Nutrient Recovery from Wastewater Using Biochar and Zeolite

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ReNUWIt 2015, New Mexico State University

Introduction

As the world's population continues to grow, farmers will need to rely increasingly on fertilizer to replenish soil and produce enough food. Two major components in most fertilizers are nitrogen and phosphorus. Currently, the Haber-Bosch process is used to produce nitrogen for fertilizer but consumes more than 1% of world's total energy production (Kitano et al. 2012). Phosphorus is a nonrenewable resource that is quickly being mined to depletion (Neset and Cordell 2011). Fortunately, a large portion of the nitrogen and phosphorus used in fertilizers eventually become present in wastewater (Rittmann 2011). Recycling these components from wastewater to fertilizer would help complete the nutrient cycle and make agriculture more sustainable in the future.

In this experiment, we explored nutrient (nitrogen and phosphorus) recovery from wastewater using two adsorbents: biochar and zeolite. Biochar is a charred organic material and zeolite is an abundant mineral material. Both are already being explored as soil amendments and can make affective adsorbents. The biochar or zeolite can remove nutrients before or during the wastewater treatment process and then be applied directly to soils as slow-release fertilizer (Yao et al. 2013, Huang et al. 2014). This experiment examined the first half of the process: loading the adsorbents with nutrients from wastewater. The parameters tested included adsorbent dose, addition of a cation, and pH.

Procedure

Each experiment tested three different adsorbents: biochar, zeolite, and a 50/50 biochar/zeolite mixture by mass along with a control that had no adsorbent added. First, the correct amounts of biochar, zeolite, or biochar/zeolite mix were weighed and added into 50 mL plastic test tubes. Next, the correct amounts of sodium phosphate dibasic (NaH_2PO_4) and ammonium chloride (NH_4Cl) were added to DI water to create a stock solution of synthetic urine. Two different concentrations of synthetic urine were used in the experiment. The high concentration mimicked human urine while the low concentration mimicked the general wastewater stream. Each tube was filled with 40 mL of synthetic urine then all tubes were placed on the shaker for 24 hours. Next, each sample was centrifuged and filtered. Nitrogen was measured by an ammonia probe and phosphorus was measured using a HACH test kit. Nitrogen was measured immediately after filtration to minimize ammonia volatilization. The pH was also measured for some samples. All experiments were performed in duplicate.

Results

The first experiment varied the adsorbent dose and was repeated for both high and low nutrient concentrations in order to determine the optimal dose of adsorbent. The results showed that the removal was fairly linear so there was not an optimal dose. A low dose was chosen for future experiments, based on the adsorbent's removal per mass. The data also showed that the biochar was unable to remove any phosphorus, in fact, it was leeching phosphorus. This was not too surprising; previous experiments showed that biochar is a poor adsorbent until it is fixed with a cation (Yao et al. 2013).

The addition of a cation was explored in the second experiment. Magnesium chloride ($MgCl_2$) and magnesium sulfate ($MgSO_4$) were each tested. It seemed that magnesium chloride produced the best results, however results were still inconclusive and even contradicted some of the results obtained in experiment 1. The process was obviously not yet fully understood.

The third experiment varied the pH. Magnesium was added to all trials. It was determined that pH was the controlling factor in this process and was the piece that was missing in previous experiments. The results are displayed in Figure 1 below.

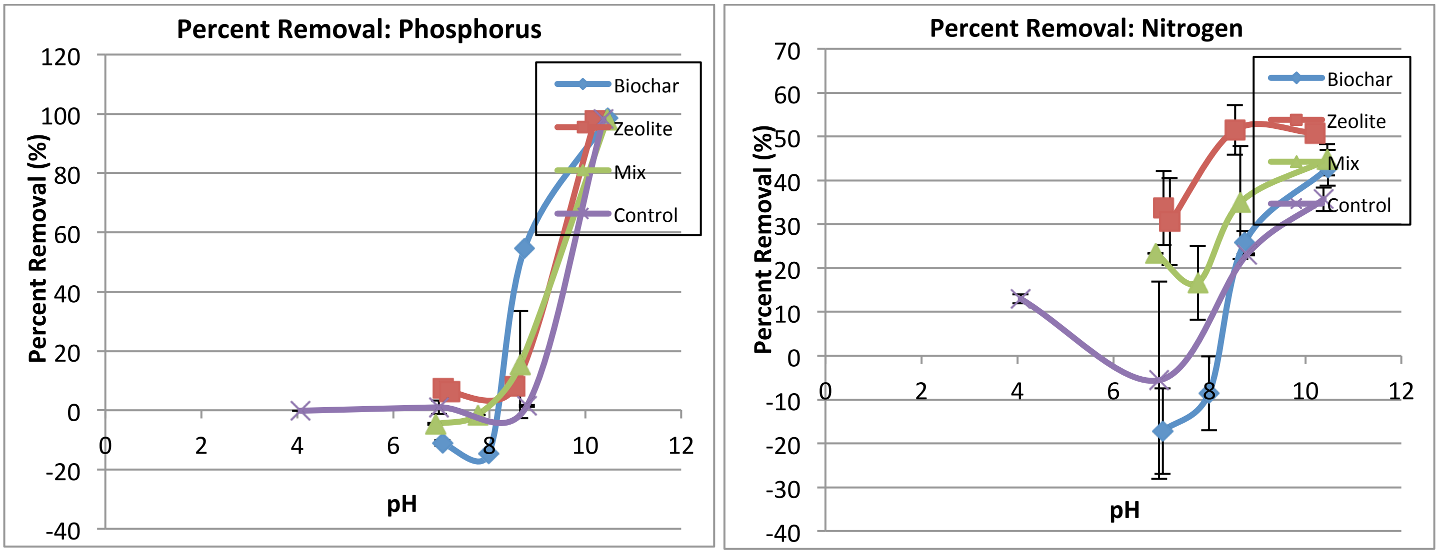

Figure 1. The effect of pH on adsorption rate

At neutral pH, even with the addition of magnesium, there was little removal. At an optimal pH of about 9-10 and the addition of magnesium, 98% of phosphorus was removed and about 50% of nitrogen was removed. This is consistent with the results of previous studies. Unfortunately, this was the last experiment that was run, so in order to better understand the process, the previous experiments should be re-run at the optimal pH. We hypothesize that some of the inconsistencies between results in experiments 1 and 2 were due to slight inconsistencies in pH that were neglected. Previous experiments were run at a neutral pH (around 6-8) where a large spike in adsorption rate occurs and pH is a significant factor in removal.

Conclusion and Future Work

The main conclusion that can be drawn from these experiments is that the adsorption process is controlled by pH. High removal (98% of phosphorus and 50% of nitrogen) can be achieved with an optimal pH of 9-10. Even at neutral pH, nutrient removal increases linearly with increase in adsorbent. Biochar and zeolite have similar removal rates, in general, and the mix of the two usually lies somewhere between them. The addition of magnesium seems to increase adsorption; however, some results were contradictory.

In order to finish this research, there are several other experiments that need to be run. First, experiments 1 and 2 (adsorbent dosage and addition of magnesium) should be repeated at pH 9-10. The higher pH obviously affects the nutrient adsorption and adsorbent properties so running all experiments at the optimal pH will give the best insight into the properties of the process. The rate of removal over time should also be determined. Overall, the process should be optimized. Additionally, researchers should explore how much this optimized process will cost, and if that cost can be offset by using the nutrients gained from removal. It is also important to consider where in the treatment train the process could be implemented and if it will cause other issues with downstream treatment processes. Finally, a completely separate experiment should be conducted that researches the release of nutrients into the soil after the loaded adsorbent has been applied.

Sources

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