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A Novel Electro-Chemical Process for Water Treatment

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Abstract – *Advanced power electronics, instrumentation and real time control have been successfully applied to municipal drinking water as a pre-treatment process and to wastewater for the removal of phosphate. In addition the process has been successfully used for industrial effluent processing for the removal of heavy metals, hydrocarbon oils and greases and bacteria from coolants and other industrial waste streams. Typically, such waste streams have been collected in storage tanks for disposal to land fill sites, pumped to sewer or processed on site by either liquid chemical and or biological treatment.*

Electro-chemical water treatment is achieved by passing polluted water between two or more electrodes. Excitation of the electrodes is controlled by an advanced programmable power electronic system, which can provide a variable AC/DC power source. In addition, real time monitoring of key physico-chemical parameters important to water quality provide the knowledge base for automatic feed back control and adjust to fluctuating changes in influent water quality.

The system has been extensively trailed, and the results of the process verified by independent analytical testing agencies. The benefits of this 'clean' technology include reduced capital and operating costs compared to conventional treatment processes, reduced environmental impact, improved health and safety, as well as opportunities for water recovery, recycling and re-use.

Résumé – *L'électronique de puissance moderne, l'instrumentation et le contrôle en temps réel ont été appliqués avec succès au traitement des eaux potables et aux flots d'eaux usées. De plus le processus a été utilise avec succès pour la suppression des métaux lourds, des huiles d'hydrocarbure et des graisses des liquides de refroidissement et des composants de machines qui proviennent de l'industrie. Typiquement, de tels flots de déchets sont collectes et stockes dans des réservoirs pour ensuite les verser dans la nature. Le système electro chimique de traitement des eaux a été conçue tel sorte que l'eau polluée passe a travers les électrodes. Ces dernières sont alimentées et contrôlées par un système de puissance programmable moderne, qui assure une source de tension AC/DC avec des paramètres variables tel que la fréquence, rapport d'utilisation, et des options de contrôle du courant en boucle ouverte et boucle fermée, etc. L'affichage en temps réel des paramètres électriques et chimiques importants fournit une base de connaissance qui permet l'asservissement et un ajustement automatique lors du changement de la qualité des caractéristiques de l'influent. Le système propose a été intensivement teste, et les résultats trouves sont importants et représentent un grand potentiel dans l'exploitation commerciale. Les bénéfices de la technologie proposée implique la réduction de la puissance consommée, technologie propre et sécurisée. C'est aussi, l'occasion, le recyclage de l'eau en vue d'une réutilisation.*

Keywords: Power electronics – Real time control – Electro-chemical – Water treatment – Electrodes – Current control.

1. INTRODUCTION

Water is essential for all forms of life. Covering 73% of the Earth's surface, the quality of our environment is very often defined by the quality of the water set around us [1]. Unfortunately the expanding demands for 'fresh' water of good quality by a growing population and industry have, inevitably, been equalled by an increased discharge of waste products to the nation's water courses [2].

Advances in technology have resulted in greater water demands from industry. The volume of wastewater from these companies has increased likewise, containing a variety of suspended solids, oils, metals, and organics. The successful cleaning of these new wastewaters prior to discharge, using existing treatments, has yet to improve comparatively.

2. BACKGROUND

The 20th century introduced new concerns regarding the environment, highlighting that its contamination and degradation will inevitably have its effects on all living things [1]. Industrial pollution alters this environment in many more ways that were initially thought, interfering with the growth rate of species, the food chain, and with the health of those in contact with it. An increased scientific knowledge of the constituents found in wastewater and the information derived from widespread environmental monitoring has resulted in a tightening of the permit requirements governing industrial wastewater discharges. New legislation is aimed directly at reducing the pressure on the environment from industry. Current guidelines aim to lower the levels of toxic chemicals, reduce quantities of readily utilizable compounds, and reduce the degree of nutrients that would support microbial growth. Unless a suitable reduction is made, these factors will continue to cause un-repairable damage to the water courses they are discharged to.

To comply with these standards industrial effluent plants monitor different parameters of their waste streams, for example; physical properties (such as temperature, colour, odour and turbidity), chemical properties (i.e. pH, total dissolved solids (TSS), biological oxygen demand (BOD), detergents and petroleum residues). For specific elements, complex ions, and organic compounds- especially for radiological properties. Additional screening also measures for microbiological properties [1].

Modern conventional treatment is often of a biological nature, using microorganisms, principally bacteria, to reduce the concentration of organic and inorganic compounds. Making use of settlement and filtration techniques, they have traditionally been adequate. Unfortunately in the food, paper, and engineering sectors these traditional effluent plants have been proved inefficient and inadequate in light of the stricter enforced regulations. Limitations highlighted have included inabilities to cope with fluctuating loads and toxic or recalcitrant materials, to remove colour, to remove heavy metals, to separate oil/water emulsions or to breakdown synthetic oils. Alternative treatments are often expensive on time, cost, and space. Also, favourable cost saving initiatives such as water recycling cannot be considered if contaminants remain.

3. ELECTRO CHEMICAL APPROACH

Great interest has been revived in electro-chemical treatments for both industrial wastewaters and for the disinfections of drinking waters. Successful application of this system to both spheres have proved that most limitations affecting modern effluent treatment can be easily overcome using this advanced technology.

The success of electrolytic treatment can be traced as far back as 2000 BC. Sanskrit writing illustrated that the dipping of copper several times into boiled foul waters followed by some form of filtration would result in sufficient disinfections [3]. Furthermore, Egyptian paintings dating from the 13^{th} and 15^{th} century BC induced speculated theories that the ancient civilizations utilized alum to remove suspended solids from their fouled waters. Yet it wasn't until the 19^{th} century that electrolysis was given any further thought, when the concept was applied to sewage waters in Crossness, Erith [4]. The inventor Webster used cast Iron electrodes to decompose composite Sodium, Magnesium, and chlorides to form free Chlorine and Oxygen, which in turn effectively bound to organic impurities and aided their successful removal. As with all earlier systems the lack of electrochemical knowledge and the high costs involved rendered such systems uneconomical and therefore unsuccessful.

Advancement in electrochemistry and power electronics has together produced an advanced, unique technology, offering distinct advantages over other treatment systems. Firstly it is environmentally compatible, it is clean and safe, using only electrons and utilizing a much smaller amount of chemicals than other treatments, if required at all. The electrochemical indirect/direct oxidation/reduction reactions that occur when polluted water is passed between electrodes, can deal with solid, liquid and gas pollutants. It can also selectively induce the production of precipitates, gaseous species, pH changes and even charge neutralisations [3]. The system as a whole can be modified to cope with any waste type (not affected by toxicity), or waste volume. The system is energy efficient having lower temperature and pressure requirements- a common concern with biological treatments.

Most importantly, electrolytic water treatment provides amenability to automation and reaction selectivity. The applied potentials can be controlled to bring about the required reaction, and prevent the production of unwanted side- products. The entire system is controlled via a programmable advanced power electronic system that is fed into the electrodes. A brief description of the Power Electronics System is given below.

4. POWER ELECTRONICS AND CONTROLS

The power electronics system comprises of an AC to DC converter and a universal programmable matrix converter which; feeds to the electrodes reaction cells Figure 1.

Modern closed loop control techniques are used to deliver the required power levels at the right conditions to initiate chemical reactions. These include electro-coagulation, -flocculation, -flotation, advanced oxidation (radical production) and electric field effects. These processes may occur concurrently under controlled conditions. The combination of modern control, advanced instrumentation and novel electrode design using emerging materials offers a viable alternative treatment method to existing chemical and biological wastewater treatment methods.

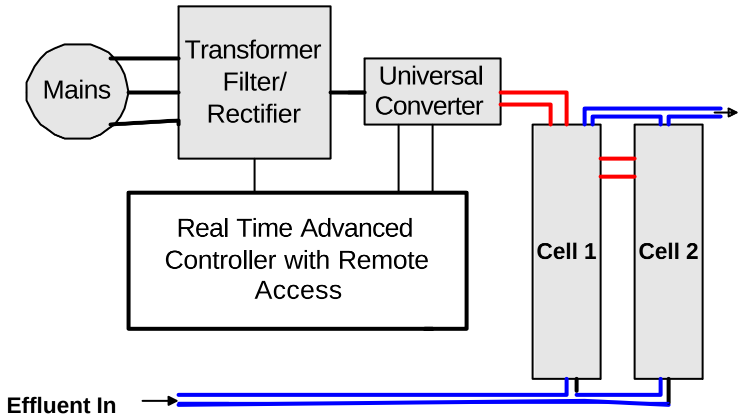

Fig. 1: System block diagram

5. PRACTICAL RESULTS

The versatility of electro-chemical treatment is presented by the following results obtained from across a wide industrial sector using a trial rig capable of treating 5000 litres/hour Tables 1-7.

Table 1: Engineering waste

Parameter	Raw	Treated	% Removal
Oil and Grease (mg/l)	925	38.1	96
Total Suspended Solids (mg/l)	884	60	93
COD (mg/l)	5100	759	85
Lead (mg/l)	27.7	0.09	99
Copper (mg/l)	39.8	0.24	99
Nickel (mg/l)	17.3	0.10	99
Zinc (mg/l)	17.3	0.004	99
Cadmium (µg/l)	10.5	0.26	97

Table 2: Water and wastewater disinfections

Rinse waters			
Parameter	**Raw**	**Treated**	**% Removal**
37 ^{0}C 1 Day plate count (cfu/ml)	$7.9x10^{6}$	4	99
22 ^{0}C 1 Day plate count (cfu/ml)	$2.7x10^{3}$	5	99
Faecal Coliforms (cfu/100ml)	490	0	99
Pseudomonas spp (cfu/100ml)	88	0	99
Engineering Coolant oil			
37 ^{0}C 1 Day plate count (cfu/ml)	$5.4x10^{6}$	1	99
22 ^{0}C 1 Day plate count (cfu/ml)	$7.3x10^{6}$	5	99

Table 3: Phosphate removal (mg/l) from waste water & rivers

Parameter	Raw	Treated	% Treatment
Sample 1	6.5	0.94	86
Sample 2	6.8	0.70	90
Sample 3	1.65	0.09	95
Sample 4	5.4	0.20	96

Table 4: Pulp and paper

Parameter	Raw	Treated	% Treatment
COD mg/L	2,559	605	78
TSS mg/L	1,265	60	94
PVOH mg/l	360	1	99
BOD mg/l	78	9	88
Phosphate mg/l	5	0.9	82

Table 5: Drinking water treatment

Parameter	Raw	Treated	% Removal
Colour (Hazen)	35	2	86
Turbidity (TFU)	15	1.7	90
Iron (mg/l)	1.65	0.03	95
Manganese (mg/l)	5.4	0.2	96

Table 6: Waste disposal

Parameter	Raw	Treated	% Treatment
PCB 028 (µg/l)	3.51	0.038	99
PCB 052 (µg/l)	1.17	<0.008	93
PCB 101 (µg/l)	0.573	<0.005	99
PCB 118 (µg/l)	0.482	<0.005	99
PCB 138 (µg/l)	0.562	<0.005	99
PCB 153 (µg/l)	0.472	<0.005	99
PCB 180 (µg/l)	0.392	<0.005	99

Table 7: Cosmetics industry

Parameter	Raw	Treated	% Removal
COD (mg/l)	16700	1050	94
TSS (mg/l)	5540	<10	99
Oil & Grease (mg/l)	2360	<10	99
Anionic surfactant (mg/l)	350	5	99

6. CONCLUSIONS

Electro-chemical water treatment employing advanced power electronics and instrumentation offers an economically viable alternative process to conventional chemical and biological treatment systems. Opportunities also exist for combining electro-chemistry with conventional treatment methods for water and waste streams that are currently difficult to treat. Such wastes include heavy metals, recalcitrant organics and colours.

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