

# **FEASIBILITY OF REMOVING NANOPARTICLES FROM WATER USING ACTIVATED CARBON- BASED ADSORPTIVE FILTER**

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by

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# CERTIFICATE

This is to certify that the thesis entitled “**Feasibility of Removing Nanoparticles from Water using Activated Carbon-Based Adsorptive Filter**”, being submitted by **Ms. Tropita Piplai**, to the **Indian Institute of Technology Delhi**, for the award of ‘**Doctor of Philosophy**’ in Department of Civil Engineering is a record of the bonafide research work carried out by her under our supervision and guidance. She has fulfilled the requirements for the submission of this thesis, which to the best of our knowledge has reached the requisite standard.

The material contained in the thesis has not been submitted in part or full to any other University or Institute for the award of any other degree or diploma.

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# ABSTRACT

Nanoparticles (NP) are growing to be a major concern in today's world. Due to their ubiquitous presence, their removal from the environment is a necessity at present.

The objective of this study was to study the removal of nanoparticles using activated carbon by batch and column studies. Adsorption of nanoparticles (ZnO, CuO and their mixture) onto Activated Carbon (AC) were studied using batch and column techniques to investigate the feasibility of the removal of nanoparticles from water. The main sub-objectives were the removal of single and mixture of selected nanoparticles by Activated Carbon in batch studies and Activated Carbon filter bed in column studies and transport modelling of nanoparticles in the activated carbon column bed.

In batch studies, the influence of contact time, pH (5,6,7,8 and 9) and adsorbent dose (0.01, 0.1, 1, 10 and 100 g/L) on the removal process were studied. Results revealed that, overall adsorption capacities of AC for Zn (from ZnO nanoparticles) in deionized water was  $0.9 \pm 0.028$  mg/g (91.3% removal) and wastewater was  $0.6 \pm 0.038$  mg/g (78% removal) at pH 8 and for Cu (from CuO nanoparticles) in deionized water was  $0.95 \pm 0.036$  mg/g (95.6% removal) and wastewater was  $0.75 \pm 0.078$  mg/g (83% removal) at pH 6 respectively in a single solution. In a mixture colloidal solution of ZnO and CuO nanoparticles at optimum conditions, overall adsorption capacities of AC for Zn in deionized water was  $0.71 \pm 0.051$  mg/g (74.7% removal) and wastewater was  $0.576 \pm 0.019$  mg/g (69% removal) and for Cu in deionized water was  $0.82 \pm 0.017$  mg/g (81.2% removal) and wastewater was  $0.6 \pm 0.032$  mg/g (71.5 % removal). Pseudo Second Order, Langmuir and Weber Morris Models co-related the best with the adsorbed data from experimental studies. The models indicated that the adsorption of the nanoparticles onto AC was favourable.

In column studies, the influence of contact time, NP dose (1, 10 and 100 mg/L) and flowrate (0.5, 1, 1.5 mL/min) on the removal process were studied. At nanoparticle concentration of 1 mg/L, for single suspension, for ZnO nanoparticles, the time-to-breakthrough was found to be 53, 55.5 and 49 hours and for CuO nanoparticles, it was found to be 49.5, 53, 47 hours for flowrates 0.5, 1, 1.5 mL/min respectively. Similarly, for binary suspensions, for ZnO nanoparticles, the time-to-breakthrough was found to be 48.5, 49 and 45.5 hours and for CuO nanoparticles, it was found to be 43, 48.5 and 43.5 hours for flowrates 0.5, 1, 1.5 mL/min respectively. Thus it was seen, that the breakthrough was reached faster for Cu than Zn. Column performance models were applied and the values supported the applicability of Thomas model for the removal of ZnO and CuO nanoparticles. The filtration parameters, such as attachment efficiency ( $\alpha_{pc}$ ), NP deposition rate ( $k_d$ ) and filter coefficient ( $\lambda$ ) were also observed to be dependent on the variation in flowrate as well as NP concentration. The total % of Zn (single) leached was 66.3% and total % of Cu (single) leached was 63.2%. In binary suspension, the total % of Zn leached was 55.9% and total % of Cu leached was 48.6%. It was reported that Zn was leached more than Cu. Furthermore, qualitative characterization analysis was done through SEM, EDX, FTIR, XRD, DLS and Zero Charge for the confirmation of nanoparticle removal using activated carbon. This study provided a detailed analysis of the removal of ZnONPs and CuONPs and an insight on the removal capacity of activated carbon for the removal of these nanoparticles from wastewater. Conclusions from this study would help to establish more treatment plants especially for the removal of nanoparticles from water.

**Keywords:** Nanoparticles, Activated Carbon, Adsorption, Filtration, Adsorptive filter bed, Leaching

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# NOMENCLATURE

|                      |                                                        |
|----------------------|--------------------------------------------------------|
| AAS                  | Atomic Absorption Spectrophotometer                    |
| AC                   | Activated Carbon                                       |
| Ag <sub>2</sub> ONPs | Silver oxide Nanoparticles                             |
| ANOVA                | Analysis of variance                                   |
| BET                  | Brunauer, Emmett and Teller Analysis                   |
| BOD                  | Biochemical Oxygen Demand                              |
| COD                  | Chemical Oxygen Demand                                 |
| CuONPs               | Copper oxide Nanoparticles                             |
| DI                   | Deionized Water                                        |
| DLS                  | Dynamic Light Scattering                               |
| DWTPs                | Drinking Water Treatment Plants                        |
| EDX                  | Energy-Dispersive X-Ray Spectroscopy                   |
| FTIR                 | Fourier Transform Infrared Spectroscopy                |
| HSD                  | Tukey's Honest Significant Difference Test             |
| NOM                  | Natural Organic Matter                                 |
| NP                   | Nanoparticle                                           |
| NP/AC                | Nanoparticle/Activated Carbon Concentration Ratio      |
| OECD                 | Organisation for Economic Co-operation and Development |
| pH <sub>0</sub>      | Initial pH                                             |
| pH <sub>f</sub>      | Final pH                                               |
| pHpzc                | Point of Zero Charge                                   |
| pK <sub>h</sub>      | Hydrolysis Constant                                    |
| SEM                  | Scanning Electron Microscopy                           |
| TDS                  | Total Dissolved Solids                                 |
| TEM                  | Transmission Electron Microscopy                       |
| TOC                  | Total Organic Carbon                                   |

|                      |                                              |
|----------------------|----------------------------------------------|
| TiO <sub>2</sub> NPs | Titanium oxide Nanoparticles                 |
| TSS                  | Total Suspended Solids                       |
| USEPA                | United State Environmental Protection Agency |
| WW                   | Wastewater                                   |
| WWTPs                | Wastewater Treatment Plants                  |
| XRD                  | X-Ray Diffraction                            |
| ZnONPs               | Zinc oxide Nanoparticles                     |