is designed to operate in modus of continuous flow, the dwell time in the cell can be calculated. Depending on the type of wastewater, the amount to be treated in a time unit, and the characteristics of the chemical compounds to be extracted, the cell and the electrical device was then designed according to the results obtained from the laboratory tests.

In the separation process of the pollutants from the wastewater the interaction between the electrical field and the electrolyte plays an eminent roll with regard to the speed of the colloid coagulation in the system. Also, the deposition behavior of the colloids in the suspension is influenced. The process can be accelerated due to high current density. However, the energy consumption rises disproportionately high, generating heat in the suspension. Therefore, the selected treatment time and the current density are important parameters of the optimum design.

All results from the laboratory tests have been used to design the industrial size device. As many parameters are influencing the process of wastewater treatment, the design was kept flexible, so controlling and adjusting the treatment conditions was possible. The first device was developed for domestic wastewater treatment that contains some ammonia. Hence, the device with two treatment reactors were designed, build and installed at the wastewater treatment site in Dongyang, China (Fig. 4). The two reactors operated in two different modes, as electrocoagulation and electrooxidation. The design of both reactors is presented in Fig. 5. For the electrodes of the electrocoagulation reactor aluminum plates were used. For the electrooxidation electrodes titanium oxide/Rutinium, Iridium plates have been used.

Fig. 4 Wastewater treatment unit by electrocoagulation and electrooxidation

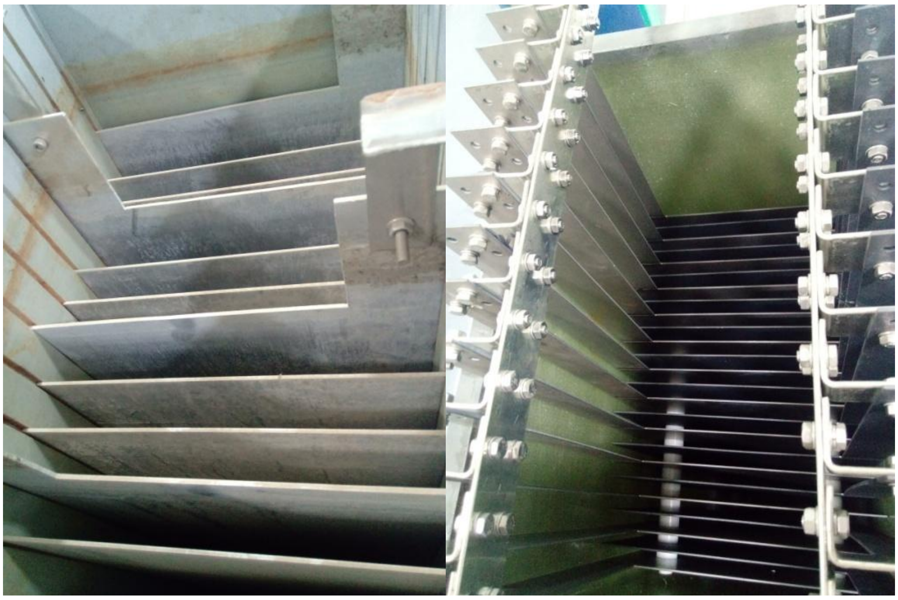

Fig. 5 Design of the reactors (electrocoagulation, left and electrooxidation right)

The results of the chemical analysis of the wastewater before and after treatment are presented in Table 1.

Table 1: Wastewater quality before and after treatment

	COD	Ammonia/ Nitrogen	SS	pH	Chroma
Unit	mg/l	mg/l	mg/l		multiple
before treatment	≈ 500	≈ 70	≈ 300	6-9	≈ 30
after first treatment by electrocoagulation	≈ 100	≈ 20	≈ 50	7-9	≈ 10
after second treatment by electrooxidation	≈ 10	≈ 5	≈ 2	7-9	≈ 1

The second device was designed for the treatment of wastewater originated from a vegetable market on a river side. This device operated in electrocoagulation mode only (Fig. 6).

Fig.6Wastewater treatment device in Hangzhou City for a food market

The device in Fig. 6 was installed in Xihu district, Hangzhou City. The device has been working for 4 years for treating the wastewater from a big food market, where they sell vegetable, fruit, fishes, and meat. The treated wastewater flows directly to the Shuanglonggang River in the city.

The results of the water quality are shown in the Table 2.

Table 2 wastewater results (unit: mg/L)

	Color	PH value	Ammonia nitrogen	Total phosphorus	Suspend solids	Permanganate index
Untreated water	Yellow and stinky	7.28	16.3	0.902	90	12
Treated water	Transparent and tasteless	6.58	0.018	0.113	8	4.6

Both devices were operating on the intended site delivering many results from treated wastewater visually and with regard to chemical analysis.

III. DISCUSSION

Many laboratory-size electrocoagulation experiments are presented and described in the literature, but very little industrial-size devices. In this presentation an industrial prototype electrocoagulation and electrooxidation device is described and the results presented. Industrial wastewater is often partly treated on site with chemicals and transported to wastewater treatment plant for further treatment. In many cases industrial plants do not have the space for full wastewater treatment plant as traditional wastewater treatment needs a large area due to time-consuming biological treatment. The presented device can be accommodated in a very small area accomplishing the treatment in less than 20 minutes. Hence, the size can be made small to accommodate the daily amount of wastewater for a certain industry and can be adjusted to its specific wastewater type.

To summarize, the capabilities of the system are:
- Removal of heavy metals as oxides
- Removal of suspended and colloidal solids
- Breaks oil emulsions in water

- Removal of fats, oils, and grease
- Removals of complex organics
- Disinfection from bacteria, viruses, and cyst

The benefits of the system are:

- Low cost wastewater treatment
- Decentralized system
- Low power consumption and small size
- No chemical additions
- Easy to build and low maintenance
- Treatment of multiple pollutants
- Appropriate for industrial wastewater
- Sludge minimization
- Treated water appropriate for agricultural use

In general, the major outcomes of the experimental tests with the two industrial size wastewater treatment devices by electrokinetics are summarized and explained:

- Decentralized and modular wastewater treatment system based on the effects of electrokinetics that is effective and fast in extracting suspended matter as well as many chemical compounds from many kinds of wastewater.

- Better understanding of the interaction processes between various types of electrical fields and electrolyte systems including suspended colloids and chemical compounds.

- Classification of different types of wastewater with regard to optimum treatment conditions.

- Indicators quantifying the success of the treatment and define the optimum conditions.

- Providing the small rural communities with decentralized wastewater treatment system, that is easy to operate and economically viable.

- Providing the industrial sites with adequate wastewater treatment system that is fitted to the specific contamination type and that allows the use of water in a cycle.

- Facilitate a steering mechanism for the integrated wastewater management also for small amounts of wastewater, for which the construction of wastewater treatment plant does not pay off.

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Dr. YujieSu, et. al. "The Utilization of Electrokinetics for the Treatment of Industrial Wastewater -Industrial Size Experimental Study-." *International Journal of Engineering Research and Applications (IJERA)*, vol.10 (06), 2020, pp 41-48.