Executive Summary

Surface Functionalization of Polyurethane Foams for Enhanced Oil Absorption

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Introduction

The growing demand for microcellular materials in rapidly emerging technologies, ranging from lightweight materials for construction and infrastructure to ubiquitous foam mattresses and energy-saving insulation, continues to fuel market growth for polyurethanes. The global market for PU, primarily covalently crosslinked polyurethane foams (PUF), will exceed $90.3B in 2032. Since only a small fraction of these crosslinked foams are recycled, this growth has also driven a growing interest in recycling thermoset PUFs at the end of their lifetime.

Since launching their first recycling program in 2015, the Mattress Recycling Council Inc. (MRC) has recycled over 15 million mattresses, leading to a diversion of over 500 million pounds of material from landfills. However, considering that over 50,000 mattresses are discarded in the U.S. daily, this represents a nationwide recycling rate of only 5-10 %, with most of the mattresses going to landfills. This, even though the MRC has demonstrated that > 75 % of the mattress components are recyclable.

A major barrier preventing broader adoption of mattress recycling is economics. The value of the recycled components simply does not cover the cost to collect, transport and dismantle the mattresses. Steel and wood are relatively easily recycled, but the market for recovered PU foam is limited to one main application – carpet padding (rebond), where the value of the recycled PU foam is low. Therefore, to drive broader recycling and higher recycling rates, identifying additional, higher value markets for the recycled PUF is needed.

One potential end use application for recycled mattress foams is environmental marine oil contamination clean-up. The cost efficiency and rapid absorption rates of organic sorbents have made them a suitable recovery method for oil spill scenarios. Polypropylene, and to a limited extent Polyurethane foams (PUFs), are among the most popular organic sorbents, with PUF use limited by the cost and relatively low oil uptake efficiency.

Existing studies have demonstrated successful surface oleophilic enhancement of polyurethane foams to increase their oil absorption efficiency, but the high cost of equipment, slow deposition rates, and bulky nature has hindered their broader commercial applicability.

Methodology

This research demonstrated simple chemical functionalization of PU foam to introduce oleophilic groups to the surface. These reactions were carried out in conventional reactors at atmospheric pressure, using readily available materials as reactive components.

Foam surface functionalization of three modified PUFs and the unmodified foams were characterized by X-ray photoelectron spectroscopy (XPS), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM). To determine the effects of these surface modifications on the oleophilicity of the foams, a series of oil/water absorption tests were completed and compared with those of the standard PUF prior to surface treatment.

Key Findings

Oil:Water Absorption properties

Significant changes in the oil and water absorption of the foams resulted from the chemical modifications. The control, unmodified PU mattress foam, showed oil and water uptake of 14.4g and 11.8 g of oil and water per gram of foam, respectively. This corresponds to a selectivity of oil:water of ~1.2

In one modification, an increase of over 3-fold in the oil uptake was achieved with the selectivity for oil over water increasing by ~ 75%, compared to the unmodified foam. In another variant, a 50% increase in oil uptake was observed, while water uptake decreased by over 4-fold. This corresponds to a selectivity of oil:water over 6 times greater than the unmodified foam.

Comparison with oil absorption data on two commercial oil spill clean-up products shows that the absorption capacity of our modified PU mattress foams are higher (ranging from 21-45 g/g) than those reported in the technical data sheets for the two commercial polypropylene-based products (8-12 g/g).

Foam Surface Characterization

Thermal gravimetric analysis and x-ray photoelectron spectroscopic analysis of the modified foams showed changes consistent with successful surface modification.

Structural Stability Following Modification Reactions

SEM imaging confirmed that modified PUFs largely maintained their structural integrity, with some breaking of cells walls occurring in one modification, while no change in cell structure was observed in another case.

Conclusion and Future Work

While considerable development work would be needed to demonstrate suitability for oil clean-up in real-world environmental applications, the data show promise that chemically modified PUFs may offer an innovative and cost-effective solution for oil spill cleanup. This approach could be one way to expand the application of post-consumer PUFs in environmental remediation.

These modifications may also offer a pathway to tune the surface characteristics of PUFs for a variety of applications in addition to oil cleanup. The methodologies developed for functionalizing the surface of PUF would lend themselves to introducing various functional groups to the foam's surface. We believe this work could be extended, for example, to such areas as water absorbing foams, or filtration media tailored for selective capture of contaminants.