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A Review: Methods and Fillers for Recycling Polystyrene

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Abstract **–** Today, with the rapidly increasing human population, the need for wood has become impossible to meet from forests. For this reason, people established industrial plantations. In addition, substitute polymers that can be used instead of wood raw material have been developed. One of these is polystyrene (PS) wood mixture composite materials. PS is one of the most used thermoplastic polymers in the world. PS is a petroleum-derived synthetic polymer and takes a long time to recycle in nature. For this reason, many researchers are working on the possibilities of recycling and reusing polystyrene. Some methods have been developed for this purpose. In these methods used, PS can be strengthened by using different fillers. The fact that these fillers are natural is also important as it reduces the degradation rate of PS in nature. Studies on this subject will help both preserve the ecological balance and use petroleum-derived materials efficiently. This is an important issue in terms of protecting the world we live in. In this study, recycling methods of PS and natural polymers used as fillers are compiled.

Keywords – Polystyrene, Synthetic Polymer, Organic Filler, Recycling, Forest Resource

I. INTRODUCTION

Polystyrene is one of the thermoplastics that has a low recycling rate. In the UK, only 8 % of plastic is polystyrene, but it represents a larger volume due to its low density and lightweight characteristics. Polystyrene is also quite brittle with low strength, so fillers can be used to improve these weaknesses. This research aims to utilize waste products as fillers, which will automatically solve two problems in recycling: waste product utilization and cost reduction [1]–[3].

One method that can be used in recycling is by mixing a polymer with another material (blend) in order to reduce costs and compete with virgin material. Usually, the cost of recycled material is still higher compared to virgin material, but with this method, it can reduce the cost by up to 50%. This is because the cost of the recycled product depends on the cost of the collecting and sorting process until it becomes a recycled product. Another method is using a filler, which involves filling the matrix of the polymer with a small amount of material to increase strength and decrease the amount of polymer used. This can increase the economic value in the recycling process because the amount of polymer used can be reduced [4]–[8].

Recycling is important from the perspective of the belief that our efforts to reduce waste products can create a good future for the next generation (Fig.1). The problem with recycling plastic (as one of the waste products) is how to increase the economic value in the collecting and recycling process, while still ensuring that the quality of the recycled product can compete with prime products. When we can achieve this goal, it will automatically increase the recycling rate [9]–[11].

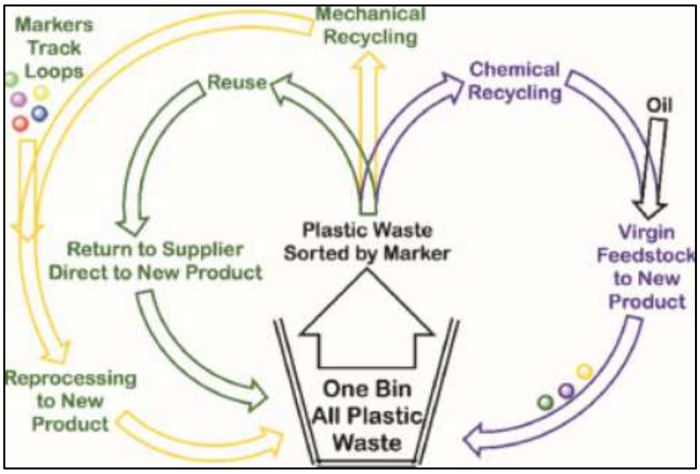

Fig. 1: Imagining the flow of plastics within the framework of the 'One Bin

In year 2015, the total production of Expanded Polystyrene (EPS) worldwide was 5.3 million tonnes and the global demand is anticipated to reach a volume of 7.74 million tonnes by the year 2020. With such a large production and demand volume of EPS, a huge problem is faced in terms of waste management. The EPS is non-biodegradable and it will remain in solid form for a very long period of time if dumped into a landfill [12]–[14].

Recycling is considered as a solution to the waste polymer disposal. This is because thermoplastic polymers (PP, HDPE, PVC, LDPE, and PS) can be recycled. Despite there are many recycling methods that had been developed to recycle these polymers, mechanical recycling makes up 85% of the total recycling. When compared to the other methods such as chemical recycling and pyrolysis, mechanical recycling is simpler and more cost effective. Mechanical recycling is the process of reprocessing these thermoplastic polymers to obtain the original monomer for a subsequent polymerization. This is done by sorting and cleaning the polymers, and then pulverized into a broken or powdered material by using various types of grinding technology. After that, the powdered polymer was fed into a machinery which consists of an extruder and a mold to produce a new product such as plastic lumbers and plastic combs. This method is more to reprocessing than to recycling. Recycling process is considered as transforming waste materials into useful products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, energy usage, air pollution (from incineration) and water pollution (from landfilling) by reducing the need for "conventional" waste disposal, and lower greenhouse gases emission [15]–[17].

II. Recycling methods

Chemical recycling involves changing the waste polystyrene physical structure with the use of chemicals. One method is Nitration. Nitrated polystyrene is an attractive material for its high heat resistance and stability. It can be used as an adhesive and it can be re-converted to aromatic polystyrene, which is a valuable material. Alkaline hydrolysis has been used to depolymerize polystyrene back to styrene. This method requires extremely high pressures and temperatures, and a catalyst such as tert butoxide or an alkali metal hydroxide. Styrene produced from this can be used to repolymerize polystyrene or the catalysts can be changed to produce lower molecular weight products from the starting material. An ideal method of recycling is depolymerization of polystyrene to a monomer or a mixture of monomers. Polystyrene is a long chain polymer made from a monomer known as styrene, and all of its properties are derived from this simple molecule. This can be done in many ways using various different solvents and catalysts, all of which can be complicated and uneconomical. A less explored method of chemical recycling is degradation of polystyrene [18]–[22]. This involves weakening the polymer chain, which makes it easier to depolymerize to lower molecular weight forms. This product can be used to make lubricants and greases, and polystyrene could possibly be recycled into these materials to overcome the problem of mixed polymer contamination. Although it is an interesting and viable method of recycling, the recent move towards environmental concerns from the general public has shown that using chemicals to recycle a polymer can give a negative image (Fig.2). During chemical recycling, it is difficult to ensure that the resultant product is of the same quality as the original polymer, and in some cases, it may be more economically viable to use the chemical process with virgin polymer rather than with recycled material. A negative image from chemical recycling may also affect the price of the recycled material as it is not a clean or environmentally friendly process.

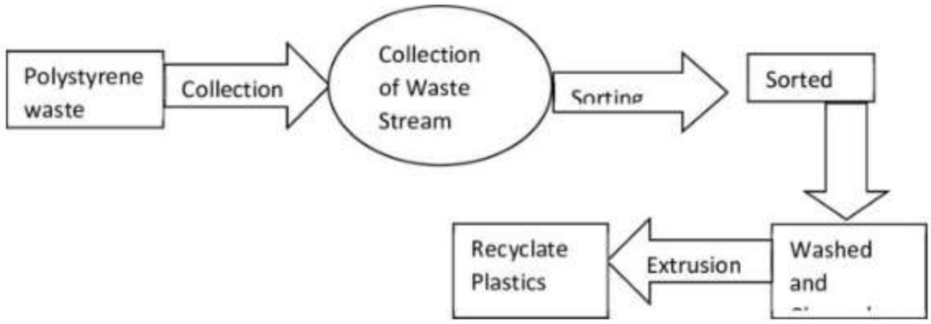

Fig.2 Polystyrene recycling process Polystyrene and its recycling: a review [23]

Mechanical recycling is processing the polystyrene so it can be used again in an article with the same or similar application without altering its molecular structure. The first step in a mechanical recycling system for polystyrene is collection and storage of the waste, it is then sorted and cleaned into a clean waste stream. Realistically, a mechanical method to recycle polystyrene is restricted as it may be contaminated with other polymers which are used for the same or similar application. It also has a reputation of being contaminated with paints and solvents. A solvent de-polymerization step may be used to dissolve the polystyrene leaving contaminants such as rubber, silicon, and pigments intact. This step is still considered to be a mechanical recycling method as the polymer is not changed. It would leave clean polystyrene waste to be re-precipitated and pelletized for resale. This is because the current mechanical recycle method is not economically viable in comparison to other methods of recycling. The increase in oil price has made raw polystyrene beads extremely expensive, and in comparison, recycled beads are of no difference in quality, so they do not match the price of the new material. Although it is not as cost-effective as re-pelletizing polystyrene, adding a step to graft the waste polystyrene with maleic anhydride modifies the surface properties so it is similar to virgin polystyrene [21], [22], [24].

III. Mechanical Recycling

These methods have the potential to decrease the amount of polystyrene waste in landfills and provide a cost-effective alternative to using more material during the manufacturing process. The quality of polystyrene can be altered after exposure to the elements and with processing, some may be unsuitable for use in higher quality consumer products. The ability to use these altered grades of polystyrene in new products with little waste adds much flexibility and an extended lifespan in recycling methods using polystyrene itself [1], [9], [25].

Physical recycling is the grinding and sanding of polystyrene into a new shape or into granules for ease of handling and storage (Fig.3). This has been experimented with wide success and can produce fast, effective results. The processed granules created from physical recycling can be used in the molding and extrusion of new plastic products[26]–[28].

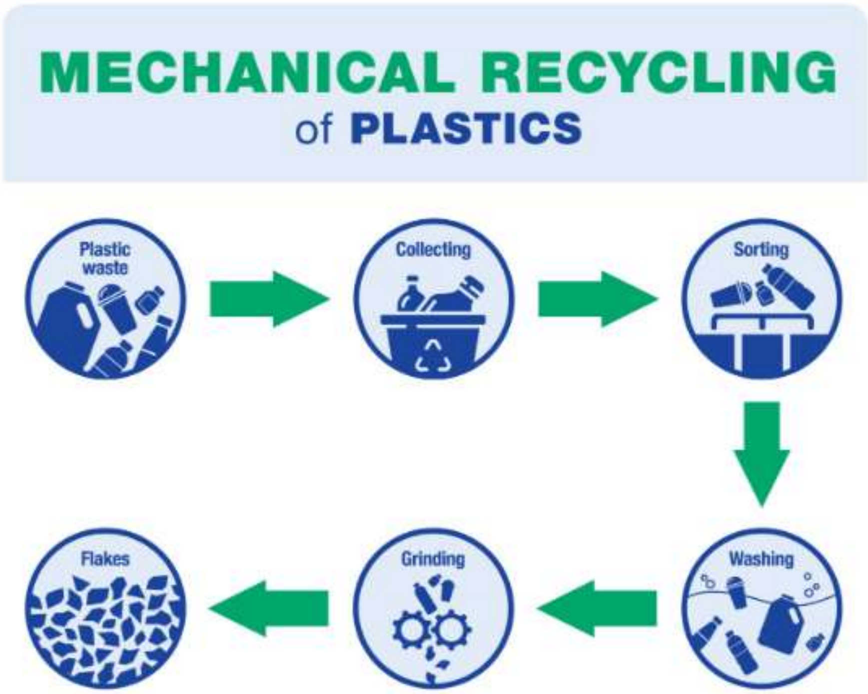

Fig.3 Mechanical recycling of polystyrene [29]

Board is inspired by fashion to physically change the shape of a polymer through grinding, washing, and related mechanical processes. I will be looking into the fact that 10% of polystyrene packaging waste occurs at the pre-consumer stage, which is typically manufactured in the form of loose fill packaging. For this, a compacting process which utilizes screw extruders may be most applicable in compacting polystyrene into a more economic form for transportation and recycling [30]–[32].

IV. CHEMICAL RECYCLING

A method that never really hit off in previous years, chemical recycling seems to promise quite a bit. Upon retrieving a polymer and subjecting it to a series of chemical treatments, where various chemicals like catalysts, heat, solvents, or microwaves can be used, a potential exists for that polymer to be converted into its original monomer so that it may be purified, repolymerized, and made into a new plastic product. Considering that the most common plastics such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET), are all made from monomers, a successful method for this process of conversion may result in the recovery and reuse of a wide variety of plastics that are currently landfilled [33]–[35]. An example to solidify the concept of chemical recycling would be the recovery of polystyrene (PS). Usually, a thermoplastic with a highly diverse market ranging from videocassettes to clear food packaging and dinnerware, when PS is discarded it becomes a burden in the disposal area as it takes a few centuries to biodegrade and is quite floatable, contributing to the pollution of bodies of water. With chemical recycling, PS could be converted back into its liquid state and then be re-expanded and used in foam products or it could be converted into its monomer, styrene, purified and repolymerized. Both processes would yield a quality product that can be very versatile into today's market. Due to its promising nature, several companies are investing into this method. Unfortunately, only a few practical systems have been developed and among these although trials have been proven successful, the true mass recovery of polymer and its subsequent reprocessing has yet to be seen with any type of polymer. This method is also currently cost more than double the price of producing fresh plastic from monomer and this is a significant barrier. Success of this method may prove to be the best way to recycle and recover plastics but there is still a lot of work that needs to be done before the feasibility is seen [36], [37].

V. THERMAL RECYCLING

Studies on the pyrolysis of polystyrene date back to the 1960s, and it is well established that the pyrolysis of polystyrene leads to a mixture of monomer, oligomers, and a variety of petroleum and olefinic products. In the early work, it was common to heat polystyrene with metals, which generally leads to some degree of degradation of the polymer, which is unwanted. In a research endeavor, the pyrolysis of polystyrene was conducted within a fluidized bed reactor employing silica sand as the fluidizing medium. The objective was to steer the degradation reactions of polystyrene towards steam gasification, aiming to achieve a minimum yield of 80% for monomer and gaseous products [36], [38] (Fig. 4).

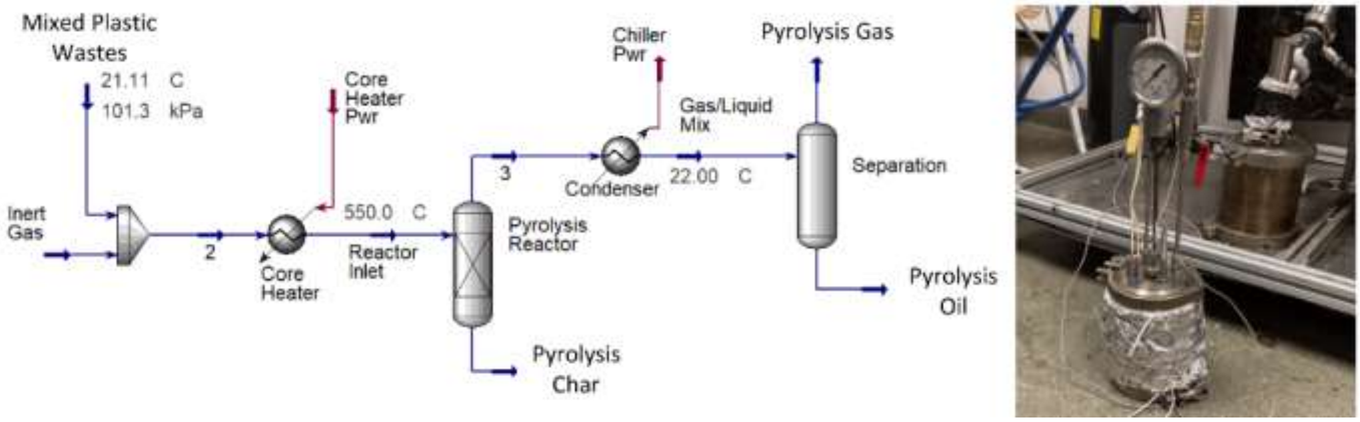

Fig. 4 Continuous fixed bed slow pyrolysis reactor for producing gas and biochar from Polystyrene [38].

As energy sources are diminishing and the world's demand for energy is increasing, there is growing interest in the recycling of polystyrene to its monomer so that it can be used as a source of energy. As heating polymers to high temperatures can generate useful products in the liquid and gaseous form, thermal recycling can be viewed as an extension of mechanical recycling. As in the case of other polymers, pyrolysis is how polystyrene can be thermally recycled. Pyrolysis involves the thermal degradation of polymers in an inert atmosphere. Typically, polystyrene is heated to temperatures in the region of 450-550°C [39]–[41].

VI. CONCLUSION

Waste polystyrene can be used in the production of wood plastic composites. Polystyrene polymer mechanical resistance properties are quite low. It is generally used due to its physical properties rather than mechanical properties. The density of polystyrene is reduced 10-100 times by using physical and chemical blowing agents. With this feature, it is frequently used as an insulation material. Recently, its usage areas have increased considerably. By being strengthened with different fillers, its usage areas in different industries have increased. The furniture industry is also conducting research on improving the mechanical properties of polystyrene and producing sheets. Polystyrene is reinforced with wood polymers such as lignin and cellulose. Thus, the physical and mechanical properties of polystyrene are improved.

One of the important issues is the recycling of waste polystyrene. Different methods are used for recycling. Chemical recycling involves altering waste polystyrene's structure using chemicals, like nitration or alkaline hydrolysis. This method can yield valuable materials like nitrated polystyrene or styrene monomers, but it's often criticized for its environmental impact and potential quality issues. Mechanical recycling, on the other hand, aims to reuse polystyrene without changing its molecular structure. However, it's hindered by contamination and cost concerns. While solvent de-polymerization can clean the waste, it's still considered mechanical recycling since the polymer remains unchanged. Economic viability remains a challenge, especially with fluctuating oil prices affecting the cost of raw materials. Both methods have pros and cons, highlighting the complexity of sustainable waste management in balancing economic feasibility with environmental impact.

More research should be done on recycling polystyrene polymer. Thermoplastic production, which increases with the increasing population, should be met from waste instead of petroleum-derived materials. At the same time, mixtures of natural polymers and petroleum-derived polymers should be provided in greater proportions and the destruction of polymers in nature should be facilitated.

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