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Chemical Bases and Regimes of Micro-Arc Wastewater Treatment

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Abstract. The capabilities of various groups water treatment technologies analyzed using the coke plant wastewater example. Emphasis is placed on the electrochemical technologies extensive potential for removing organic and inorganic contaminants. The prospects of using a micro-arc discharge in a packed-bed electrode medium for this purpose is shown. A interconnected physicochemical processes model occurring during micro-arc wastewater treatment is constructed, including plasma-, electro-, photo-, and thermochemical processes, secondary reactions, and adsorption. The secondary processes predominant role in wastewater treatment is substantiated. These processes are initiated by the active agents supply – radicals, molecular products, ions, and electrons – from the micro-discharge channel into the solution, which, in contrast to the micro-arcs, creates a volume-distributed rather than a point-distributed effect. Possible chemical transformation equations that may contribute to the coke plant effluent purification by this method are provided. It is noted that a micro-arc discharge on an aluminum or coke bed electrode disperses the it material, forming an active suspension of amorphous particles. It was found that the Fe or Al dispersing produces a hydroxide-based ion-exchange coagulant, while the coke use yields a fine carbon sorbent; the coagulant enables the heavy metal ions removal, and the sorbent targets organic impurities. It is shown that the ratio between the overall purification mechanism components can be controlled by selecting the type and characteristics of the applied voltage, as well as the type and formation features of the bed electrode. Electrical power input modes for the micro-arc reactor are determined, defining the removing various pollutants efficiency in the different types bed electrodes presence.

1 Introduction

Industrial development is accompanied by the generation of complex, multicomponent wastewater systems. These effluents must be treated either to protect natural water bodies or to prepare water for recirculating water supply various stages. Even during treatment facilities normal operation, there is an environmental pollution risk in the event of emergency releases or synergistic effects, which requires further loads pollution reduction from industrial and municipal enterprises [1, 2]. The most contaminated such systems include effluents from coke-chemical, metallurgical, and electroplating industries, which contain both organic and inorganic pollutants, including heavy metal ions and benzo(a)pyrene. Traditional water treatment technologies employ sedimentation, chemical coagulation, filtration, sorption, and biological degradation; however, these methods have technological drawbacks and specific limitations. These may include large footprints, high energy consumption, removable substances narrow range, insufficient removal degree, and water secondary contamination with new impurities. For instance, standard technologies remove heavy metals while simultaneously increasing the water's salinity. Modern industrial water final treatment at factory biological plants requires thorough many compounds pre-removal that adversely affect the specific microorganisms vital activity, such as phenols, thiocyanates, resins, oils, benzo(a)pyrene, etc. The removal of phenols, thiocyanates, and ammonium nitrogen often involves the use different microbial strains, which significantly increases the treatment facilities overall scale. Therefore, there is a need for both effective pre-treatment and effluents tertiary treatment.

is consumed in carbon electrodes oxidation. Due to the microarc localized nature, uniform treatment cannot be achieved solely within discharge channels. Instead, microarc act as sources of reactive species (radicals, molecular products, ions, electrons), which propagate into the bulk liquid and sustain secondary oxidation processes. Based on the transformation of wastewater components, the following mechanisms are proposed: phenols are removed through a combination of microdischarge decomposition, adsorption on dispersed carbon particles, and subsequent oxidation; thiocyanates are primarily degraded via radical and chlorine-mediated oxidation pathways; chlorine participates in cyclic oxidation processes without net consumption; ammonium nitrogen is both partially decomposed and formed during thiocyanate degradation. Dispersion of Fe or Al electrodes leads to the formation of amorphous nanoparticles and hydroxide-based coagulants with ion-exchange properties, enabling heavy metal ions efficient removal. The different mechanisms relative contribution can be controlled by selecting the electrical power supply type and the bed electrode material properties. Optimal electrical regimes for power input into the micro-arc reactor have been determined. The organic compounds removal is most effective at a specific power input of approximately 2, while for thiocyanates it is 2.6–2.9 $W \cdot cm^{-3}$. Under these conditions, removal efficiencies reach up to 97 % for thiocyanates and 99% for phenols, with an energy consumption of about 20 $kWh \cdot m^{-3}$ and a treatment capacity of 0.15 $m^3 \cdot h^{-1}$. Overall, the study demonstrates that microarc discharge treatment in bed electrodes is a highly efficient and controllable method for complex wastewater purification, combining oxidation, adsorption, catalysis, and coagulation within one technologically simple process.

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