Enabling Circular Economy and Sustainability through "Waste-2-Wealth" and Applications

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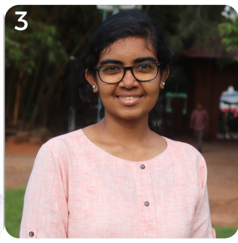
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Introduction

To extend the life of any extracted materials from planet Earth and to maintain its circularity, waste management follows the vital principle of the 3Rs - reuse, recycle, and recovery. Reuse is defined as using the substance for the same/different purposes without any further processing. Recycling involves techniques that convert the waste substance to a useful one. Recovery is defined as the extraction of materials or energy from the waste. Our group works on the elements of recycling and recovery on waste management and its applications in the energy and environmental sector. Our GREENS group, led by Dr Ambika S in the Environmental Nanotechnology Laboratory, Environmental Engineering, Department of Civil Engineering, is actively engaged in multiple "Waste-2-Wealth" projects along with applications and assessments on their circularity and sustainability development. This kind of study involves multiple steps such as waste sample collection, characterization, figuring out the options in recycle and recovery, technical analysis in recycle/recovery and possible applications, laboratory trials, purity analysis of resultant materials, and applications-related experiments to understand the optimum conditions to obtain the best efficiency.

Most of these studies were tested for their efficiency to work under solar-based energy to eliminate fossil fuel-based greenhouse gas emissions. Besides, life cycle analysis was carried out in the aspects of impact assessment of waste on the environment and the sustainability and circularity analysis of the resultant recycled and recovered materials during their extended life.

Recycling the Waste Management into Valuables and its Environmental and Energy Applications

Paper Sludge to Foam for Sorption and Separation Processes

In this work, the solid sludge from the pulp and paper industry was recycled to get the foam-based product, as shown in Fig. 1.

Further, the composition of the foam was modified, and its surface was functionalized with specific chemicals to exhibit desirable characteristics. Then, the final products were experimented with for the focused separation of selective substances from the passage stream, which needs to be processed or treated. This way of recycling paper waste to foam gives it a new life, thus cutting the materials cost in the process and treatment industries.

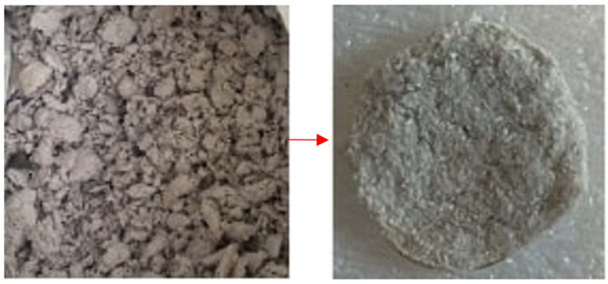

Fig. 1: Conversion of paper sludge to foam

Waste Plastics to Useful Products

The types of plastics that were obtained from different sources of waste were tested for their conversion to useful such as thin films and particles of various sizes, as shown in Fig. 2. Various physicochemical techniques were trailed to find the best possible methods for attaining the most beneficial recycled materials out of the plastic waste. The resultant materials were tested for characterization, fate, and transport in various scenarios of soil-aqueous media. These materials were further converted to membranes, adsorbents, electrodes, etc., to test their workability on the laboratory scale. Currently, the group is working on the perspectives of applying these useful products in environmental pollution abatement, energy, and implying in product manufacturing industries.

Fig. 2: Waste plastics to useful products

Agricultural Residue to Biochar-based Materials

In this study, the agricultural residue such as leaves, stems, etc, which were about 50%-80% of the agricultural waste, was converted to useful biochar materials through the modified chemicothermal process, as shown in Fig. 3. The obtained biochar was tested for its efficiency in aqueous pollutants removal applications such as adsorption, photocatalysis, and filtration. The material was further value-added by embedding it with functionalizing groups and catalytic materials. Besides, it was studied for efficiency enhancement to fit the latest applications. This direction of using agricultural waste to solve water pollution problems is a perfect example of the effective use of eco-safe resources that are considered waste.

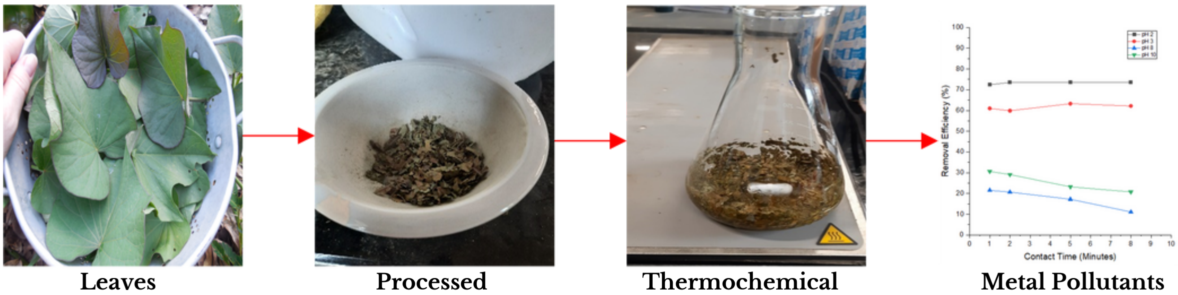

Fig. 3. Agricultural residue to biochar-based materials and pollution removal studies

Spent Graphite to Graphene-based Materials

A diverse group of industries uses graphite due to its versatile applications, say, as a lubricant. In this study, the collected graphene from industry has been experimented with for its conversion to useful materials such as graphene oxide, reduced graphene oxide, expanded graphene, composite materials, and functional materials as shown in Fig. 4. The obtained materials were tested for environmental pollution removals such as water and air pollutants, and energy-related applications. This route of using industrial waste to tackle another problem of industry, not only solves that industry's problem but also ceases another.

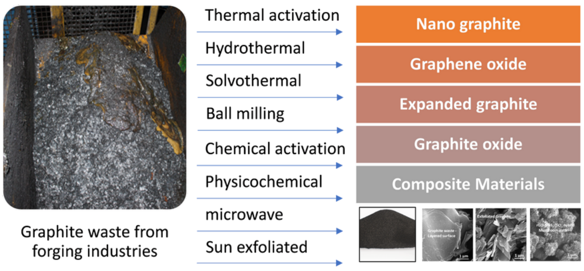

Fig. 4: Graphite Waste to Graphene-based Materials

Recovery of Chemicals and Water from Electroplating Rinse Water

This project focused on using solar thermal energy for extracting the spent chemicals and recovering deionized water by following the evaporation and distillation process, as given in **Fig. 5**. Different solar thermal reactor setups were studied to obtain the best configuration utilizing all the influencing factors. Also, the operating conditions were optimized to match the changing weather conditions to utilize the maximum thermal energy for the highest resource recovery. Here, the circularity of the materials was obtained to be 88% to 95%, depending on the composition of the feed stream.

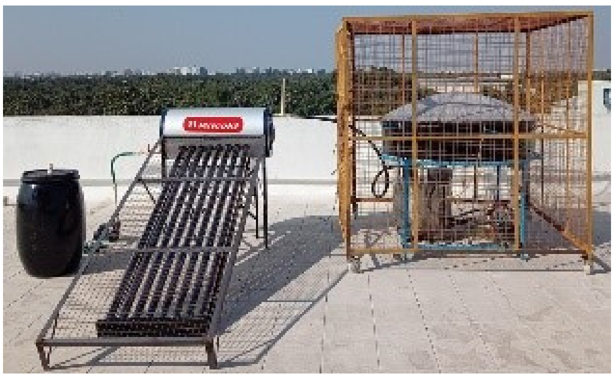

Fig. 5: Solar Thermal-based Resource Recovery Unit

Life Cycle-based Sustainability and Circular Economy Analysis

To understand the actual effects of recycling and resource recovery on the economy, society, and environment, a life cycle analysis was followed considering the entire processes involved in the selected recycling and recovery techniques. At each stage, the emissions and waste utilizations were incorporated into the analysis to calculate the improvisation in terms of materials circularity and sustainable development. Furthermore, the studies were analyzed to check the degree of their addressal of the 17 sustainable development goals that were developed by the United Nations. This kind of analysis is important as it involves all the energy and material balance from the beginning to its applications.

Summary

Our works on the types of wastes and their conversion to useful products and extraction of valuables through eco-safe techniques are the need of an hour. After obtaining the resultant products and materials, the same were tested for their diverse applications. Further, life cycle analysis-based sustainability and circularity assessment were carried out to understand the actual improvement in terms of sustainable development in the selected sectors. These studies could prove that utmost wastes with known characteristics and with the help of available techniques, can be converted to their useful form and thus their life can be extended. Similarly, recovery of valuables from the waste can lead to cyclic use of it which subsequently reduces the negative impact on the planet Earth by limiting the mining and the extraction processes. To have these findings to be implemented on a practical scale, through policies, the government must emphasize the industries and research sectors to invest in the research, development, and applications.

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