Applications of Polymer Materials in Power Industry, Tissue Engineering and Fuel Cells

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Abstract. A huge effort has been done over the past 20 years to research the possible electrical benefits of such newly developing materials, polymer composite, and a significant amount of data have been published. Recent research suggests that polymer materials are capable for insulating system particularly unfilled XLPE and epoxy resins or filled with many types of fillers. The principal applications for polymer composites by XLPE and epoxy resins include cables, motors, and generators, but further study is needed to enhance their capabilities. This research will mainly introduce the application of polymer materials in the fields of power Industry, medicine and fuel cells. Some typical polymers, including polyglycolic acid (PGA), poly(lactic acid) (PLA), collagen, polypyrrole, polyacetylene and polythiophene, will be introduced in detail. We expect that the advantages and disadvantages of polymer functional materials in these application fields can provide a new idea for the development of new functional polymer materials in the future.

Keywords: Polymer Materials, Application, Power Industry, Medicine, Fuel Cells.

1. Introduction

Polymer is a type of macromolecule which consist of a massive amount of repeating monomer (subunit). For example, cellulose is some nature polymers that play significant role in biological process. Meanwhile, polyethylene, nylon and Teflon are some common synthetic polymers in our daily life. However, it is somehow more relevant and essential to human-being life because synthetic polymers can be engineered or tailored for desired application and special needs. Natural rubber is a polymer that made from isoprene units and some impurities. It's expensive, unreliable and not ideal for traction performance and rolling resistance. Because of its thermoplastic property, it may flex in warm temperature, while synthetic rubber is cheaper, reliable and temperature resisted. Polyethylene is the polymer that we deal with the most in our life. Polyethylene has a broad application range. Plastic container, bottles, crates, trays, bags, plastic toys, films, tubes and caps for food packaging are all made from polyethylene. Three main types of branched is LDPE, LLDPE and HDPE. They vary from chemical resistance, temperature resistance, flexibility, and tensile strength. For example, LLDPE has the best tensile strength and HDPE is excellent chemical resistance. Polyethylene is the polymer that we deal with the most in our life. Polyethylene has a broad application range. Plastic container, bottles, crates, trays, bags, plastic toys, films, tubes and caps for food packaging are all made from polyethylene.

The biggest advantage of polymers is that the properties of polymer materials are determined by their structure, and different properties of polymer materials can be obtained by controlling and modifying the structure. Secondly, different from metal and ceramics, the motion unit of polymer is chain segment, and the motion mode of the chain is relative motion and relative slip of the chain. Therefore, the polymer has Tg and Tf transition temperature. Below Tg, the polymer is in glass state and can be used as plastic and fiber. When the temperature is between Tg and Tf, the polymer is in rubber state and can be used as rubber. Above Tf, the polymer is in viscous flow state, which is conducive to processing. Thirdly, polymer materials have excellent electrical insulation because it is

basically connected by a covalent bond and lacks free electrons. Fourthly, compared with other traditional chemical materials, polymer materials are lighter in mass and rich in variety, and can be used in various fields.

Polymer materials also have some disadvantages. Firstly, polymer materials are usually considered to be not eco-friendly enough, the processes of production, using products and dealing with the waste have can cause a certain degree of environmental pollution. Take polyvinyl chloride as an example, ethylene, which is the raw material used in the synthesis process, is very harmful to human health and can cause chronic poisoning. In addition, it is necessary to use a lot of toxic additives in the polyvinyl chloride process, which can directly cause cancer to human body. Even some non-toxic additives can also cause bioaccumulation pollution. Secondly, the thermal conductivity of polymer materials is very poor. Therefore, it requires high heat dissipation ability of equipment in the process of polymer synthesis and processing. Moreover, polymer materials are easy to age, so the performance of polymer materials will decline after long-term use.

Polymer materials have been widely used in a diverse of different fields. For agricultural production, polymer chemical fertilizer is a new product in recent years. It has little pollution to the environment, high utilization efficiency and is beneficial to the development of ecological agriculture. For the application of polymer materials in the field of medicine, both pharmaceutical packaging and medical equipment are inseparable from the polymer materials, such as tablets and film clothing tablets using hydroxypropyl methyl cellulose and polyethylene pyrrolidone. For public pipelines, polymer materials not only have long life, excellent performance of corrosion resistance, but also have strong resistance. At present, the newly laid urban gas outdoor pipeline is HDPE pipeline, which has no pollution after combustion, energy saving and environmental protection, and there is no risk of leakage. For the application of polymer materials in aerospace, with high temperature resistant adhesive as an example, it can be used under temperature conditions of more than 150 degrees, with strong heat resistance. As a result, this research will mainly introduce the application of polymer materials in the following three aspects: power Industry, medicine and fuel cells.

2. Application of polymer materials in power industry

As technology grown rapidly, more and more advanced, engineering materials are on increasing demand. It is not easy to design and optimize electric insulation systems in a smaller and compact equipment while having better electrical, mechanical, and thermal performance compared to traditional ones [1]. Polymer materials can be used in power and high-voltage engineering, particularly insulating system based on cross-linked polyethylene and epoxy [2,3]. They give enhanced improved insulation systems which conduct at severe condition, high temperature and electrical stress. Besides of its improved performance, its relatively low-cost and energy-efficient satisfy marketable products. Due to their improved performance, such as their high strength, high heat resistance, light weight, toughness, and stability in thermal condition and chemicals. Composite materials are intended to replace traditional materials.

Nanocomposite materials with polymer matrix can function well under high-voltage conditions, as shown in Figure 1. Polymers are classified into thermoplastics, thermosets and elastomers by their physical property and chemical structure. Thermoplastic is defined as any plastic materials that become moldable above certain temperature and become solid when cooled. The process is completely reversible and will not affect plastic physical integrity. PE, polyamides, linear polyester, PP and PVC are examples of common thermoplastic polymers, and can be classified into two categories: amorphous and crystalline [4]. Amorphous thermoplastics have characteristics of liquids. Crystalline or semicrystalline materials are processed above both the crystalline phase's melting point and the amorphous phase's glass transition temperature (Tg) [4]. Thermoplastic materials are used in electrical field. In the 1970s, PE was specifically utilized in an insulating layer between medium-high voltage energy cables. PE based insulating systems were replaced by XLPE because of massive cable failures. During that period, although high-voltage direct current (HVDC) is currently be able to use

in cable technology, XLPE is mostly used for alternating current (AC) applications. However, it is still challenging to adapt the cable to support higher voltage applications, downsizing, better purity, and more dispersion of the inorganic filler [5].

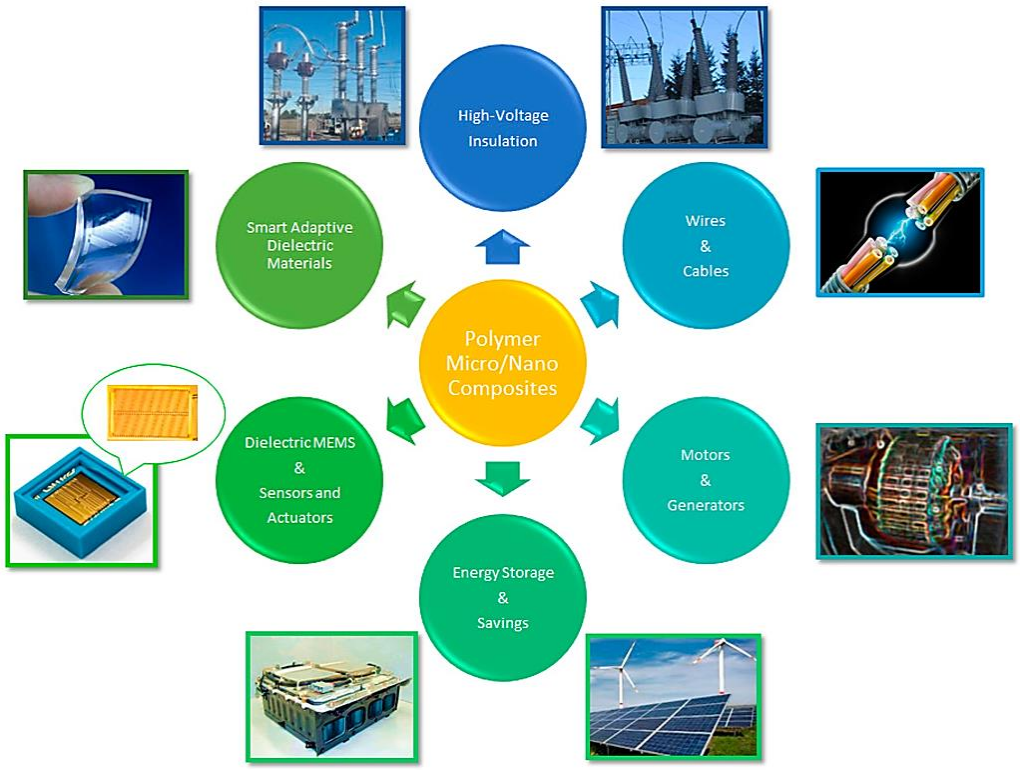


Figure 1. Application of polymer materials in power industry [6]

PE, polyester, silicone, imide, and epoxy resins are some of the most popular polymers utilized in nanocomposites. PE exhibits decent electrical, mechanical properties, but they have to operate at low temperature. By adding inorganic filler, the working temperature is raised and the mechanical qualities are enhanced. Thermosetting polymers have lower heat conductivity but improved operating temperatures [4]. A polymer and filler-based mixture of two or more components is called a polymer composite. Different geometries of fillers, such as fibrous spheres, fibrous shapes, etc., are possible. Utilized fillers come in a wide variety of shapes, sizes, chemical compositions, and inherent characteristics [4]. They are typically solid or molten materials with stiff properties that are immiscible with polymer matrix to generate a variety of morphologies. With respect to chemical, Inorganic fillers (oxides, hydroxides) and organic fillers can also be categorized (carbon, graphite, nature polymers and synthetic polymers). The polymer matrix and filler, integrations and adhesion between fillers and the polymer matrix, all influence and determine the attributes of composite materials.

Compared to original composites, polymer composites have unique features. Depending on the desired mechanical, thermal, and electrical properties, fillers are chosen for application. For instance, calcium carbonate is frequently utilized for low-cost and relatively high numbers of deposits [4,7], while CNTs increase thermal and electrical resistivity, Al_2O_3 is typically used under high temperature. Nanofiller is able to dramatically alter or improve a variety of properties, including electrical, mechanical, and thermal ones [7]. As shown in Figure 2, a diverse of different composites can exhibits different thermal conductivity.

Two novel electrical uses are for structural and electronic composites. Polymer composites are made of resins and polymers that have been heavily filled with inorganic fillers for use in insulation engineering. This kind of structural material is typical. The standards for certain properties vary greatly. While electronic composites seek for good thermal conductivity and low thermal expansion, structural composites aim for high strength and high modulus. Due to all of these factors, the industry

is constantly exploring for better substitute materials that are both more affordable and more effective. Although composite materials provide benefits including light weight, resilience, and better environmental protection, they may also incur production expenses. In the beginning, ceramic and natural materials were used to make solid electrical insulating materials for high-voltage applications. It continues to be the main insulating method used as power transformers, sub-water cable applications, high-voltage cables and bushings [8]. However, in recent decades, polymer composites with improved performance have been created. Electrical engineering applications that used plastics and epoxy resins made it possible to create insulating systems with specific qualities. Epoxies are able to generate electrical insulation, which is particularly useful to achieve a more compact electrical power equipment design, and plastics are generally easier to reshape and manufacture than ceramics and glass. To enhance the mechanical, electrical, and thermal qualities, fillers have been added. Mineral-filled epoxies become an ideal insulating chemical under different sites due to their high flexibility and simple manufacturing process. The aging of internal interfaces is an issue with epoxy resins [9].

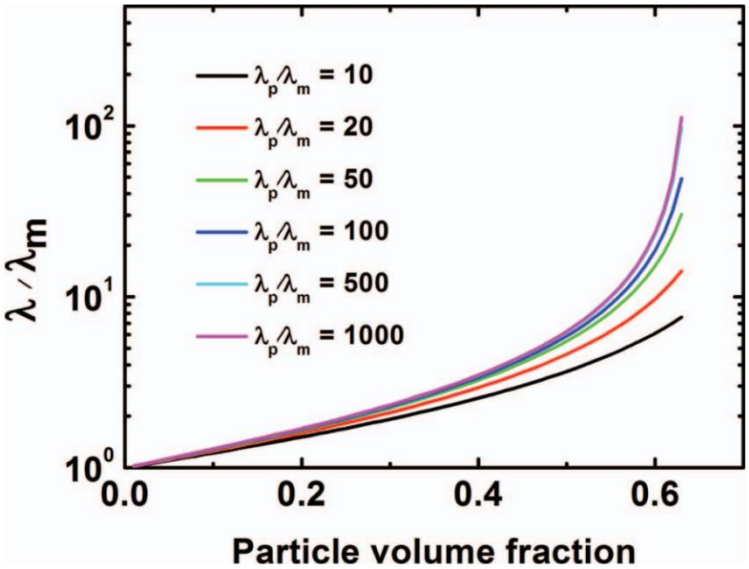


Figure 2. Different thermal conductivity of the composites by theoretical prediction [7]

3. Application of polymer materials in tissue engineering

3.1. Basic introduction to tissue engineering

Originated from organic matter, the polymer is suitable to be applied in biomedicine. This research will give information about how it is applied in tissue engineering, which is a promising area in modern biomedical engineering. The main aim of tissue engineering is to repair human organs and tissues. The basic process of tissue engineering is to obtain living tissue from human body, and to make the cells in the tissue propagate and expand in vitro by certain methods. At the same time, the bio-scaffolds with excellent biocompatibility, absorbable and degradable properties were prepared *in vitro*. The tissue cells cultured in vitro were immobilized on the scaffolds, and finally the scaffolds loaded with tissue cells were implanted into the diseased tissues or organs *in vivo*. As the scaffolds absorb and degrade in the body, the cells implanted in the body proliferate and secrete extracellular matrix, eventually forming corresponding tissues or organs for the purpose of repairing human organs and tissues.

Tissue engineering can be applied in various areas, which includes muscles, bones, cartilage, tendons, ligaments, skin, artificial blood vessels, and articular cartilage can all be repaired with it. Besides, it can be used to create bioartificial organs such a synthetic pancreas, liver, kidney, and other organs. Additionally, it can be employed for the delivery of drugs, the manufacture of artificial blood,

and brain prostheses. There are three elements of tissue engineering-cells, scaffolds and biological signals, among which scaffolds are the most important part. As a carrier for the proliferation of tissues or cells taken from the body, biological scaffolds need to be of excellent Biocompatibility. They are porous, three-dimensional structures that provide space for cell growth and expression of biological signals, so they are carriers of cell adhesion, differentiation, proliferation and migration.

A bioresorbable polymeric material is made to break down over time, at an appropriate speed, with no ongoing risk of a response to a foreign body. Throughout its service life, this material must offer considerable mechanical qualities such as scaffolding and retentive mechanical support. This part will introduce three typical types of polymers used in tissue engineering, including synthetic polymers [10] and natural polymers [11].

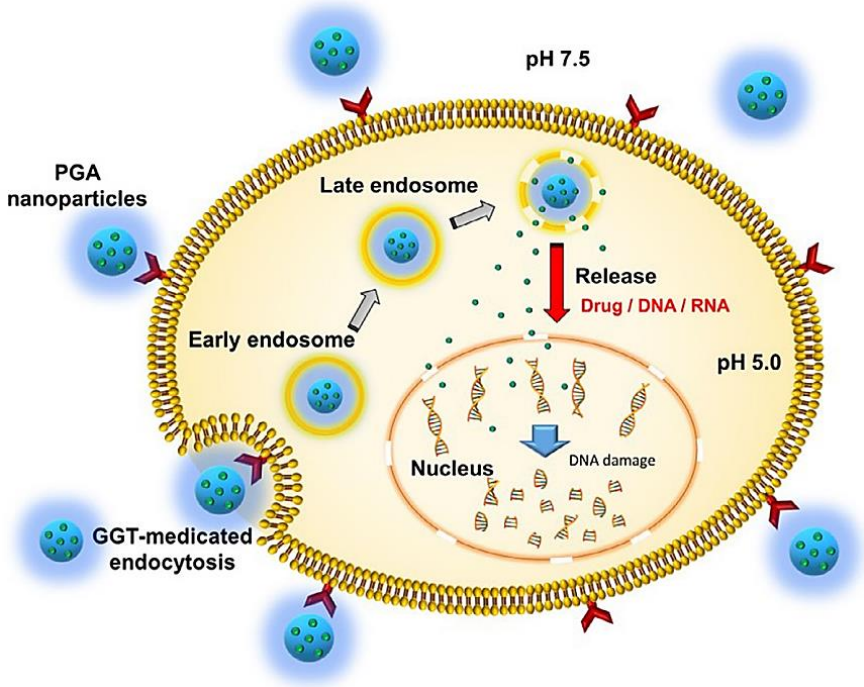


Figure 3. The delivery process of polymer materials in drugs, DNA and growth factors [12]

3.2. Application of PGA

Due to its numerous benefits, including its quick degrading behavior, outstanding mechanical qualities, and high biocompatibility, polyglycolic acid (PGA) is often employed as a bioresorbable tissue-engineered material. There are two main elements which contribute to the degradation of PGA—its hydrophilicity in rubber-like state and its hydrolytically cleavable chemical structure. Although the Tg of PGA (35℃-40℃) is above the ambient temperature, it could be lowered because of the water absorption in body environment. This makes the amorphous region transform into a rubber-like state, which together with its high hydrophilicity, will facilitate the degradation of PGA. On the other hand, PGA's narrow methylene spacing, which renders it more vulnerable to hydrolytic attack, also has the effect of speeding up the degrading process. The excellent performance of PGA makes it have a broad application prospect in the field of biomedicine. Nowadays PGA has been applied in the fields of wound healing, bone tissue regeneration and cancer therapy and so on [12], as shown in Figure 3.

3.3. Application of PLA

Poly (lactic acid) (PLA) which is a kind of synthetic material is also a very popular polymer in tissue engineering. PLA can be produced by two methods. One is from polycondensation of lactic acid. While the other is a method of ring opening polymerization and the raw material is cyclic dimer

lactide. Because PLA can be hydrolyzed without the need of enzymes and its byproducts can be removed by regular cellular metabolism, PLA is biodegradable.

Electrospinning is the most popular method of PLA preparing. This method makes it simple to adjust the properties of PLA, including porosity, pore size, and fiber size [13]. Another typical technique for making PLA is thermally induced phase separation (TIPS). A homogeneous polymer solution can be split into a solvent-rich and a polymer-rich phase by chilling the mixture or by adding an immiscible solvent [14]. PLA scaffolds can have different applications in tissue engineering, such as musculoskeletal bone repair and regeneration, nerve conduits and vascular scaffolds. However, PLA also have some defects in application. The degradation product of PLA is lactic acid which is likely to elicit an inflammatory response. Consequently, some researchers are working on new synthetic methods in order to mitigate this shortcoming.

3.4. Application of collagen

Collagen is a kind of protein which is in abundance in the animal body, belonging to insoluble fibrin, which is distributed in various organs and tissues, such as skin, bone, cartilage, tendon, cornea and so on. Gelatin is a partially denatured derivative of collagen, which mainly consists of a unique amino acid sequence glycine-proline-hydroxyproline. These sequences allow the gelatin to hold water molecules in place to form a helical structure. Collagen has antigenicity under physiological conditions, while gelatin has no antigenicity. Gelatin is easy to make into a thick solution and inexpensive.

As a natural polymer, gelatin has many advantages over other synthetic polymers. It is biologically active in the sense that it can promote cell adhesion and engage in interactions with signaling molecules. As a result, it is appropriate for tissue regeneration and cell transport. The gelatin is a perfect substance for drug delivery due to its gelling properties, tunable cross-linking density, and kinetics of degradation. In addition, gelatin can also be incorporated in other polymers to make composite materials of better properties.

4. Application of polymer materials for hydrogen fuel cell

A particularly significant use is conducting polymer for hydrogen storage and fuel cells, and the structural composition of the fuel cell is shown in Figure 4. Clean energy source hydrogen is a plentiful renewable energy source. Scientists have worked very hard in recent years to create materials that can store hydrogen. Due to their low cost, ease of synthesis, processability to obtain desired morphology and microstructure, ease of doping and recombination formation, chemical stability, and functional properties, conductive polymers have received extensive study as potential hydrogen storage and fuel cell membranes.

In hydrogen fuel cells, polymer electrolyte membranes (PEM), especially proton-conductive polymer electrolytes, are gaining popularity due to their simple and compact design, enabling the cell to provide high power density. The electrolyte membrane serves two important functions: (a) It acts as a barrier to separate hydrogen and oxygen from direct mixing; (b) It transports or “directs” protons from the anode to the cathode. The membrane material must be “proton-conductive” material. The important properties of solid polymer electrolytes as polymer electrolyte membranes are high proton conductivity, low electronic conductivity, low permeability of fuel gases and oxidants, considerable hydrolytic stability under operating conditions, appropriate water transport, chemical stability and low-cost [15]. Here are some common polymer materials in fuel cells.

Polypyrrole is known for its excellent electronic conductivity and excellent thermal stability. Conductive polymers are generally large molecules with conjugated π bond structure. The above polyaniline is a benzene ring structure, and the heterocyclic polypyrrole is the first example of heterocyclic polymers. The conductivity of these polypyrroles depends on iodine doping and can be about 1S/cm. Polyacetylene was first discovered in 1874, when the decomposition of acetylene into non-recracking solids was first described. Subsequently, research involved photochemical or

radiochemical methods of forming acetylene polymers (or oligomers). More practical methods for synthesizing polyacetylene were discovered in the 1920s and 1930s. The breakthrough in the synthesis of polyacetylene, especially linear polyacetylene, took place in 1958. At that time, the future Nobel Prize winner Giulio Natta first applied Ziegler-Natta catalyst to the polymerization of acetylene. As early as the 1960s, polyacetylene was considered a potentially conductive polymer. But it was conventionally synthesized polyacetylene with a conductivity of 0.00001S/cm, not much more than a semiconductor. Although its electrical conductivity was not significantly enhanced, the material was easier to process into films, which could be used for spectral studies.

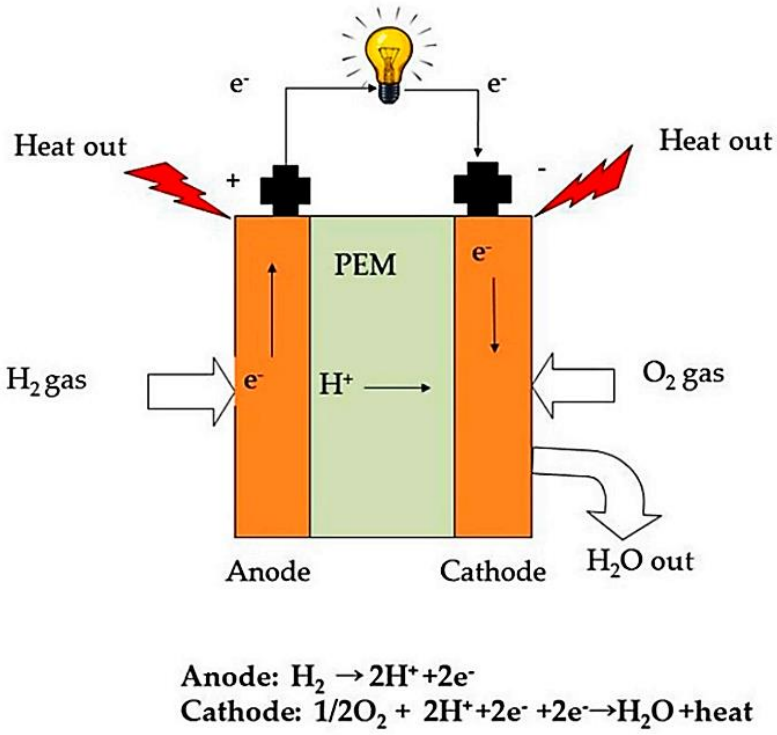


Figure 4. Schematic diagram of the structure of a hydrogen fuel cell [15]

However, compared with polyaniline and polypyrrole, the conductivity of polyacetylene at this time is still far from enough, not as promising as the first two. Using elemental analysis, the researchers found that a small amount of halogen impurity had a positive effect on conductivity. In the follow-up study, by adding bromine, the conductivity of polyacetylene has taken a qualitative leap—the conductivity of the doped polyacetylene has been enhanced by 10 million times, reaching the conductivity of 1000S/cm. Due to the difficult processing and instability of doped polyacetylene, so far, all attempts at industrialization have basically failed. It has been shown that substituted polythiophenes, such as poly3-alkylthiophene, have significant conductivity in the doped state. However, these polythiophene and polyacetylene, polyaniline and polypyrrole, the highly conductive form is unstable, especially humid air, is destructive to its performance.

Some promising alternative candidates are oxygen-substituted polythiophene because oxygen substituents can be further delocalized as stable free radicals and positively charged carriers. The breakthrough came when researchers extended the thiophene structure to a two-ring system. 3, 4-thickened thiophene of dioxane, dioxane, or dioxheptane by closing the loop of two alkoxy substituents. Initially, the most interesting candidate was the dioxane derivative, 3, 4-methylene dioxythiophene (MDOT). However, 3, 4-methylene dioxythiophene (PMDOT) produced by electrochemical polymerization has low conductivity and poor stability of the doped state. Finally, it wasn't until the introduction of the 3, 4-ethylenedioxythiophene EDOT, a 6-dioxane, that the technology really broke through. PEDOT obtained by the polymerization of ferric chloride showed almost immediately the special properties of the target polythiophene, especially in the doped state, with very high conductivity and stability [16].

5. Conclusions

This research analyzes the application of different polymer materials in the fields of power industry, medicine and fuel cells. Although different kinds of polymer materials have been used, it is still difficult to make huge progress on the study of nanocomposites materials. There are many questions that need to be investigated. It will be achievable to get the appropriate materials with specific qualities suitable for high-voltage applications once all the mechanisms have been discovered and explained. Owing to its excellent biocompatibility and low density, polymers are ideal materials for tissue engineering. However, both natural polymers and synthetic polymers have their own defects which are to be improved by researchers. Due to their unique properties, conductive polymers are not only widely used as conductive materials, but also have potential application value in energy, optoelectronic devices, sensors, molecular conductors and other fields.

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