Research Article

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Polymer-based Nanocomposites for the Separation of Oil from Water

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Abstract:

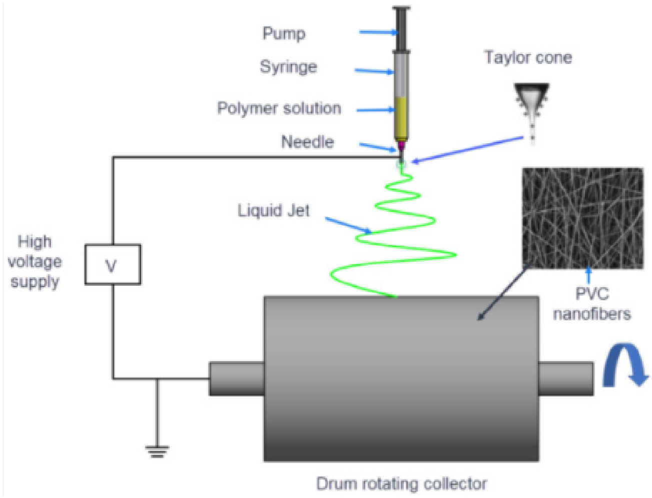
Oil spills are a major cause of water pollution, with serious consequences for the environment, biological systems, and economic systems. To preserve the survival of marine animals and the health of the ecosystem, oil spills must be cleaned up as soon as feasible. In order to restore the damaged marine environment to its native ecology, effective methodologies and removal processes (as well as materials) must be developed. Following the rupture of the Gulf of Mexico on April 20, various studies on oil spills were conducted, and it was discovered that polymeric nanocomposites may be used to clean up oil spills. When it comes to oil-water separation, traditional methods are insufficient. Many studies have shown that nanotechnology can help clean up oil spills in water, especially when combined with polymer/carbon nanocomposites like polyvinyl chloride (PVC)/clay nanofiber composites, which have been studied for their morphology, porosity, density, and mechanical properties, among other things. Polymers are used in everything from huge Boeing jets to the smallest nano-electronic devices. It is hard to imagine a world without them. Everywhere we go, we see polymers in things we use every day, like toys and mattresses and clothes and shoes and drugs and adhesives. Since the early days of humanity, polymers have intrigued us with their myriad forms, often wonderful properties, interactions, and roles in different phenomena. Polymers are a group of materials that can be used in many different ways. They are made up of giant molecules (macromolecules). In nature, they can be found in things like the biopolymers, DNA in our bodies and starch in potatoes; or they can be man-made like ordinary plastic polythene in bottles and toys or polyurethane-based composite foam for oil water separation (Oil spills). The effect of clay content on the oil sorption capacity of PVC nanofiber mats is explored in this review, as well as how to enhance it. The findings show that, among other things, the porosity, density, mechanical properties, and sorption capacity of nanofiber mats are all controlled by their porosity, density, mechanical properties, and sorption capacity. It is feasible to improve the porosity and oil sorption capacity of nanofiber composite materials by using clay.

Keywords: Polymer/carbon nanocomposites; Polyvinyl chloride (PVC)/ clay nanofiber; Composites; Porosity

Introduction

At the moment, the oil spill treatment problem is a pressing issue, especially in light of the many environmental challenges that must be addressed and resolved, such as greenhouse gas emissions, air and water pollution, and climate change. An oil leak happens as a result of the extraction, transportation, and storage of oil for industrial usage as well as for human activity. The oil spill has a negative impact on the quality of saltwater and marine ecosystems, including as flora and animals, as well as the populations in the surrounding region. When an oil spill happens, it is critical to collect and treat the oil as soon as possible in order to reduce the negative impact on the environment. Oil spills can be dealt with in a variety of ways, including mechanical methods, microorganisms, chemical dispersion, and sorbent, among others. In comparison to other approaches, the sorbent method is particularly effective and affordable. Nanofiber sorbents are an example of a potential material for use in oil absorption that has lately grabbed the curiosity of experts. A huge number of scientists are interested in nanofiber polymers, which have been produced in parallel with the development of nanomaterials in recent decades. When compared to previously known fibres, polymer nanofibers have a number of distinguishing characteristics, including a tiny diameter, a big surface area, a high porosity, and a high mechanical strength, among others. The applications of these materials are many and include water filtering, air purification, water purification, water separation, medication delivery, tissue engineering, energy storage, reinforcing components in composites, and many more. There are nanofiber polymers may be made in a variety of methods, including drawing, template synthesis, self-assembly, melt-blowing, phase separation, and electrospinning. Drawing is one of the most common methods. When it comes to fabricating nanofibers, electrospinning is an excellent approach due to its benefits such as a simple procedure with great efficiency, a continuous process with changeable size, and the ability to control the orientation of nanofibers. PVC (polyvinyl chloride) is a commonly used polymer in both industry and everyday life. PVC is a versatile material that may be used in a variety of industries, including construction, health care, and electronics. Electrospinning technology's prowess in fabricating nanofibers has broadened the application of polymers throughout the last few decades PVC nano-fibers have been successfully produced using electrospinning. PVC nanofibers with diameters varying from a few hundreds of nanometers to several micrometers may be obtained by altering the initial electrospinning conditions. PVC nanofibers offer several benefits, including high porosity, high mechanical strength, wide surface area, waterproofness, and lack of toxicity. PVC nanofibers have shown to be very effective in a range of disciplines, including air filtration, water treatment, oil spill remediation, battery technology, protective apparel, corrosion resistance, and many more. In this study, the fabrication process, properties, applications, and future prospects of PVC nanofibers are explored. Furthermore, in recent years, a number of companies have begun to develop technology to mass-produce nanofibers, increasing the probability that nanofibers will be employed in a range of applications in the future. The electrospinning technique has the advantage of allowing nanofiber composite polymers to be made from polymer-polymer combinations or polymer mixtures with different particle kinds. When particles are included, nanofibers have several benefits over pure polymer nanofibers. Electrospinning polymer/clay nanofibers is one method of combining polymers with clay particles. Clays' inclination to combine with polymer chain molecules increases the mechanical strength of nanofiber mats. The mechanical strength, thermal properties, and fire resistance of polymers improve when clays are added. According to various studies, they also have a greater ability to absorb heavy metals. According to studies, the inclusion of clay to PU/clay nanofiber mats increases their tensile strength and Young's modulus. Kaolinite, montmorillonite, vermiculite, and chlorite are some of the clays found in nature. Heavy metals, such as iron, copper, lead, zinc, and chromium (Cr), as well as oil, can be absorbed by clays (Bentonite clay, for example).

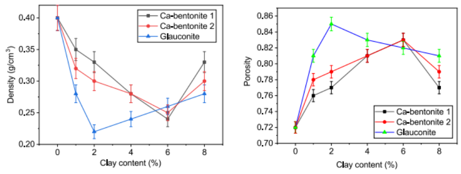
These PVC nanofibers have been successfully manufactured and may be used in a variety of applications, including air filtration, water purification, oil-water separation, anticorrosion material, and optical components for terahertz frequencies. However, there is currently a shortage of study into the manufacturing of PVC/clay nanofibers. We can make materials with strong oil sorption capacity and use them for oil-water separation by mixing clay into PVC solution before it is used to make nanofiber mats. This would boost the mechanical strength and oil sorption capacity of the mats.



1. Results

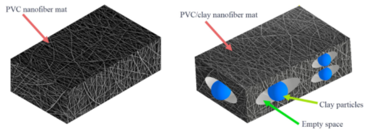
Electrospun PVC/Clay Nanofibers: Morphology and Applications.

When viewed under a scanning electron microscope (SEM), the PVC/clay picture reveals that the nanofiber mat includes small clay particles. Clay particles are scattered throughout the mat's empty area or are coated with PVC to create a textured surface. Small clay particles will be coated with PVC, while bigger clay particles will be found in the empty spaces between the nanofiber mat's fibres and will be covered with PVC as well. When the clay concentration of the nanofibers grows, the diameter of the nanofibers decreases. Because clay particles contain cations, it is possible that adding clay particles to a solution will result in an increase in conductivity. The solution is exposed to a greater magnitude of electric field force during the electrospinning process, resulting in the formation of smaller nanofibers during this phase. Given that Ca-bentonite has a smaller particle size than glauconite, we believe that they will perform better when it comes to dissolving cations in solution. As a result, solutions containing Ca-bentonite are more significantly impacted by electric field force than solutions containing glauconite. As a result, the diameter of PVC/Ca-bentonite nanofibers is less than that of PVC/glauconite nanofibers. PAN/Na-montmorillonite nanofibers and PU/clay nanofibers, among other materials, exhibited this behavior.



(a) (b)

Figure 4. Density and porosity of PVC/clay nanofiber mats with different clay contents: (a)—density and (b)—porosity.



(a) (b)

Figure 5. Representation of the nanofiber mat structure: (a)—PVC nanofiber mat and (b)—PVC/clay nanofiber mat.

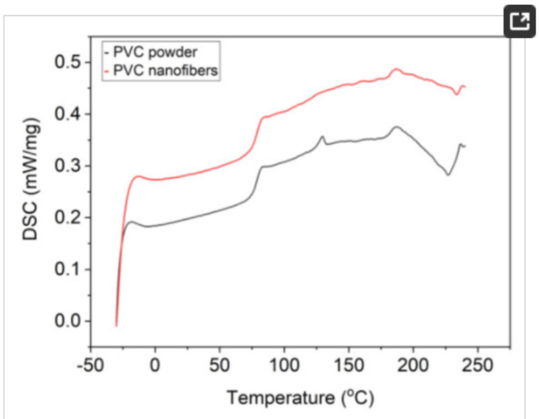
Density

PVC/clay nanofiber mats are more expensive than pure PVC nanofiber mats because they have a lower density. As previously indicated, the clay particles in the nanofiber mat can take one of two forms: completely coated in polymer or alternatively covered with nanofibers. The nano-fibers will rise and expand if the clay particles are placed in the void zone of the mat, leaving more empty space in the nanofiber mat. Finally, adding clay particles to the nanofiber mat increased the void space, causing the mass of the nanofiber mat to shift. Conclusion As a result, the density of PVC/clay nanofiber mats that contain clay is lower than that of pure PVC nanofiber mats. The lowest density was found to be attained with PVC/glauconite nanofiber mats when the glauconite content reached 2%, while the lowest density was found to be achieved with PVC/bentonite nanofiber mats when the bentonite level reached 6%. Because the particle diameter of the clay has an effect on the electrospinning process during the electrospinning process, this is the case. The porosity of the nanofiber mat changes as the density of the mat changes. The largest porosity of the nanofiber mats including glauconite was produced by the smallest diameter of Ca-bentonite 1 particles, while the lowest porosity of the nanofiber mats containing Cabentonite 1 was generated by the smallest diameter of Ca-bentonite 1 particles. the clay particles and PVC nanofibers form empty spaces (voids) in the PVC/clay nanofiber mat Because clay has a higher density than PVC, mixing the two will result in an increase in the density of the mixture under typical circumstances. Two factors, on the other hand, impact the mass change of the nanofiber mat. In the first step, the formation of gaps between the clay and the nanofiber mat results in a decrease in overall mass. The second is the increase in mass that occurs when the amount of clay present grows. As a result, the density of the nanofiber mat is lowered when the first element is greater than the second. When the first factor is smaller than the second factor, the density of the nano-fiber mat rises, and vice versa when the first factor is more than the second factor.

As a result, the density and porosity maxima and minima occur after the density and porosity minima and maxima, respectively.

Thermal Properties

The characteristic peaks at 1328, 1253, 964, and 613 cm1 were determined to be the same as those of PVC nanofiber using PVC powder. It was revealed that the glass transition temperatures of PVC nanofiber and PVC powder were almost equal at 83 degrees Celsius. PVC nanofibers began to degrade at 276 degrees Celsius, which is 6 degrees lower than the temperature at which PVC powder begins to decompose.

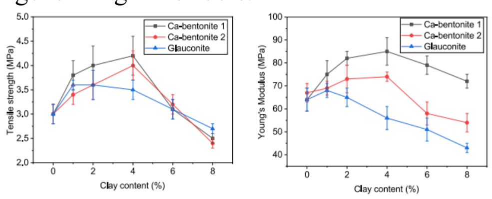


4. Differential scanning calorimetry thermogram of PVC powder and PVC nanofibers

The TGA curves for the original PVC powder and the nanofibers, on the other hand, were found to be similar in our most recent research, with two heat deterioration phases. At 233 degrees Celsius, the first stage of thermal degeneration begins, and at 320 degrees Celsius, the second stage begins. It was revealed that using THF, a very high crystalline membrane with an extraordinarily high exothermal peak could be generated at temperatures as low as 30 degrees Celsius. According to the research findings, when ENR is added to PVC, the resulting nanofibers become more flexible and have a lower glass transition temperature than nanofibers generated from pure PVC.

Mechanical Properties of Nanofiber Mats Made of PVC and Clay

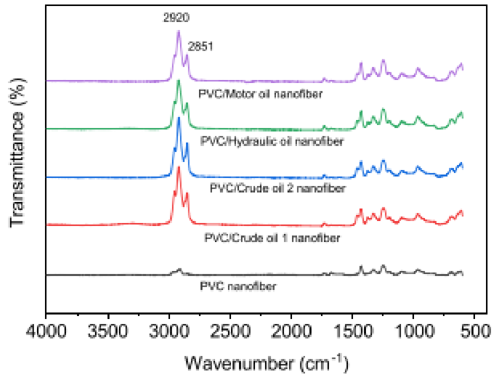
High-tensile-strength nanofiber mats will become increasingly popular. When compared to textile fibres manufactured from the same polymer, the mechanical properties of nanofiber mats are frequently inferior to those of textile fibres. Electrospinning produces a nanofiber mat with randomly scattered fibres. The Young's modulus increased by 2.2 percent from 2.2 to 9.1 MPa and 53 14 MPa, respectively. As demonstrated in Table 5, the mechanical properties of these PVC nanofiber mats differ. To improve the mechanical properties of PVC nanofiber mats, other polymers might be added. Tensile strength and length at break increased as the PU concentration increased from 0% to 100%, whereas the elastic modulus reached its maximum value when the PVC/PU mix was 50%. When 8 percent CA was added to a PVC nanofibers mat, the breaking strength rose by 350 percent, the breaking extension increased by 210 percent, the first modulus grew by 164 percent, the second modulus climbed by 227 percent, and the rupture work increased by 753 percent. The tensile strength of PVC/PEDOT nanofiber mats was 5.6 MPa, whereas PVC nanofiber mats were only marginally stronger at 1.2 MPa. The addition of clay particles to nanofiber mats boosts their mechanical strength, according to these studies. The same results were seen with electrospun pullulan/montmorillonite nanofiber mats. The clay particles utilised in this investigation had two tetrahedral and one octahedral layers of montmorillonite. After the polymer and clay have been dissolved in the solvent, the polymer can migrate through the clay layers and take up residence there. As a result of the improved bonding between the polymer and clay particles, the mechanical strength of the nanofiber mats is boosted. A decrease in the diameter of the nanofibers may improve the mechanical strength of the nano-fiber mats. As a result, clay particles cluster together in a solvent, producing large-scale blocks. As a result, when the clay concentration was high, electrospinning created nanofiber mats with a considerable number of defects. The mechanical strength of PVC/clay nanofiber mats is reduced when the Ca-bentonite concentration is more than 4% and the glauconite content is greater than 1%. The microscopic clay particles connected to the polymer are responsible for boosting mechanical strength, whereas the bigger clay particles are responsible for increasing porosity when generating nanofibers.



(a) (b)

Figure 7. Effect of clay content on the mechanical properties of PVC/clay nanofiber mats: (a)—tensile strength and (b)—Young's modulus.

In the FTIR spectra of clay particles in general and Ca-bentonite 1 particles in particular, two peaks representing the OH and SiO functional groups can be detected at 3620 and 993 cm1, respectively. Pure polyvinyl chloride and PVC/clay nanofiber samples were found to be indistinguishable (PVC). Similar results were also found for the PVC/Na-sebacate organoclay nanocomposite. After the oil has been removed from the PVC nanofiber mats, no new chemical connections have formed. The presence of oil has no effect on PVC nanofibers, according to this study. The CH bonding of the oil is reflected as peaks at 2920 and 2851 cm1 in the spectra of PVC nanofibers after oil removal. Thermal stability of nanofibers in PVC/Clay. PVC and PVC/Ca-bentonite 1 nanofiber mats were studied thermodynamically and thermally differentially. The TGA and DTA thermograms show that the degradation of PVC nanofiber mats occurs in two stages. In terms of TGA, PVC/clay nanofiber mats were not considerably different from PVC nanofiber mats. DSC was used to examine PVC and Ca-bentonite 1 nanofiber mats. According to the findings, when clay was injected, the glass transition temperatures of nanofiber polymer did not change.

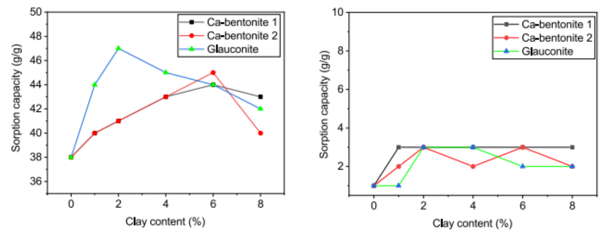


9. FTIR spectrum of PVC nanofiber mats after removal of oil.

XRD results for PVC/Clay Nanofibers. X-ray diffraction patterns of PVC/clay nanofiber mats. PVC is discovered to be an amorphous polymer with a big peak at 30° on the diffraction map. This might be explained by the fact that, as previously indicated, clay particles can be located in the crevices between nanofiber mats or are covered by the polymer. In a composite form, the hydrophobic polymer PU in conjunction with clay has comparable properties.

Oil Sorption Capacity of PVC/Clay Nanofibers

Clay Content Has an Impact on Sorption Capacity. The addition of clay particles to nanofiber mats improves their sorption capacity. Nanofiber mats required to become more porous in order to increase their sorption capacity. As shown in the images, PVC/clay nanofiber mats have a higher water adsorption capacity than PVC nanofiber mats. The surface tension of PVC varies between 32 and 38 mN/m. Surface tension is higher than that of oils and lower than that of seawater. PVC-based materials can be used for oil sorption and oil-water separation.



(a) (b)

Sorption capacity of PVC/clay nanofiber mats: (a)—motor oil and (b)—water.

PVC nanofibers have a larger surface area, which improves their capacity to absorb oil. Temperature and Oil Sorption Capacity The capacity of the nanofiber mat to absorb oil is highly influenced by temperature. Even in cold climates like the arctic, air temperature varies depending on the season and location.

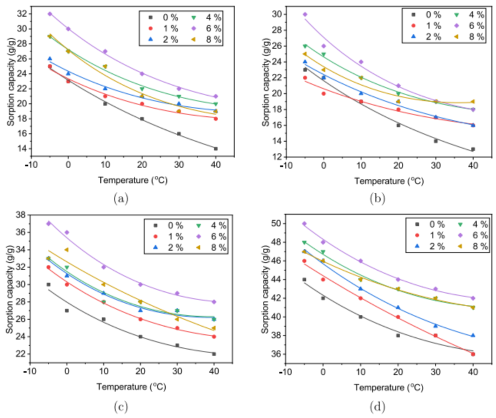


Figure 13. Effect of temperature on oil sorption capacity of PVC/Ca-bentonite 1 nanofiber mats: (a)—crude oil 1; (b)—crude oil 2; (c)—hydrau oil; and (d)—motor oil.

As a result, it's vital to test the nanofiber mats' oil absorption at various temperatures to ensure their suitability for usage. How does temperature effect the sorption capacity of PVC/Ca-bentonite nanofiber mats for different oils? Researchers discovered that when the temperature rises, the sorption capacity of nanofiber mats diminishes. At lower temperatures, nanofiber mats have a higher absorption capacity. The nanofiber mats remain effective even when the temperature increases over 40 °C due to their high sorption capacity. PVC/clay nanofiber mats show amazing potential as oil sorption materials in cold settings like the arctic and hot ones like the equator.

2. Conclusion

The nanofiber mats' durability will also be an issue. There have been claims recently that adding natural polymers to nanofiber mats can strengthen them. Individual nanofibers were shown to be more durable than nanofiber mats, which were found to be less durable due to their random fibre arrangement. More study on how to make nanofiber mats stronger is now possible. Nanofibers with a diameter of less than 100 nm have much higher strength and modulus than those with a larger diameter.

Table 3. Composition of the Substances of the PVC/Clay Solution

the concentration of solution wt %/v	mass of PVC (g)	mass of clay (Ca-bentonite 1, Ca-bentonite 2, and Glauconite) (g)	clay content, %	volume of THF (mL)	volume of DMF (mL)
15.2	3	0.03	1	10	10
15.3	3	0.06	2	10	10
15.6	3	0.12	4	10	10
15.9	3	0.18	6	10	10
16.2	3	0.24	8	10	10

One of the potential applications for PVC nanofiber materials is to enhance the environment, such as cleaning the air, removing oil from water, and creating corrosion-resistant materials. Wearing PVC nanofiber-based protective clothes might help individuals fight diseases and protect them from toxic substances. Despite this, little study has been done on the use of PVC nanofibers as a composite reinforcement component. Materials with a lot of space and good thermal characteristics may be made with PVC nanofiber.

PVC nanofibers are used in window panels that filter out air and germs, keep moisture out, and protect against radiation. On the other hand, PVC nanofibers offer excellent features such as great corrosion resistance and water repellency. They may thus be utilised to create waterproof fabrics. People who want pipes to last may be interested in research into PVC nanofiber as a corrosion-resistant material for pipes. Clay particles can be found in nanofiber mats in two places: on top of polymer nanofibers or in the nanofiber mat's empty area. Clay particles increased the porousness, strength, and ability to retain oil in the PVC/clay nanofiber mats. Clay lifts the nanofibers and creates gaps around them when it is spread out in the voids of the nanofiber mats. PVC/clay nanofiber mats have more pores than pure PVC nanofiber mats, which explains why. The number and size of clay particles in the PVC/clay nanofiber mats induced a change in the mats' Young's modulus. The findings demonstrate that the PVC/clay nanofiber mat is quite effective at absorbing cold.

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