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# Nutrient Recovery and Recycling from Human Urine: A Circular Perspective on Sanitation and Food Security

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**Abstract**

Closed-loop nutrient cycling is a simple, persuasive and elegant approach to realize efficient natural resource management, improved human well-being and long-term food security. In the spirit of sustainable sanitation through nutrient cycling, this study proposes a new pathway to realize resource recovery from anthropogenic waste fractions by the application of physico-chemical separation processes. Microwave Activated Carbon (MAC) prepared from coconut shells (agro-waste) were immobilized on etched glass bead supports and utilized within a continuous flow packed-bed column. Physical adsorption experiments were performed by passing human urine through the column to strip and recover more than 80% of the intrinsic urea. Backwashing of the column was performed to demonstrate the ease of urea-N desorption, reusability of MAC over multiple cycles and the reversible nature of the process. Further nutrient recovery was realized by dephosphatizing the column overflow with MgO to allow phosphate precipitation (>90%) as struvite. Sorption kinetics, behaviour and influence of process parameters were studied by testing the experimental data against Yoon-Nelson, Thomas and Adams-Bohart models. The column adsorption was also numerically optimized using Response Surface Methodology to determine the optimal parameters as: sorbate flow rate – 8.5 $L.h^{-1}$, urea concentration – 100%, support size – 1 cm and consequently, column capacity of 21.58 g. Nutrient recovery, concentration and recycling from diverted human urine can be seen as a synergistic and circular solution to the issues of sanitation, hygiene, water, and food security.


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*Keywords:* Column adsorption; Immobilization; Activated carbon; Optimization; Wastewater; Ecological sanitation.

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## 1. Introduction

The manifestations of rapid population growth, urbanization, improved standards of living and concurrent intensification of socio-economic activities on the overall environmental health are well-recognized and acknowledged today [1-4]. However, technological solutions that are aimed at addressing this deteriorating state of our life support systems fail to recognize the dynamic interconnectedness between its various aspects such as, food security, hygiene, water scarcity, sanitation, resource conservation, waste management, etc. and fall short of satisfying the imperative of sustainable development. Moreover, in various instances, despite conceptual realization, the implemented solutions to overcome our issues do not achieve systemic synergy; conventional models have failed to demonstrate sustainability in their operation [5] and hence, the search for holistic solutions that simultaneously address several thematic concerns continue.

The water, sanitation and hygiene nexus in the developing world offers a promising platform to develop and implement sustainability-centric solutions. Further integration can be achieved within this nexus by looking at it through the lens of sustainable agriculture. The notion of closed-loop fertility cycle claims to provide a simple, persuasive and elegant approach to realize efficient natural resource management, improved human well-being, and long term food security [5,6,7]. It entails the use of urine diversion toilets that provide not only access to sanitation but more importantly, segregation of human waste fractions at source [8]. Recent research effort has been focused on developing cost-efficient and implementable technologies to concentrate, recover and recycle nutrients from the waste fractions to shift towards a more circular way of resource management [9-13]. Given the variability in effectiveness of nutrient recovery demonstrated by these studies, it thus becomes necessary to investigate alternative resource recycling pathways.

Through previous batch investigations on urine and urea recovery therein, we have demonstrated that nutrient recovery can be attained by the application of agro-waste sourced activated carbon [14-18]. Specifically, *Cocos nucifera* shells were demonstrated as an effective adsorbent to recover more than 90% urea from human urine [15,18]. In the present study, to investigate the ease of implementability and scale-up of this process, we employ a continuous packed-bed column that treats a larger amount of influent urine using a predefined quantity of the adsorbent. Further, an initiative was undertaken to reduce the process energy requirements by minimizing the systems' adsorbent loading. To do this, immobilization procedures were performed on the prepared carbon using etched glass beads as the support. Immobilized column adsorption is well suited for non-destructive resource recovery, is resistant to chemical toxicity and has been shown to enhance sorption selectivity and effectiveness [19]. Hence, the objectives of this study are to (i) examine the urea and phosphate removal efficiency using a continuous, immobilized packed-bed column; (ii) analyze the effect of various process parameters, viz., initial concentration, flow rate and size of sorbent support on the removal efficiency (iii) model the column breakthrough and sorption kinetics (iv) optimize the process parameters by using Response Surface Methodology (RSM).

## 2. Experimental

### *2.1. Sorption raw materials and setup*

Human urine was obtained from 40 healthy male volunteers (aged 18-21) for a period of 45 days. The samples were collected in polypropylene containers and stored at -20°C to inhibit $NH_3$ volatilization. Before use, the urine was thawed to room temperature (23±1°C), mixed and characterized; the initial urea and phosphate concentration were determined to be 18750 $mg.L^{-1}$ and 595 $mg.L^{-1}$, respectively. Microwave Activated Carbon (MAC) was prepared from waste *Cocos nucifera* shells and immobilized onto etched glass beads as described in earlier studies [14,15,18]. All reagents and chemicals (analytical grade) were purchased from Sigma Aldrich Chemicals, Mumbai India. The sorption experiments were performed in a Pyrex glass column (ϕ 4 cm and height 80 cm), randomly packed with immobilized MAC beads. The effect of the following process parameters on urea uptake capacity of MAC was investigated for sorbate flow rate (1-10 $L.h^{-1}$), initial urea concentration (20-100%), and size of MAC support (ϕ 1.5, 2 and 2.5 cm). Effluent urea concentration was measured at different time intervals by analysing 3 mL aliquots through UV-vis Spectrophotometry (Shimadzu UV-1601, Japan) at 430 nm [19]. Upon saturation of the column, the MAC was regenerated by pumping deionized water at 2 $L.h^{-1}$ in up-flow mode to recover the adsorbed