Technical Note:

Risks on PFAS Contamination related to engineered containment facilities: Challenges and Strategies

Abstract:
This comprehensive technical note critically examines the disposal of PFAS (Per- and Polyfluoroalkyl Substances) contaminated materials and soils in engineered containment facilities, emphasizing the inadequacies of conventional lining systems, specifically geomembrane and geosynthetic clay liners. As geosynthetic manufacturer with an international footprint, we underscore the need to highlight and understand PFAS loss mechanisms through lining systems and develop enhanced containment solutions. Drawing from extensive literature and technical references, this note highlights the pressing need to adopt innovative materials and strategies to curtail PFAS diffusion and prevent environmental contamination.

1. Introduction:

The recent concerns linked to Per- and Polyfluoroalkyl Substances (PFAS), due to their exceptional persistence, mobility, and potential health hazards, necessitate urgent action in addressing the challenges posed by PFAS-contaminated waste and soil disposal in containment facilities. While conventional geomembranes and geosynthetic clay liners have long served as primary containment solutions in the waste industry, the intricate relationship between PFAS and these barriers demands a revaluation of their effectiveness in the containment of these contaminants.

PFAS encompass a diverse group of human-made chemicals that have gained substantial attention due to their widespread presence in the environment and potential adverse impacts on human health. PFAS are characterized by the presence of fluorine-carbon bonds, which contribute to their unique properties such as water and grease resistance, making them prevalent in various industrial and consumer applications.

This group comprises thousands of individual compounds, including perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS) and Perfluorohexane sulfonic acid (PFHxS), which were among the most extensively used compounds. Their versatility has led to their incorporation in products like firefighting foams, non-stick cookware, water-repellent textiles, and food packaging. However, the chemical stability that imparts these useful properties also makes PFAS resistant to degradation in the environment.

The potential harm of PFAS to humans stems from their persistence, bioaccumulation, and toxicity. Due to their resistance to breaking down, PFAS can accumulate in the environment, in wildlife, and in human bodies over time. This process has raised concerns regarding potential side effects, including:

Health Impacts: Some PFAS compounds have been associated with adverse health effects such as developmental issues, reproductive problems, liver damage, immune system dysfunction, and even certain cancers. (1)

Bioaccumulation: PFAS can accumulate in the bodies of organisms higher up the food chain, which may lead to increased exposure for humans who consume contaminated food. (2)

Long Half-Lives: The half-lives of many PFAS compounds in the human body can be measured in years, resulting in prolonged exposure even after the cessation of exposure sources. (3) The longer the half-life expected, the more persistent this compound is in theory to degradation. Hence the current regulations in Australia and USA usually aim for thresholds for these compounds, namely PFOS, PFOA and PFHxS. (4)

Compound		**Half-life**
PFHxS	Perfluorohexane sulfonic acid	1,044 days
PFOA	Perfluorooctanoic acid	647 days
L-PFOS	Linear perfluorooctane sulfonic acid	1,063 days

The potential risks posed by PFAS have prompted regulatory actions and heightened research efforts to understand their behaviour, effects, and the best approaches to mitigate their presence in the environment and protect human health.

2. PFAS Diffusion Through Geomembranes:

Conventional geomembranes, originally designed for general containment in various engineering applications, are synthetic barrier materials that play a pivotal role in isolating hazardous substances from the surrounding environment. These materials are typically composed of polymers such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), and polyvinyl chloride (PVC). Geomembranes are designed to be impermeable to various substances, with their effectiveness often validated through rigorous testing and certification processes.

However, the complex nature of PFAS compounds poses a unique challenge to the containment capabilities of conventional geomembranes. PFAS molecules are renowned for their distinctive properties, including strong carbon-fluorine bonds, which give them their remarkable persistence in the environment. These characteristics make them resistant to degradation and cause them to behave differently from many other pollutants that geomembranes were originally designed to contain.

The diffusion of PFAS compounds through geomembranes is not simply a matter of porosity. While conventional geomembranes can resist the passage of many contaminants, their effectiveness in mitigating PFAS diffusion has been questioned due to the small molecular size of certain PFAS compounds. The minute dimensions of these molecules allow them to exploit even the smallest imperfections or pores present in geomembranes. As a result, PFAS compounds have the potential to escape these traditional structures and migrate into the surrounding environment.

This phenomenon is particularly concerning when considering the long-term containment of PFAS-contaminated materials in containment facilities. The durability of conventional geomembranes, while advantageous in many scenarios, can inadvertently facilitate the diffusion of persistent compounds like PFAS over extended periods. Over time, the cumulative effect of molecular migration could result in the gradual release of PFAS into the environment, posing risks to groundwater quality, soil health, and even the food chain.

Research has shown that diffusion through geomembranes is influenced by factors such as molecular size, the nature of the polymer matrix, the presence of additives, and environmental conditions. The interaction between organic compounds and geomembranes is complex, involving a combination of adsorption, desorption, and diffusion processes.

Addressing the challenges posed by PFAS diffusion through geomembranes requires a multidisciplinary approach involving material science, environmental chemistry, engineering, and regulatory frameworks. The complexities of PFAS behaviour and geomembrane interaction call for innovative solutions that balance the benefits of conventional geomembranes with the need for specialized barriers capable of containing PFAS compounds effectively.

3. PFAS leakage through traditional composite liners:

Geosynthetic clay liners (GCLs) and geomembranes are the main containment barriers for leachate in the waste industry. Their combined use is often referred to as composite liners, where the GCLs serve as a redundancy containment under the geomembranes. Despite the enormous development in the quality of geomembranes and their installation on site, these materials are often subject to systematic failures. The geomembranes are supplied in rolls with practical dimensions for transport, however, during the installation, the panels of geomembranes need to be joined together aiming to create a uniform and impermeable layer of containment. To join these panels, different welding techniques are possible, such as extrusion and hot wedge. Irrespective of the technique used, the welding areas are susceptible to failure due to the manual and labour-intensive requirements for these processes.

The welding technologies available were refined across decades of experience as well as the auditing processes to ensure quality standards. However, damages to geomembranes and/or failures in the welding process are widespread against the industry's wishes. To consider these failures on geomembranes, containment facility designs are usually guided by a maximum level of permeability of leachate that is under an acceptable level of risk.

These levels, however, do not consider the possible impact that PFAS contaminations can have on groundwater and soils. As mentioned above, the persistence of PFAS compounds is unprecedented and traditional designs need to be revised to address the risks of contamination. Recent research calculated the probability of traditional composite liners failing to contain PFAS-impacted leachate, depending on the level of quality control and consequent transmissivity of composite liners in containment facilities. (8) In Australia and the US, the probability of failure of a composite liner causing a spike in concentrations of PFAS compounds in adjacent groundwater above the current guidelines can be higher than 90%. In Germany, the probability exceeds 85%.

Furthermore, containment facilities with poor quality control during construction could impact the environment less than a decade after construction. Highlighting the importance of a detailed revision of traditional designs to attend to the risks of these emerging contaminants.

4. Risks and Concerns:

PFAS loss through lining systems raises several critical concerns:

> **Groundwater Contamination:** PFAS migrating through geomembranes via diffusion or leakage can contaminate groundwater, compromising its quality and rendering it unfit for consumption (9).
>
> **Soil Degradation:** The infiltrated PFAS can deteriorate soil quality, potentially impacting agricultural productivity and ecological stability (10).
>
> **Food Chain Contamination:** The bioaccumulation of PFAS compounds entering the food chain can pose health risks to both wildlife and humans (11).

5. Overcoming the challenges:

Effectively countering the containment of PFAS through lining systems necessitates the deployment of advanced strategies, with composite barriers emerging as a promising solution. Hybrid systems that synergistically combine geomembranes, GCLs and complementary materials, such as reactive barriers, have the potential to significantly enhance containment efficacy.

The versatility of geocomposites extends beyond bentonite-based solutions like GCLs. Reactive barriers comprising other active materials can be harnessed. For instance, granular or powdered activated carbon (GAC / PAC).

Widely known for their efficacy in filtering and containing hydrocarbons and diverse contaminants, these sorbents can be integrated into geocomposites to act as a reactive barrier. In the context of PFAS, innovative approaches involving anion exchange resins showcasing ion exchange capacity exhibit remarkable performance.

The anion exchange resins exhibit high efficacy in sorption capacity and desorption minimization, making them well-suited for PFAS removal. As such, the implementation of reactive barriers boasting such capabilities presents an opportunity to introduce an additional layer of protection focused on the removal of PFAS congeners.

By embracing these innovative strategies, we can take significant strides towards mitigating PFAS migration (diffusion and leakage) through geomembranes, advancing environmental protection and upholding the efficacy of containment systems. Advanced Monitoring should also be implemented, providing real-time monitoring systems capable of detecting PFAS diffusion can facilitate proactive interventions (4).

6. Conclusion:

Given the criticality of mitigating PFAS containment failure and consequently contamination of groundwater and soils, the development of innovative strategies must be prioritized. As a responsible geosynthetics manufacturer, we advocate for the proactive collaboration between manufacturers, industry, research, and regulatory agencies to pioneer solutions that effectively contain and prevent PFAS from diffusing and/or leaking through engineered geosynthetic barrier systems. Safeguarding our environment necessitates a collective commitment to advancing technology and policies that mitigate the risks associated with PFAS contamination.

Striving to safeguard the environment from the risks associated with PFAS contamination, the development of containment strategies that account for the PFAS’ unique characteristics is a critical priority. HUESKER is committed to contributing to these solutions through research, collaboration, and the advancement of containment technologies that align with the evolving understanding of PFAS behaviour.

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