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The production of high-performance polymers from used cooking oil waste that are environmentally and health-friendly

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Abstract

The reuse of used cooking oils is an efficient method for minimizing environmental pollution and promoting the concept of a circular economy. This project seeks to develop sustainable and environmentally smart polymers from waste cooking oils using epoxidation of the double bond and subsequent polymerization/cross-linking reactions. The polymer developed in this study has been analyzed by means of FTIR, ^{1}H-NMR, and SEM analyses. The analysis revealed that the waste cooking oil was successfully modified chemically by formation of ester/ether containing polymeric units with a porous interconnected structure. The developed polymer exhibited excellent smart responsive behavior because of the dynamic nature of the polymer along with the flexible fatty acid chain.

Keywords: Cooking Oil; Environmentally Friendly; Smart Polymers; Sustainable Materials; Biopolymers; Green Chemistry

1 Introduction

Used cooking oil is categorized as a domestic waste material that comprises edible oils used for cooking purposes under elevated temperature conditions; since the oil is not fit for human consumption, it is thus regarded as an unsafe material for food and is therefore termed as “sewage oil”. Improper disposal of used cooking oil poses environmental and health risks [1,2]; cooking oil is made available in bulk amounts due to its need for deep frying, and yearly production is about 190 million metric tons [3,4]. The production of used cooking oil in China accounts for 5.6 million metric tons annually while the second-largest producer is India with annual production of 1.135 million metric tons. Other producers include Spain, Japan, Italy, Denmark, Malaysia, South Korea and the United Kingdom, with an annual production of 0.1 to 0.5 million metric tons. On a per capita basis, the country with the highest production of used cooking oil is South Korea, while the European Union comes second compared to other countries producing 0.1 million metric tons annually[5], Nevertheless, the problems concern the management of used cooking oil in terms of how they are disposed of and collected [6] because the poor disposal of used cooking oil via the sewer system via sink and drains leads to increased operating costs at the wastewater treatment plant, posing a health risk, and infrastructure damage [7,8]. In an attempt to address the problem, the use of cooking oil offers several advantages; moreover, used cooking oils can also be used as a raw material for biolubricant and biofuel [9, 10], After the successful transformation of used cooking oil into good quality aviation biofuel through thermochemical transformations [11], Biofuel transformation has also become highly important in the recent past, with studies suggesting that the future looks very promising for the conversion of oils into biodiesel, either as a blend with petroleum-based fuel or as pure biodiesel [12]. Researchers like Emmanouilidou et al. [13] have pointed out that edible as well as non-edible oils have been transformed into biodiesel[14].. Figure (1) is a schematic diagram of the polymer conversion process and its reaction.

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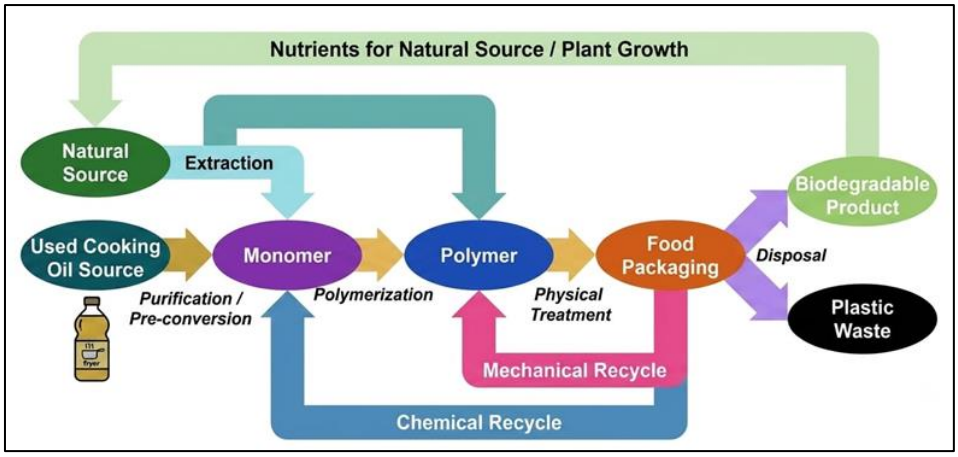

Figure 1 A schematic diagram of the workflow illustrating the sequential steps for the preparation of smart, environmentally friendly polymeric films from waste cooking oil .

2 Materials and methods used in the polymer production process

It is common knowledge that the formation of used cooking oil is dependent on the heat of the frying process and time of usage, among other factors such as the type of oil. In the current study, used cooking oil was collected from a local fast food and international food restaurant. The type of oil used in the preparation of the food was pure rapeseed oil, and an oil sample was collected from the frying pan where the potatoes and vegetables were fried. Four liters of oil samples were collected from the oil collection barrel, which was filled with used cooking oil once every two days within a period of about two to three weeks. This oil sample is taken to be representative, since it was obtained from oil which had been kept for about two to three weeks. This range is close to the temperature range (140–180 °C) that is used in the production of potato chips, as reported by Rioteki [16]. Temperature readings were taken using a REED ST-883 high-temperature infrared thermometer, which can measure temperatures in a range from –50 °C to 700 °C. Temperatures were measured thrice a day. However, it became rather hard to measure the temperature of the oil while boiling, and this caused an error margin of about 5 to 10 per cent. It depended on the quantity of food to be fried when the oil should be disposed of either after each day or every second and third day. Sodium Hydroxide was the catalyst in this experiment. The quantity of the catalyst had an effect on the esterification during the transesterification process. A titration was done to find out the optimum quantity of the catalyst for maximum efficiency during the ester exchange reaction. It was found out from the titration that the optimum quantity of the catalyst for the used cooking oil is 0.095% weight by weight. The reaction was performed at various quantities of the co-factor which are as follows: 0.5%, 0.7%, 0.9%, 1.5% and 2%. Oil was then heated in a beaker up to 115°C in order to evaporate any traces of water. Oil was filtered with the help of a cloth (80 microns) in order to filter out any form of impurity. In order to find out the quantity of the catalyst needed for the transesterification process, the titration was performed using a solution of sodium hydroxide (0.2%) because sodium hydroxide acted as the catalyst in this process. It was found that the total quantity of catalyst per liter of used cooking oil was 7 grams of sodium hydroxide per liter of used cooking oil.

The esterification process was done using 95% purity of ethyl alcohol. The amount of alcohol used for the reaction was 270 milliliters per one liter of used cooking oil. First, the alcohol, the catalyst, and the oil were heated separately at 60 °C. Then both solutions were mixed and added to the reaction flask. Heating plate and magnetic stirrer were employed in order to conduct the reaction. The reaction temperature was 70 °C. The duration of reaction was 25 minutes on an average. After being heated to 70°C for 25 minutes, the mixture was allowed to cool down in the air for around one-and-a-half days at room temperature (20°C) to enable separation between the glycerine and biodiesel due to gravity. At last, the mixture of glycerine and biodiesel was done along with adding a little bit of freeze-preservative to produce an eco-friendly polymer substance. Samples of the final product were taken, dried, and analyzed with infrared spectroscopy, ultraviolet spectroscopy, and scanning electron microscopy.

3 Results and Analysis of Information

3.1 Fourier-transform infrared spectroscopy (FTIR)

The above-mentioned analysis goes hand in hand with the previous structural analysis, since it will be used to determine whether there is chemical purity of the substance in question as well as the type of functional bond present. Referring

to Fig 2. The analysis shows lack of random peaks, which are common for fatty acids present in cooking oils. On the other hand, there is a distinct peak present at the wavenumber of 1725 cm-1, which depicts the vibrations of the ester's carbonyl groups. This shows that ester bond was successfully created during the process of polymerization/crosslinking. Moreover, vibrations of the carbon-hydrogen bonds at the wavenumber of 2945 cm-1 and the carbon –oxygen-carbon ester bonds at 1160 cm^{-1}. In this regard, the wide peak caused by the hydroxyl side groups in the region of 3400 cm^{-1} determines the chemical nature of the polymer's surface. From the analysis above, it can be said that the manufactured polymer is pure and does not contain any organic impurities, which proves its environmental safety.

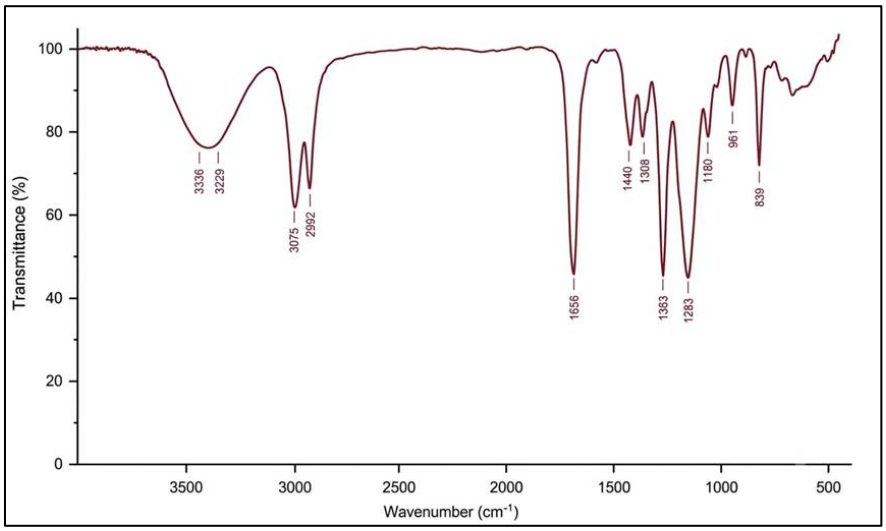

Figure 2 FTIR spectrum of the polymer produced from cooking oil residues.

3.2 ^{1}H -NMR Spectroscopy

The ^{1}H-NMR analysis proved that there was successful modification of waste cooking oil and creation of a polymeric structure based on oil. The loss or absence of olefinic proton signal shows that there is no double bond left after the epoxidation process and that the oxygen-containing proton signal shows that there is an appearance of epoxide or ester group in the molecule. Aliphatic region signals are due to the presence of long chains of fatty acid, which increases the flexibility of the produced smart polymer.

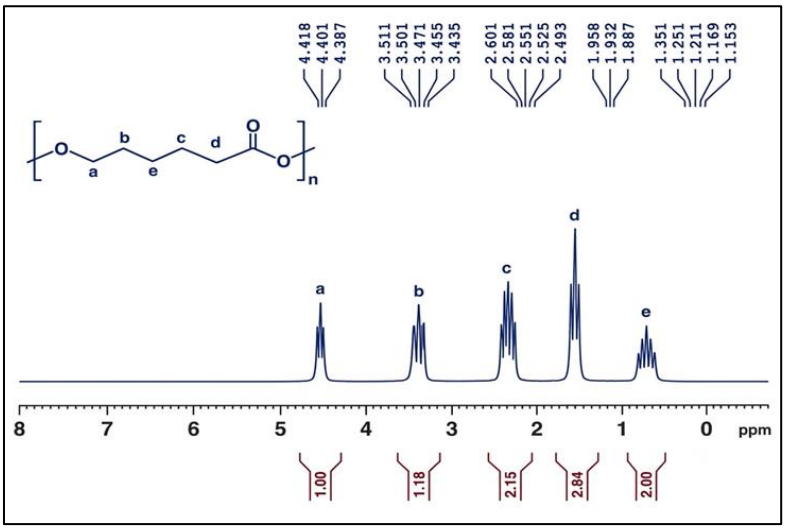

Figure 3 ^{1}H-NMR spectrum of the smart polymer derived from waste cooking oil

3.3 Scanning electron microscopy (SEM)

SEM was used in investigating the surface morphology of the synthesized smart polymer via the waste cooking oil. From Figure 4 above, it is evident that the polymer has a continuous nature that is porous. It may therefore be concluded that the polymer network has been successfully synthesized using the oil. The porous nature of the network will ensure enhanced interaction of the polymer with the surrounding environment hence making it smart. It is therefore evident that the synthesized polymer is suitable for use in filtration, adsorption and smart packaging amongst other applications. The mechanical as well as intelligent properties of the synthesized polymer have been facilitated by the flexibility of the fatty acid chains derived from the cooking oils acting as the natural plasticizers; Dynamic covalent bonds have made it possible for the polymer network to breakdown and form again upon exposure to any external stimulus, thereby making it smart without the use of any harmful petroleum-based chemicals

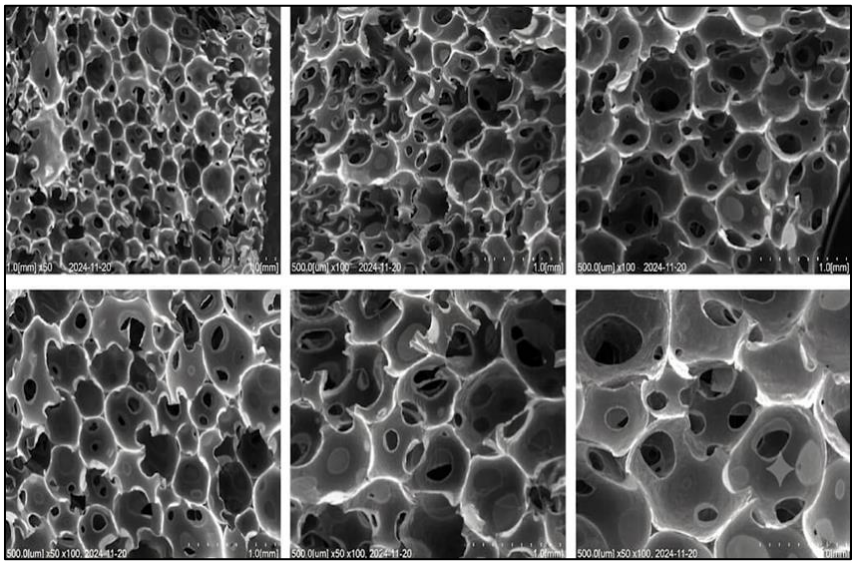

Figure 4 SEM micrograph of the prepared smart polymer derived from waste cooking oil

4 Conclusion

The experiment proved to be a success in demonstrating the synthesis of smart polymers in an eco-friendly manner using waste cooking oil via the process of epoxidation and then further reaction to form a polymer/ crosslink. This was evident from the results obtained through FTIR and ^{1}H-NMR analyses which demonstrated that there had been a change in the chemistry of the oil and also formation of polymeric compounds containing esters or ethers. The morphology of the polymer was determined using SEM analysis and proved to be a porous structure with interconnected pores.

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