

Sustainable Treatment Of Automobile Wash Wastewater Using Electrocoagulation Integrated With Waste-Derived Fly Ash Cenosphere Electrode Material

Mr. Anurag Chandravanshi, Dr. Ravi Kumar

Research Scholar, Associate Professor, Department Of Mechanical Engineering, Ramchandra Chandravansi University

Abstract

Water pollution from automobile wash effluents poses significant environmental challenges due to the presence of oils, grease, suspended solids, heavy metals, and high chemical oxygen demand (COD). This study investigates an efficient, low-cost, and sustainable treatment method using electrocoagulation (ECT) integrated with surface-modified fly ash cenosphere (FAC) as a novel electrode material. A continuous-mode electrocoagulation reactor (ECR) was developed and operated under varying conditions of current density (20–35 A/m²) and flow rate (50–150 mL/min) to evaluate treatment performance. The modified Ceno-TiO₂/Al electrode demonstrated superior efficiency compared to conventional aluminum electrodes, achieving up to 94% COD removal at an optimal current density of 25 A/m² and a hydraulic retention time of 48 minutes. The study also highlights the enhanced performance of chitosan-coated cenosphere particles (CCP), which improved adsorption capacity, reduced sedimentation time to 20 minutes, and achieved maximum COD removal efficiencies of up to 97.6% when integrated with Cu–Al electrodes. Increasing current density improved pollutant removal, while higher flow rates negatively affected treatment efficiency due to reduced contact time. Additionally, the modified electrode system produced significantly less sludge compared to traditional electrodes. The findings demonstrate that incorporating waste-derived materials such as fly ash cenospheres in electrocoagulation systems offers an environmentally sustainable and economically viable solution for treating automobile wash wastewater, with strong potential for reuse applications in industrial and domestic sectors.

Keywords: chemical oxygen demand (COD), electrocoagulation (ECT), fly ash cenosphere (FAC), chitosan-coated cenosphere particles (CCP).

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I. Introduction

Water pollution caused by industrial and vehicular activities has become a pressing environmental concern worldwide. Among various sources, automobile wash water effluent contains significant pollutants such as oils, greases, suspended solids, and organic contaminants, which pose threats to aquatic life and human health. The present study investigates an innovative, cost-effective, and environmentally sustainable approach for treating automobile wash water effluent by employing electrocoagulation (ECT) integrated with surface-modified fly ash cenosphere (FAC) as a novel electrode material. For both living and non-living things on Earth, water is a necessary component. Wastewater is produced as a result of the country's significant industrial expansion and development, which also increases water consumption. Developing nations have demonstrated a strong interest in wastewater recycling throughout the past ten years. Water demand is decreased by using the treated wastewater for a variety of uses. Effective wastewater treatment should be easy to use, affordable, and capable of producing high-quality treated water. It may be used for a variety of purposes, depending on the condition of the treated water. Another important resource is the enhanced quality that results from treated water. The treated wastewater is used for a number of environmental uses, including boiler feed, vehicle washing, flushing the toilet, cooling for power plants, landscape irrigation, and air conditioner chillers.

Freshwater consumption is decreased by recycling and reusing treated water. Additionally, by using waste materials to treat wastewater in an economical manner, the need for water is mostly satisfied. By lessening the influence on the environment, recycling waste materials for a variety of environmental uses created a sustainable environment.

India needs a large number of cars for transportation due to its ongoing population increase, economic expansion, and urbanization. The expansion of the car sector has boosted India's economy. In 2014–2015, an estimated 23.37 million automobiles were produced annually (Mahajan & Husain, 2016). India ranks fourth globally in terms of car sales. Additionally, India's automotive sector ranked sixth in the world for producing

commercial vehicles in 2017. The car industry's steady expansion might propel it to the top of the global market by 2020 (IBEF, 2015).

Tamil Nadu, a state in southern India, is referred to as the "Detroit of India" due to its massive manufacture of vehicles and their parts. The cumulative use of cars in Tamil Nadu is evidence of this. The number of auto repair shops is increased by this massive automobile production. Both private and public vehicles require routine maintenance. As a result, a sizable number of vehicle repair shops were built. In addition to producing a significant amount of wash water effluent, these service facilities used a lot of water to clean cars. Oil and grease, as well as chemical oxygen demand (COD), cleaning products, dust, and heavy metals are all included in this released effluent (Rubí et al. 2009).

For their various procedures, the car repair shops used a lot of fresh water, which turned out to be unclean and perhaps harmful wastewater. A car needs about 200 liters of water to clean. Each person's annual water use per automobile is between 0.33 and 1.24 m³. The amount of wastewater produced at service stations might differ depending on a number of variables, including the kind of vehicle, its condition, the washing technique, and the person performing the cleaning (Phipps et al. 2013).

Total suspended sediments, dissolved solids in general, oil and grease, chemical and biological oxygen demands, detergents, and heavy metals are all present in the car wash water effluent. An automotive servicing station's wastewater contributes to environmental contamination. The direct discharge of wash water effluent from vehicle repair shops has a negative impact on the land and aquatic habitat. Therefore, a preliminary treatment was needed to lower the concentration of dangerous pollutants in the discharge effluent. Coagulation-flocculation, adsorption, chemical precipitation, and electrocoagulation were among the physico-chemical treatment techniques used. The contamination may be removed using the coagulation treatment procedure. The removal of contaminants from car wash water effluent was investigated using chemical coagulation using several coagulants, including calcium chloride, ferrous sulfate, alum, and a mixture of alum and bentonite. In this case, a greater quantity of chemical coagulants resulted in a significant proportion of contamination clearance. Additionally, it requires a very lengthy retention and sedimentation period and causes an undesirable change in its constituents.

The present study investigates the efficacy of electrocoagulation (ECT) utilizing modified fly ash cenosphere as an eco-friendly and cost-effective electrode material for treating wastewater generated from automobile wash processes. The research encompasses the characterization and modification of fly ash cenosphere waste from thermal power plants, development of novel electrode configurations, and evaluation of operational parameters such as current density, electrode spacing, pH, and flow rate in both batch and continuous electrocoagulation systems. The study aims to optimize treatment conditions to maximize removal efficiency of pollutants such as COD, suspended solids, oils, grease, and metals, thereby advancing sustainable wastewater management practices. The incorporation of waste materials aligns with environmental conservation goals and highlights the potential for cost-effective solutions in small-scale industrial settings.

Several treatment methods have been used to the car wash water effluent. An integrated electrocoagulation system effectively treated the industrial effluents. Significant attention was needed due to the electrocoagulation's high current density consumption and electrolysis duration. A proposal has been made in this study to use the electrocoagulation method (ECT) to treat the car wash water effluent. Fly ash cenosphere, a waste product of thermal power plants, was adapted and used to cleanse the effluent from car washes. Analysis was done on the effectiveness of the electrocoagulation procedure with cenosphere in treating car wash water effluent.

II. Experimental Details

Through continuous mode electrocoagulation studies, the viability of the Ceno-TiO₂/Al anode electrode for the process of treatment of car wash wastewater was determined. Figure 1 shows the design and use of the lab-scale continuously electrocoagulation reactor. The circular reactor's upflow allowed for smooth operation and consistent flow distribution. The constant upward flow in an ECR that encourages the creation of H₂ gas. Additionally, the gas is dispersed uniformly. This kind of flow is preferred when employing electroflotation to remove flocs. Overflow continually removes the generated muck. The reactor's bottom was where the denser sludge collected (Merzouk et al. 2011). The Ceno-TiO₂/Al anode electrode's performance in the continuous investigation was assessed by changing the flow rate and current density, two important operational parameters. The COD measurement was used to gauge the electrode's therapy effectiveness.



Figure 1 Experimental set-up of Continuous electrocoagulation

III. Results And Discussion

In ECR, current density is thought to be the most crucial operating parameter for regulating the electrochemical process and reaction rate. Al-Al and Ceno-TiO₂/Al-Al electrodes were used in the ongoing investigation of electrocoagulation at wastewater's natural pH of 6.5. The wastewater's pH is quite close to neutral, thus there is no need to adjust it, according to the electrocoagulation batch study's findings. The impact of current density on COD elimination was assessed between 20 and 35 A/m². The continuous investigation was conducted at a hydraulic retention time of 48 minutes with a constant flow rate of 50 mL/min.

Figure 2 shows the COD elimination % using Al and Ceno-TiO₂/Al as a function of the different current densities and electrolysis times. As the current density increased, the residual COD content dropped.

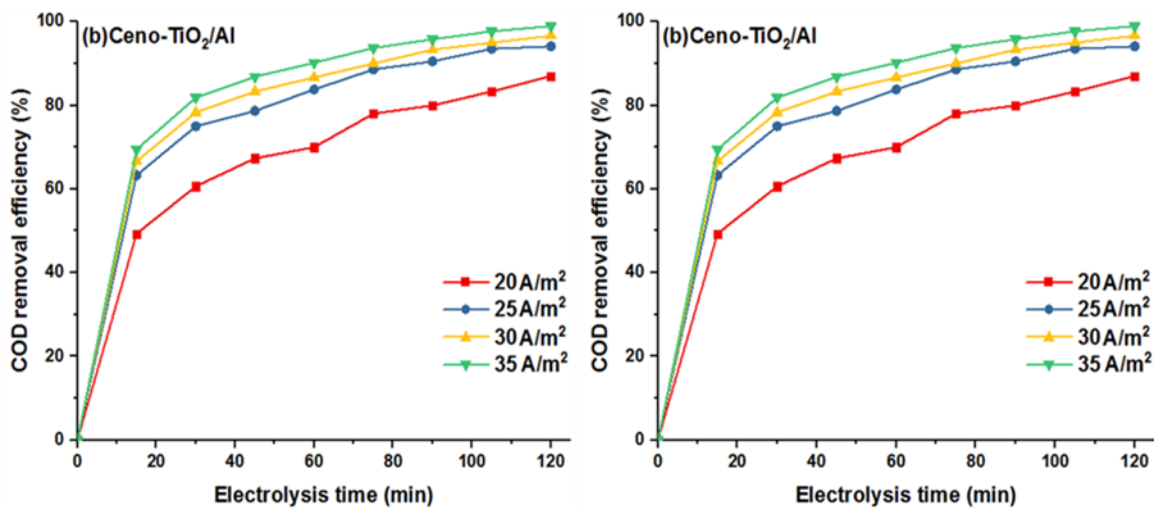


Figure 2 Performance of the electrodes with current density

As the applied current density in ECR grew, so did the generation of ions (coagulation agent) from the anode and cathode. This suggested that the formation of the metal hydroxide complex in ECR may control the removal of COD from the car wash water effluent (Kobyas et al. 2014). Al electrodes eliminated 35.2% to 72.11% of COD at an electricity density of 20 A/m², while Ceno-TiO₂/Al electrodes removed 49.3% to 87.24% of COD when used as an anode. Following a 120-minute trial, these electrode removal percentages were determined.

For the continuous form of electrocoagulation therapy, the hydraulic retention time is crucial. The impact of the flow rate in ECR was examined in order to control the amount of time needed for the treatment. The hydraulic retention period of the reactor is negatively correlated with the influent input rate in ECR. The ECR's dynamic flow rate can either boost or reduce the effectiveness of removing contaminants. Al-Al and Ceno-TiO₂/Al-Al electrodes were therefore used to examine the impact of the flow rate in ECR. Three distinct rising flow rates—50 mL/min, 100 mL/min, and 150 mL/min—were used in the the continuous mode of the experiment.

As a result, the hydraulic retention period was progressively shortened to 48, 24, and 16 minutes, respectively. Figure 3 illustrates both the electrodes' elimination of contaminants and the effects of flow rate as a function of current density.

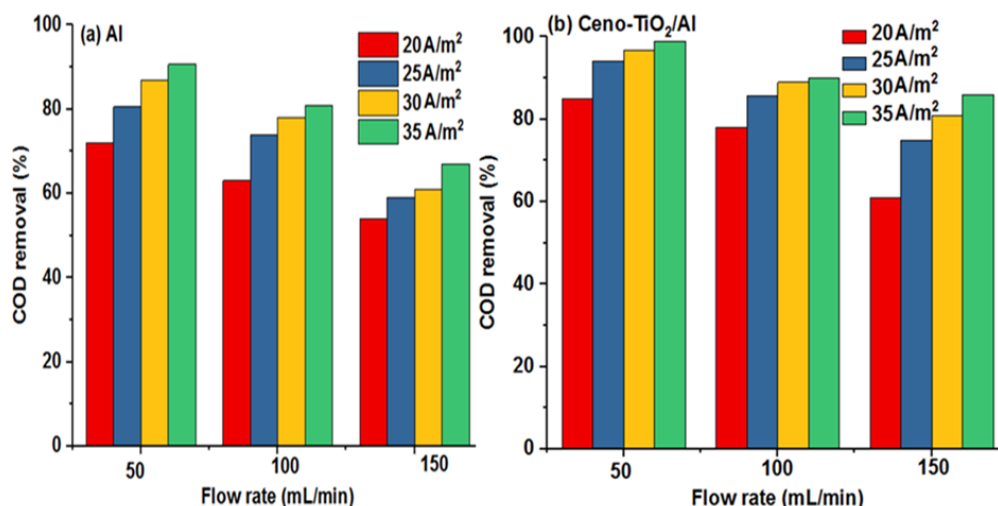


Figure 3 Performance of the electrode with the flow rate

The electrodes' ability to remove contaminants is reduced when the flow rate is increased from 50 mL/min to 150 mL/min. Additionally, at 25 A/m², the COD removal percentage dropped from 80% to 59% using Al electrodes and from 94% to 75% using the Ceno-TiO₂/Al electrode. The reduced flow rate of 50 mL/min made it possible to create the coagulants by appropriate mixing, which eliminated the impurities from wastewater. The Ceno-TiO₂/Al electrode outperformed the Al electrode, as seen in Figure 4. It appears that the ECR's flow rate has an impact on the electrocoagulation treatment's efficacy. Rapid mixing caused by the greater flow rates in ECR also shortened the retention time (electrolysis time), which decreased both the reaction rate and the electrodes' ability to remove contaminants. Because of the quick mixing that results in the destabilization of the produced flocs, the increased flow rate decreases the contact between the particles. The contamination removal effectiveness was directly correlated with the ECR's electrolysis time, in line with the findings of the batch experiment. With a high HRT of 48 minutes, the maximal removal was achieved. The findings of the batch investigation indicate that 40 minutes is the minimum electrolysis time needed to lower the electrodes' substantial proportion of COD in ECT.

Figure 4 displays the functionality of CMC, PMC, and CCP as a function of contact time. This study showed that the percentage of PMC and CCP contaminants removed rises as reaction time increases. Simultaneously, CCP reduced reaction time while achieving greater elimination. After 40 minutes of PMC and CCP reaction time, the quick decrease was achieved. The cenosphere covered with chitosan reacts more quickly than the cenosphere coated with NaOH. Due to the restabilization of colloids in wastewater, the extended mixing period of CMC raises the percentage of contaminants removed up to 50 minutes before beginning to decline. The surface roughness of FAC-NaOH is increased.

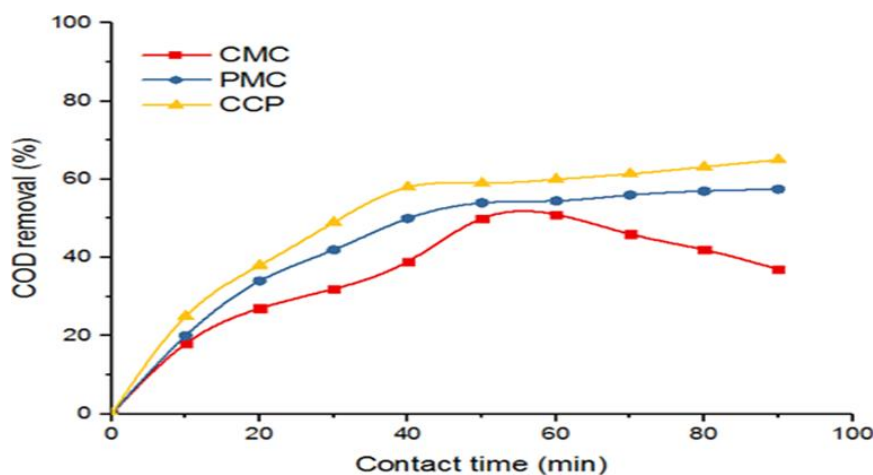


Figure 4. Influence of contact time

The Al-O and Si-O bonds in FAC are broken by the hydrothermal reaction that occurs of CMC, which increases the surface's adsorption sites and improves the effectiveness of pollutant removal (Gao et al. 2016).

The functional amino group in PMC and CCP both agglomerates and adsorbs the oil particles in wastewater. The pollutants are constantly filling the active outermost layer of the enhanced cenosphere samples because of the ongoing adsorption process. Additionally, by extending the contact period, the changed sample and COD-producing material interacted more. Due to insufficient active adsorption surface, the modified cenosphere samples' contamination removal efficacy begins to decline beyond the optimal contact time (Ramavandi & Farjadfard 2014).

The two key elements influencing the coagulation rate are particle velocity and collision efficiency. Figure 5 shows the impact of the changed cenosphere samples' sedimentation time. It is evident that the CCP sedimentation process took significantly less time than that of the CMC and PMC. While CMC and PMC took about 50 minutes to settle, the adsorbed CCP settled in 20 minutes. It takes a long time for CMC and PMC to fully sediment. The density of the two modified cenosphere samples, CMC and PMC, was lower than that of CCP because they were taken from the original cenosphere. Additionally, CMC and PMC have slower floc generation rates than CCP. CCP carried out the combined PMC and CMC contamination removal processes. The CCP is made by pelletizing MMC particles with chitosan polymer and cross-linking them with NaOH. This improves the quick removal of impurities from the car wash water effluent. Because of their larger pores, the pore-filled and mesoporous surfaces of the CCP readily absorb pollutants, making it more practical to collect them (Siyal et al. 2020). As a result, the CCP eliminated over 58% of COD from wash water discharge after 20 minutes of sedimentation, whereas CMC and PMC needed roughly 50 minutes to settle and achieve a comparable level of contamination removal.

The sedimentation duration affects the coagulation rate and raises the percentage of contaminant removal at a certain point, beyond which it stays constant (Liu et al. 2005).

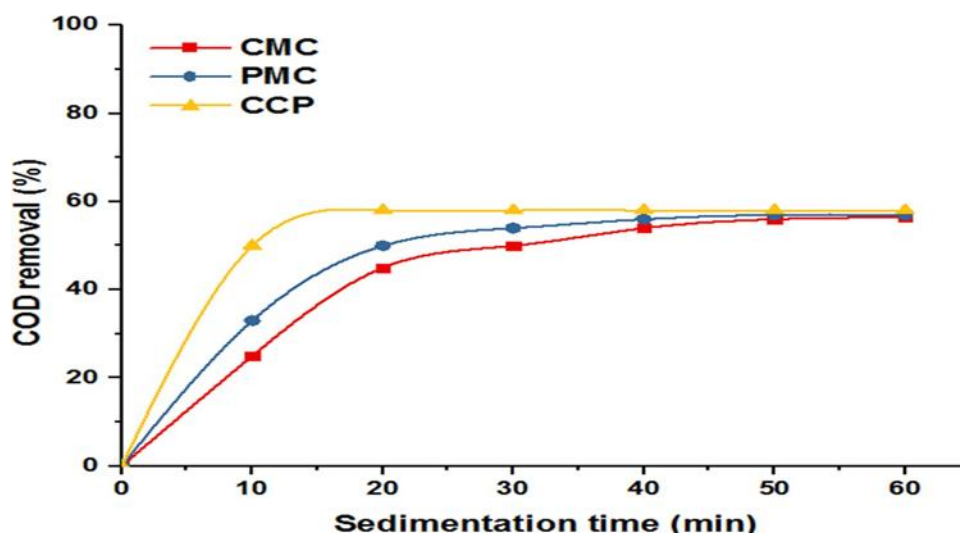


Figure 5. Influence of sedimentation time

IV. Conclusion

- As the current density increased, the residual COD content dropped. Al and Ceno- TiO₂/Al electrodes removed about 72.11% and 87.24% of COD at 20 A/m² and 48 minutes of hydraulic retention time, respectively. About 94.14% of COD was eliminated at 25 A/m², whereas the Al electrode produced comparable results (90%) at 35 A/m². Additionally, the Al electrode produces more than 50% more sludge in ECR than the Ceno-TiO₂/Al electrode. The batch investigation demonstrated the effectiveness of the Ceno-TiO₂/Al anode electrode.
- The electrodes' ability to remove contaminants was reduced when the flow rate was increased from 50 mL/min to 150 mL/min. Additionally, at 25 A/m², the COD removal percentage dropped from 80% to 59% using Al electrodes and from 94% to 75% using the Ceno- TiO₂/Al electrode. By creating the coagulants by appropriate mixing, the decreased flow rate of 50 mL/min eliminated the pollutants from wastewater.
- The CCP was shown to be an efficient modified environmental sample for electrocoagulation treatment of car wash water effluent. The CCP's general characteristics were observed.
- When CCP was used in ECR at a current density of 25 A/m² utilizing Cu-Al and Al-Al electrodes, about 95% and 81% of COD were eliminated within 30 minutes of reaction time, respectively. These outcomes were contrasted with the Cu-Al and Al-Al electrodes used for batch coagulation processes in stage I. As a result,

during optimal electrolysis times of 40 and 50 minutes, respectively, Cu-Al and Al-Al electrodes eliminated 91% and 87% of COD.

- For Cu-Al electrodes, the current density was lowered by 40% and the reaction time needed for the maximum elimination was lowered by 25%. Similarly, using Al-Al electrodes with CCP decreased the response time by 40% and the current density by 17%. With Cu-Al and Al-Al electrodes at current densities of 25 A/m² and 30 A/m², respectively, the inclusion of CCP in ECR only needed a minimal current density to reach the maximum COD elimination percentage of around 97.6% and 93.5%. At an optimal current density of 25 A/m² and 30 A/m², respectively, the batch experimental investigation achieved 91.6% and 90% COD elimination using Cu-Al and Al-Al electrodes.
- The ECR's treatment efficiency was improved by adding waste material to the ECR. Automotive wash water effluent may be treated using the waste material from thermal power plants as a supportive electrolyte.

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