Where do landfills fit in the changing paradigm of circular economy- resource recovery and social aspects

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Introduction: Landfill leachate, which is the product of water percolating through waste deposits, necessitates effective treatment before releasing into environment. Although stringent regulations have been poised regarding management of leachate [1], the current paradigm that considers leachate as challenging waste has been proved to be a tremendous burden for landfill managers [2]. In terms of carbon and nitrogen loading, the practice to dump leachate in the influent of WWTP interferes with the sustainability of the leachate management approach because of the heavy metals affecting bio-processes involved. Again, Phosphorus which is one of the fast depleting nutrients [3], if not recovered, affects the eutrophic status of water-bodies. High carbon loading impedes the treatment efficacy, which makes leachate one the most complicated waste-streams [4]. Therefore, an integrated approach is necessary to treat high ammonia concentration as compared to low phosphorus in landfill leachate adapting shortcut pathways for nitrogen elimination, Anaerobic Ammonium Oxidation(Anammox) after recovery of nutrients. Also, low biodegradable content but high COD in leachate demands an additional treatment of the recalcitrant organic and toxic matters.

With landfills becoming overloaded or limited, there are constant efforts in place to minimize waste going to landfills. There is also a growing need to prevent food waste, recover useful products such as nutrients from food waste and recycle those back to soil system. This is circular economy. But the inherent risks associated with these approaches should be considered. There is a strong need to consider socio-economic incentives and risks associated with public health in the overall approach of circular economy. Therefore, the concept of resource recovery in landfill operations under economic and risk framework has been emphasized recently. Although, this changing paradigm of waste processing (i.e circular economy) has been well implemented in many municipal wastewater treatment facilities, its application in solid waste area has been very limited. One major challenge which preclude the application of source separation of municipal solid waste and its further use is people's perception. In order to move from a linear metabolism in solid waste handling where useful resources are wasted to a circular metabolism where useful resources are recovered, the inherent economic and environmental benefits and, the risks have to be identified. The appropriate technologies, protocols and government policies which ensure economic benefits and reduced risks should also be identified. The fate of contaminants need to be evaluated of emerging concerns during processes aimed at recovering useful resources out of organic waste. Furthermore, people's perception needs to be incorporated into technology development related to the processing of different types of source separated food wastes. Then, the results generated through lab and/or pilot scale testing need to be disseminated back to the people for better decision making and improved public perception about solid waste handling. People's perception about resource recovery from landfill leachate and the fate of pharmaceuticals and heavy metals during resource recovery processes will be studied in this research project. The results generated will be fed to a life cycle and economic analysis model. This research plan is built upon the present ongoing research on nitrogen and phosphorus recovery from landfill leachate followed by the treatment of leachate using innovative granular activated sludge process. In this study, complete P recovery has been demonstrated followed by efficient residual nitrogen and carbon removals from landfill leachate.

Materials and methods: The complete study has been divided into several phases. Phase1, which has already been established, included determining the optimal conditions for maximum recovery of nutrient, in terms of struvite (NH_4 $MgPO_4 \cdot 6H_2O$). Characterization of the recovered struvite to determine its fertilizer quality was determined through XRF and XRD. Phase 2, aimed at addressing high organic loading, therefore, a high rate lab-scale sequential granular activated sludge reactor was initiated with pre-cultured granules in the lab. Measurement of chemical parameters to evaluate its efficiency was performed on a daily basis. The high rate lab-scale sequential granular reactor was run with real leachate for 170 days. Leachate was analyzed from two different landfills in Utah. But, both leachate contained

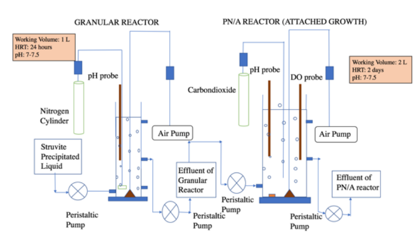

Figure 1: Treatment train

very low concentrations of biodegradable organics and as a result, the true potential of granular reactor could not be tested. Hence, to demonstrate the concept of the proposed treatment scheme, the path of synthetic leachate, prepared based on published recipes, was opted. Usage of synthetic leachate also eliminated the possibility of any toxic effect which the real leachate might have exhibited. Shift or increase in microbial population was assessed by PCR and qPCR and Live Dead BacLight was performed monthly to have a comparative analysis of living cells over dead cells at various phases with the passage of time. Treatment of residual ammonia nitrogen in liquid was initiated by establishing a single stage attached growth partial nitrification/anammox (PN/A) reactor. A treatment train was built where the struvite precipitated liquid was fed to the granular reactor followed by single stage PN/A reactor which is shown in Figure 1. Upon initiating the granular reactor fed with synthetic leachate, the single stage PN/A was directly fed with real leachate. A membrane bioreactor was also initiated to address the organic load of leachate whilst the initiation of granular reactor fed with synthetic leachate took place. Phase 3 will address the fate of antibiotics and hormones in both raw leachate and treated leachate after each unit's operation along with the fate of nanoparticles. Non-biodegradable recalcitrant organic matter which is the hackneyed problem in terms of treatment of leachate, will be addressed in this phase as well.

As each operational unit emerges to be fully functional and reaches their maximum efficiency, as in Phase 4, perception of mass people will be addressed while determining the pathway of contaminants. At this point, three anaerobic co-digesters will be set up to digest three types of food wastes with bio-solids to incorporate food wastage into circular economy. The reactors will be monitored in terms of volume and quality of methane gas produced, organic contents in the influent and effluent of reactors and pH. For households, a special survey sheet is designed with specific questions. These sheets will be filled up by community members. Before the initiation of this project, institutional board review approval for conducting such surveys will be sought. Eventually, the data from experimental plan and community survey will be used to conduct life and cost analysis.

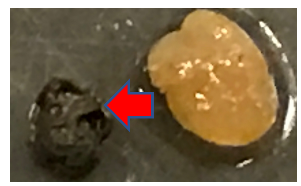

Figure 2: Change in color of granules

Results and discussion: Struvite precipitation of raw leachate was capable of 87% and 56% recovery of phosphorus and ammonia respectively. The first stage of experiment was carried out for 170 days which followed the treatment train presented in Figure 1. The granular reactor was capable of 60% removal of organics. But a reduction of size in granules was observed with change in granule color (Figure 2). When the reactor operation was shifted from feed with struvite precipitation from feed without struvite precipitation, at second stage, a reduction in organics removal percentages was observed with rapid change in color of granules. Switching the reactor operation mode from real leachate to synthetic leachate improved organics removal efficiency upto 88%. The ammonia removal in single stage PN/A increased when the reactor was fed with real leachate (Figure 3). The removal efficiency was limited to 50% when effluent from granular reactor was used.

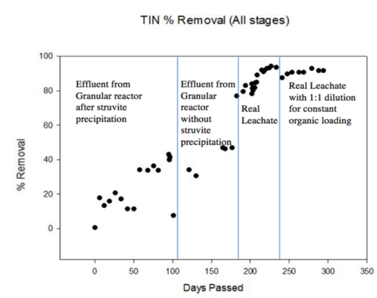

Figure 3: Effect of TIN in single stage PN/A at all the experimental

With the advancement of research, the microbial community analysis will be assessed using 16s rRNA metagenomics and ammonia monooxygenase (amoA) and hydrazine synthase (hzsA) gene sequencing and meta- transcriptomics analysis combined with tools such as fluorescent in situ hybridization (FISH) and T-RFLP analysis to understand the ecophysiology of key microorganisms. Elucidating diversity of Ammonia Oxidizing Bacteria(AOB) and Anammox will offer valuable insights into novel biochemical possibilities for innovative implementation in mainstream application. Determining the correlations between AOB and Anammox communities and various chemical parameters of wastewater will pave the way for energy efficient treatment approaches.

Conclusion: The concept of circular metabolism where resources recovered from waste streams are recycled back is not prevalent in solid waste industry due to; (1) lack of experimental data and, (2) people's perception about source separating food waste. The study will address both these aspects. Incorporation of landfill operations in the overall urban water cycle in a sustainable manner based on a concept of combined management of landfill leachate and municipal wastewater promotes a completely different perspective, minimizing the burden of solid waste management.

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