Remediation of Per- and Polyfluoro-alkyl Substances in Landfill Leachate

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Background
Per-and polyfluoroalkyl substances, or PFAS, are a large and diverse group of over 4,730 organo-fluorine compounds, meaning fluorine are attached to carbon chains of varying lengths. These compounds have been manufactured and used for over 80 years for a variety of industrial applications and consumer products. Uses range from surfactants and water-resistant coatings to aqueous film-forming foams, such as fire extinguishers. These compounds have a half-life of over 90 years, meaning they break down slowly, and thus accumulate in water sources, soil, animals, and humans. As PFAS accumulate in the body, they can cause decreased fertility, adverse developmental effects in children, increased risk of cancers, and reduced vaccine response due to suppressed antibody activity. Consumer products containing PFAS are disposed of in landfills, where rainfall causes the PFAS molecules to leach into the runoff, which is collected as leachate.

Project Objectives
The College of Engineering at UGA and the Athens-Clarke County (ACC) Landfill have tasked us with designing a system to remove PFAS from the ACC Landfill leachate to adhere to drinking water regulations from the Environmental Protection Agency (EPA). Currently, the ACC Landfill, the leachate is recirculated back into the landfill, but this method carries the possibility of environmental contamination, should there be a leak in the landfill liners or leachate storage tanks. Additionally, regulations on PFAS in water are becoming stricter, meaning proper removal systems are necessary to keep the environment and community safe.

The design objective of this project was to design an on-site remediation system for the ACC landfill to remove 99% of PFAS from 3,000 gallons of leachate per day, which will reduce PFAS levels of treated leachate to proposed EPA standards. We considered the six PFAS of the highest concentration in the ACC Landfill leachate: 6:2 FCFA, PFHxS, PFBA, PFOA, PFOS, and PFHpA. These six PFAS account for 86% of the typical PFAS concentration profile in leachate from municipal solid waste facilities in the U.S. Therefore, the remediation design will be applicable and scalable for municipal solid waste landfills across the country.

Process Design
The process design consists of mixing an inorganic aluminum flocculant into a tank of collected leachate, which causes suspended solids in the leachate to form large flocs. A steeply-inclined settler removes the flocs which would otherwise interfere with the filtration step. Nanofiltration removes 99% of PFAS from 90% of the process volume, resulting in a concentrated PFAS stream which continues to an anion exchange unit. The anion exchange column uses resin to capture negatively charged PFAS molecules from the nanofiltration concentrate stream, effectively removing PFAS from the leachate. The spent resin from the column will be sent off-site for incineration.

Safety & Ethics
One critical safety consideration is the requirement for a high-pressure pump prior to nanofiltration. A typical centrifugal pump has a maximum system pressure of 10 bar, which we result in dangerous overpressure and pump failure. Secondary containment will be installed around pumps, as pumps are a common source of process failure. The key chemical hazard is the corrosive nature of the PAX flocculant utilized in the mixing unit, which requires rubberized steel to be used in mixer construction. Maintenance and labor operations present the final type of main hazard. The sludge hopper of the inclined settler will require emptying. Since landfill contents are unknown and variable, respirators should be worn during emptying.

To ensure our process is ethical, we adhered to the fundamental engineering principles during development. However, it is impossible to eliminate all ethical concerns. One ethical concern of our process is the emissions released from burning the single-use resins. Another is the potential for leakage of leachate contaminants into the environment. However, this is not a new issue for landfill operation, and secondary containment strategies, as well as environmental monitoring wells are employed to mitigate this concern. Additionally, we have two waste streams that will need to properly disposed of. The last ethical concern is the risk to workers, including contaminant exposure or injury. Therefore, we will want to make sure that there are proper safety guards and procedures in place.

Results
A working process simulation in SuperPro Designer was developed. The process is able to remove 99.2% of PFAS from 3000 gallons of leachate per day.

The total initial cost to implement the process is approximately $600,000. Including labor, maintenance, operation, and other fees, the total annual operating cost for the process is approximately $2M. With tipping costs at $55/ton and about 300 tons of trash dumped per day, the landfill is bringing in revenue streams of about $16M per year, which should be sufficient to cover the PFAS removal system since all other costs are less than $4M and they are consistently bring in this revenue and revenue from their other operations across the landfill. Furthermore, as of April 10th, 2023, the Bipartisan Infrastructure Law will provide $9 billion in funding to address emerging contaminants in drinking water, including PFAS. This indicates the relevance and economic feasibility of implementing our process.

Table 1: Initial and Final Mass Flow Rates

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial Mass Flow</th>
<th>Final Mass Flow</th>
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</thead>
<tbody>
<tr>
<td>Leachate</td>
<td>34098.00 kg/batch</td>
<td>3078.917 kg/batch</td>
</tr>
<tr>
<td>PFAS</td>
<td>0.00375 kg/batch</td>
<td>0.00003 kg/batch</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>34.7700 kg/batch</td>
<td>3.1293 kg/batch</td>
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