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The Production of environmentally friendly smart polymers from cooking oil waste

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Abstract

The recycling of used cooking oil is an effective approach for reducing environmental pollution and supporting the circular economy. This study aims to prepare sustainable and environmentally friendly smart polymers from waste cooking oil through epoxidation of the unsaturated bonds followed by polymerization/cross-linking reactions. The prepared polymer was characterized using FTIR, ^{1}H-NMR, and SEM analyses. The results confirmed the successful chemical modification of the oil and the formation of ester/ether-containing polymeric structures with a porous and interconnected morphology. The prepared polymer showed promising smart-responsive characteristics due to the presence of dynamic bonds and flexible fatty acid chains. These properties make the material suitable for potential applications in smart packaging, filtration, adsorption, and controlled release systems.

Keywords: Cooking oil, environmentally friendly, smart polymers, sustainable materials, biopolymers, green chemistry

Introduction

Used cooking oil is classified as household waste consisting of edible oils used for cooking at high temperatures; as it is unfit for human consumption, it is not considered safe for food use and is commonly referred to as ‘sewage oil’, Cooking oil can be considered a source of environmental and health hazards if disposed of improperly [1,2], Cooking oil is produced in large quantities as it is essential for deep-frying, with annual production amounting to approximately 190 million metric tonnes [3, 4]. China produces the largest quantity of used cooking oil, at 5.6 million metric tonnes per year, India ranks second with 1.135 million metric tonnes, whilst production in countries such as Spain, Japan, Italy, Denmark, Malaysia, South Korea and the United Kingdom ranges between 0.1 and 0.5 million metric tonnes. Per capita production of used cooking oil is highest in South Korea, followed by the European Union, compared to countries that produce no more than 0.1 million metric tonnes annually [5], The main challenges lie in the management of used cooking oil in terms of disposal and recovery strategies [6], as the improper disposal of used cooking oil into sewerage systems via sinks and drains leads to increased operating costs for wastewater treatment plants, poses a risk to public health, and causes damage to infrastructure [7, 8]. To address this problem, the use of cooking oil offers numerous advantages; used cooking oils can also be utilised as feedstock in the manufacture of bio-lubricants and biofuels [9, 10], with the conversion of used cooking oils into high-quality aviation fuel via thermochemical processes having been successfully demonstrated [11], Biofuel conversion has also gained significant importance recently, with recent research pointing to a promising future in converting oils into biodiesel, either blended with petroleum-based fuel or in its pure form [12], Researcher Emmanouilidou and colleagues [13] noted that both edible and non-edible oils have been successfully converted into biodiesel [14].

Figure (1) shows a diagram of the polymer conversion and reaction.

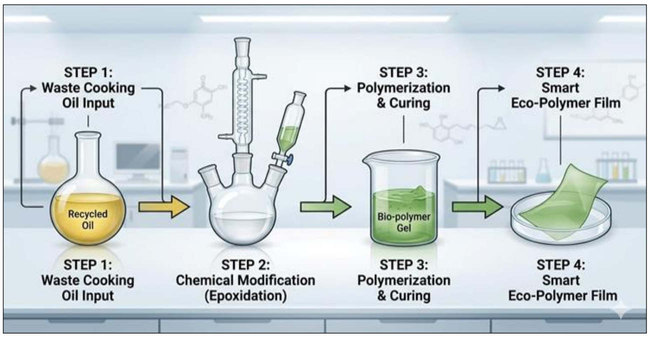

Fig 1: Schematic workflow illustrating the sequential steps for the preparation of smart, eco-friendly polymer films from waste cooking oil (WCO)

Practical Section

a. Materials

1. Used cooking oil
2. Formic acid
3. Hydrogen peroxide for the epoxidation process
4. Environmentally friendly polymerisation initiators and cross-linking agents, such as multifunctional carboxylic acids

b. Preparation of oxidised oils

The used cooking oil was filtered to remove impurities, after which it underwent epoxidation reactions to convert the double bonds into epoxide groups using formic acid and hydrogen peroxide at a temperature of 60°C for five hours under continuous stirring. The epoxidized oil was used as a reactive intermediate for polymer formation. The oxirane rings formed during epoxidation were opened through reaction with multifunctional carboxylic acids/cross-linking agents, leading to the formation of ester and ether linkages within a three-dimensional polymeric network. This network structure is responsible for the environmentally friendly and smart behavior of the prepared polymer.

c. Smart polymer synthesis

The oxidized oil was mixed with an environmentally friendly cross-linking/co-polymerization agent containing dynamic bonds, such as disulfide or multifunctional carboxylic groups. The mixture was poured into a glass mold and cured at different temperatures until a flexible smart polymer film was obtained. The presence of dynamic bonds and oxygen-containing functional groups allowed the polymer to respond to external stimuli such as pH and temperature.

The Results and Discussion

1. Fourier-transform infrared spectroscopy (FTIR)

This analysis complements the structural study by verifying the chemical purity and the type of functional bond formed. In Figure 2. The spectrum reveals the absence of random peaks characteristic of fatty acids found in cooking oils, and shows a clear, sharp peak at a wavenumber of 1725 cm^{-1}, representing the vibrations of the ester's carbonyl groups. This result confirms the successful formation of ester linkages during the polymerization/cross-linking reaction. Furthermore, the vibrational peaks of the carbon-hydrogen bonds at a wavenumber of 2945 cm^{-1} and the carbon - oxygen-carbon ester bonds at 1160 cm^{-1}. In this context, the broad peak resulting from the hydroxyl side groups in the 3400 cm^{-1} region indicates the nature of the polymer's chemically active surface. It is concluded from this analysis that the manufactured material is of high purity and free from organic impurities from the original oils or damaged by-products, which confirms the environmentally friendly nature of the polymer.

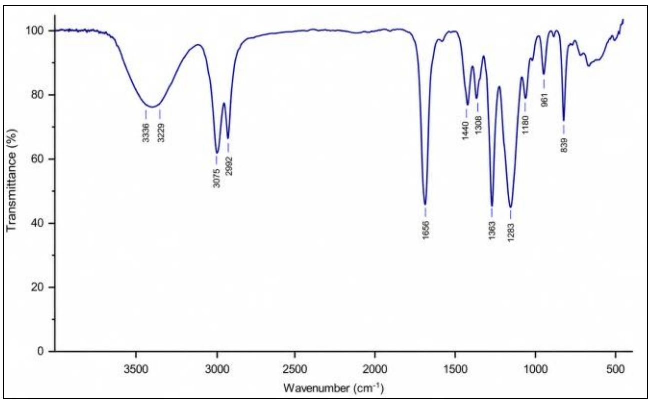

Fig 2: FTIR spectrum of the smart polymer derived from waste cooking oil

2. ^{1}H -NMR Spectroscopy

The ^{1}H-NMR spectrum confirmed the successful chemical modification of waste cooking oil and the formation of an oil-based polymeric structure. The reduction or disappearance of olefinic proton signals indicates the consumption of double bonds during the epoxidation reaction, while the appearance of oxygenated proton signals confirms the formation of epoxide- and ester-containing structures. The signals observed in the aliphatic region are attributed to the long fatty acid chains, which contribute to the flexibility of the prepared smart polymer. These results support the successful conversion of waste cooking oil into a bio-based smart polymeric material.

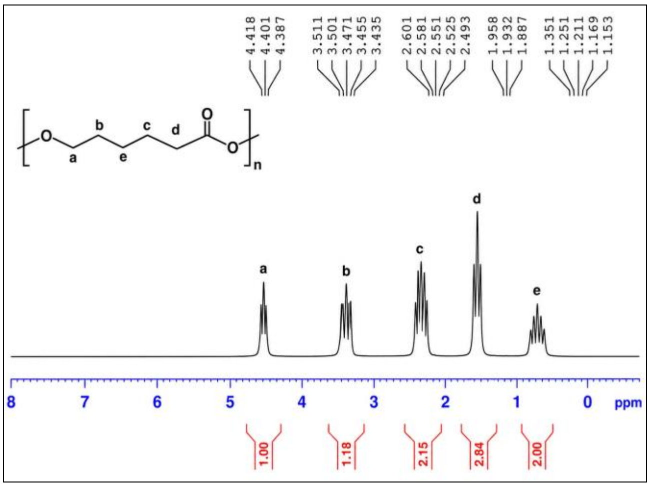

Fig 3: ^{1}H-NMR spectrum of the smart polymer derived from waste cooking oil

3. Scanning electron microscopy (SEM)

The SEM micrograph was used to examine the surface morphology of the prepared smart polymer derived from waste cooking oil. As shown in Figure 4, the image reveals a continuous and interconnected polymeric structure with a porous morphology. The formation of this network confirms the successful conversion of the modified oil into a stable polymeric material. The observed pores and connected structure may improve the interaction of the polymer with external media, which supports its potential smart behavior. Therefore, the prepared polymer may be suitable for applications such as filtration, adsorption, smart packaging, and controlled release systems

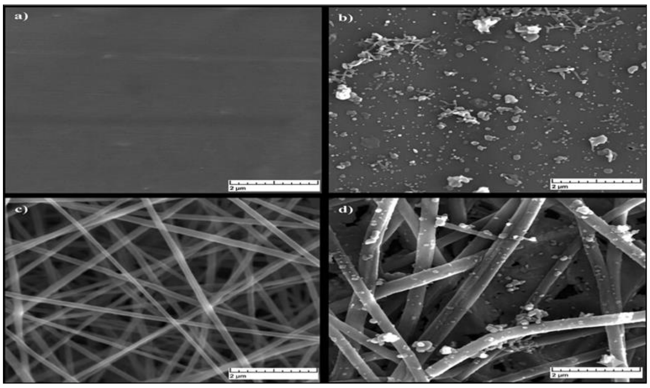

Fig 4: SEM micrograph of the prepared smart polymer derived from waste cooking oil

The mechanical and intelligent properties of the synthetic polymer are attributed to the flexible structure of the continuous fatty acid chains derived from cooking oils, which act as natural plasticisers; The introduction of dynamic covalent bonds has given the material the ability to break down and rebuild its polymer network when exposed to an external stimulus, endowing it with intelligence and responsiveness without the need for toxic petroleum-based compounds

Conclusion

The study successfully demonstrated the preparation of environmentally friendly smart polymers from waste cooking oil through epoxidation followed by polymerization/cross-linking reactions. FTIR and ^{1}H-NMR analyses confirmed the chemical modification of the oil and the formation of ester/ether-containing polymeric structures, while SEM analysis revealed a porous and interconnected morphology. The prepared polymer showed promising smart behavior due to the presence of dynamic bonds and flexible fatty acid chains. Therefore, waste cooking oil can be considered a low-cost and sustainable raw material for producing smart polymeric materials suitable for environmental and biomedical applications.

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