Immobilization of Enzymes by Polymeric Materials

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Abstract: Enzymes are the highly efficient biocatalyst in modern biotechnological industries. Due to the fragile property exposed to the external stimulus, the application of enzymes is highly limited. The immobilized enzyme by polymer has become a research hotspot to empower enzymes with more extraordinary properties and broader usage. Compared with free enzyme, polymer immobilized enzymes improve thermal and operational stability in harsh environments, such as extreme pH, temperature and concentration. Furthermore, good reusability is also highly expected. The first part of this study reviews the three primary immobilization methods: physical adsorption, covalent binding and entrapment, with their advantages and drawbacks. The second part of this paper includes some polymer applications and their derivatives in the immobilization of enzymes.

Keywords: enzyme; polymer; immobilization

1. Introduction

Enzymes are the biocatalysts of mother nature [1]. Those biocompatible and biodegradable materials are derived from the cell of flora and fauna [2]. Whether people realize it or not, enzymes are more closely related to our lives than we thought. Generally, salivary amylase is the first enzyme the foods meet when they enter our body and ATP synthases are the essential material for photosynthesis. Without them, the daily life we are familiar with may look very different. Typically, the enzymes can catalyze the many complex chemical reactions in mild conditions, bind their substrates and then use the functional group to achieve the catalysis [3]. Based on their outstanding properties like high selectivity, activity and specificity, the enzymes are promising catalyst candidates in many areas, such as food chemistry, fine chemistry, medical chemistry, fuel industry and control environmental contamination [4]. Most of the enzymes are proteins. One property of them is that they are marginally stable when they leave their native habitats because the amino acid groups on the protein are susceptible to the harsh environment [5]. In addition, many enzymes are water-soluble, which means they are not collectible and reusable in most circumstances very expensive. The production of enzymes is costly and the pure enzymes are usually not considered. The suitable catalyst for industrial-scale reactions if the factories want to remain the economy of the biocatalyst. To address this problem, numerous efforts have been put into this area by developing the immobilization of enzymes. Immobilization of enzymes, as the name suggests, is using the exterior material to stabilize the enzyme, to make them collectible and reusable to reduce the cost. The immobilized enzymes should have the free enzymes’ characteristics, such as high activity and selectivity. They are also required to have a good performance in recyclability, applicability and stability of thermal, temperature and pH [6].

The materials used in immobilization can be divided into inorganic materials and organic materials [7]. The SiO2 is an outstanding example for the inorganic materials. Many applications in the field of enzyme immobilization have been reported [8–10]. Scientists believe that the inorganic supports are the material of choice in the area’s immobilization
due to the thermal, mechanical and microbial resistance and the cost [11,12]. However, the organic supports, particularly the polymers, have drawn much attention from scientists worldwide because of the other features the inorganic materials do not have. Compared with their competitors, the polymers are relatively simple to produce and modify to interact between polymers and enzymes [13,14].

In this article, we focus on polymetric immobilized enzymes. First, we introduce different techniques used for enzyme immobilization. Second, we discuss the polymers used for the immobilization of enzymes, along with their recent applications.

2. Methods of Immobilizing Enzyme

Because of the properties of the different supports and enzymes, it is impossible to find a universal preparation method for immobilization [15]. Then, picking an appropriate preparation method for the immobilization is the significant beginning. As shown in Figure 1, there are four different main methods of enzyme immobilization [16]. However, the cross-linking method is a carrier-free approach based on the formation of precipitates by adding the conjugate agent such as glutaraldehyde [17]. Which does not need the participation of polymeric materials, in that case, this method does not apply to this review. According to the relative positions and the contact methods of the enzyme and support material, the rest three method enzyme immobilization methods with the polymer can be roughly cataloged into three different aspects, absorption to the surface of the polymer, covalent binding to the surface of the polymer and entrapment inside the polymer particles.

Figure 1. Different methods for immobilizing enzymes [16].

2.1. Adsorption

Adsorption is mainly driven by the van der Waals interactions, hydrophobic interactions, or electrostatic interactions. In this method, there is no formation of the chemical bonding between the polymers and the enzymes and does not involve functionalization of the polymers, which means there is no or significantly less configuration change of enzymes. The immobilization of enzymes by van der Waals interactions, electrostatic and hydrophobic adsorption can make the activity of the enzyme get maximum preservation. In addition, this method is relatively easier, simpler and cheaper to perform [18].

For the immobilization of enzyme by van der Waals interactions, the supports and polymer both need lipophilic surface areas [19]. Although this immobilization technology
has many advantages, it still has some disadvantages. The van der Waal interactions are too weak to hold the enzymes on their supports due to environmental changes, such as pH and temperature. Therefore, enzymes immobilized by this absorption method face low stability, which limits the usage in industry. Physical adsorption is driven by hydrophobic interaction between polymer and enzymes [20]. However, van der Waals force is too weak to force the enzyme immobilized on a hydrophobic carrier and the entropy is indeed the real driven power [19].

Electrostatic interaction is a method by charging the enzymes and absorbing them on the supports with the opposite charge [21]. There are two techniques developed by this primary method. The first one was called layer-by-layer (LbL) deposition, which was developed in 1991 [22]. The second one is called electrochemical doping, which puts the polymer film in the enzyme solution, followed by electrochemical oxidation [23].

2.2. Covalent Binding

Using the covalent bonds between the functional groups of enzymes and the support materials to immobilize enzymes is widespread [20,24]. In this method, enzymes are held tightly on the surface by covalent bonds, which means the enzymes immobilized in this method are less likely peeled off during the reactions and more suitable for industrial-scale reactions [25]. Furthermore, covalent bonds can ensure that this method has a high loading efficiency [26], which is not available in other methods. However, the intense bonding comes with consequences and the enzymes are chemically modified. Thus, the enzymes have a probability of losing the partial catalysis function [27,28]. One of the challenges here is that, during the synthesis, the amino groups of the enzymes with catalytic function should not be part of the covalent bond [18].

2.3. Entrapment

Unlike adsorption methods, enzymes are not straight located on their supporters’ surface in the entrapment method. Instead, they are physically trapped in the polymeric matrix, which allows the substrate and products to come and go with the hold position of the enzymes. This method can protect the enzymes from harsh environments and enhance stability. However, same as the physical adsorption, enzymes are physically confined in the polymer. Physical interactions are also relatively weak to prevent leakage completely without forming the chemical bond [29]. The encapsulation method can be considered as a type of entrapment method [30].

3. Polymetric Material Used for Immobilization

Choosing the right support is a very significant step in the immobilization of enzymes. Ideal support should be selected with the correct suitable parameters, such as the particle size, surface charge, surface area, hydrophobic/hydrophilic ability to be edited and its stability. Numbers of nature and synthesis polymer have been widely used as the supports of immobilization of enzymes. The chemical and physical properties of some frequently used natural and synthetic polymers (Figure 2) are described in the following section.
Figure 2. Some frequently used natural and synthetic polymers. From 1 to 6 are the polysaccharides: Chitosan, Cellulose, Dextran, Alginate, Pectin and Agarose; from 7 to 12 are the synthetic polymers: Poly(4-vinyl pyridine), Polystyrene, Polyurethane, Polyaniline, Poly(Lactic Acid) and Polyethylene glycol.

3.1. Natural Polymers

Among various polymers, the following polysaccharides, cellulose, chitosan, alginate and their derivatives are frequently used in enzyme immobilization. In these polysaccharides, we would like to use chitosan (one in Figure 2), the second abundant natural polymer in the world, as the example to introduce [31]. Chitosan is the N-deacetylated derivative of chitin and they share a very similar structure with cellulose, the hydroxyl group replaced by the acetylamino group and the amino group on C2, respectively [32]. Due to the huge amount, easy access, low toxicity, solubility, biodegradability, biocompatibility and
readily modified, chitosan rapidly became a research hotspot in drug delivery in recent years [33–35]. As a promising candidate for enzyme support, chitosan has many different formats in the application of immobilization, such as beads, gel and microspheres [36]. Yi et al. developed chitosan beads with amino acid modification to immobilize the *Candida rugosa* lipase [37]. Noda et al. immobilized sweet potato β-amylase on the chitosan beads by the simple adsorption. Not only the activity remained good, but the thermal stability had also been proved higher than the free amylase [38]. Chitosan nanofibrous membrane also has been reported for the lipase immobilization by Huang et al. [39]. Tang et al. utilized the chitosan nanoparticles to immobilize the neutral lipase [40]. In addition, those forms, the composites of chitosan with other materials, are also drawn much attention. Hou et al. immobilized lipase by the Fe$_3$O$_4$-chitosan hybrid microcapsules [41]. In addition, Chen et al. used Fe$_3$O$_4$-chitosan-sodium tripolyphosphate to develop a co-immobilization biocatalyst with alcalase and trypsin [42].

Rather than chitosan, other polysaccharides also been well studied. Cellulose (2 in Figure 2), the most abundant biopolymeric raw material, is found in different life forms. Xing et al. from Louisiana use the cellulose microfiber to immobilize the laccase and urease [43]. In addition, Singh et al. used one kind of modified cellulose with inorganic material—carboxymethyl cellulose-silver nanoparticle (AgNp)-silica hybrid as the immobilization supports for the amylase [44]. Dextran (3 in Figure 2), a highly hydrophilic neutral polysaccharide, which is also used as the support of enzymes. A cellulase conjugate of cellulase and dextran was prepared by Arslan et al. [45]. The cellulase/dextran conjugate showed better activity and thermal stability than the free enzyme [45]. In addition, the conjugate protected for enzymes from the surfactant [45]. Alginates (4 in Figure 2) are a member of linear unbranched polysaccharides, naturally occurring biopolymer can be extracted from brown seaweed, it usually can mild gelation by adding divalent cations such as Ca$^{2+}$, Sr$^{2+}$, or Ba$^{2+}$ [46]. Flores-Maltos et al. immobilized the *aspergillus niger* tannase in the alginate-Ca$^{2+}$ polymers [47]. From their experiment result, the immobilized tannases have a better performance than the free enzyme in applying the liquid system [47]. Pectin (5 in Figure 2) is a natural polysaccharide that can be found in the lamella and cell walls of the plant. This high molecular weight macromolecule has biocompatibility and is used in immobilized cells, proteins and drugs [48,49]. Agarose (6 in Figure 2) is a natural linear component natural polysaccharide that can be obtained from an algal source. Guerrero et al. reported they immobilize β-galactosidase with lyoxyl-agarose and its three different heterofunctional modified glyoxyl-agarose materials(amo-oxy-glyoxyl-agarose, carboxy-glyoxyl-agarose and chelate-glyoxyl agarose) by multi-point covalent bond [50].

### 3.2. Synthetic Polymers

Synthetic polymers are those polymers which do not exist in nature and are artificially made. Here, in this section, we would like to use two synthetic polymers as examples. Poly(4-vinylpyridine) (P4VP) (seven in Figure 2) is a synthetic polymer derived from pyridine with a vinyl group at C$_4$. The polymer consists of multiple 4-vinylpyridine monomers attached at the C$_4$ positions of each monomer. Poly(4-vinylpyridine) (P4VP) is an effective candidate due to the nitrogen atom in its pyridine group being a strong hydrogen-bond acceptor [51–53]. Suthiwangcharoen and Li et al. generated novel Core-Shell nanoparticles by P4VP to immobilize glucose oxidase and horseradish peroxidase on the single particles, the activity of enzymes was increased about 20% compared with free enzymes [54]. Polystyrene (8 in Figure 2), one of the cheapest synthetic polymers, is already available in many sizes [55]. Li et al. utilized gigaporous and macroporous polystyrene microspheres to immobilize the lipase [56]. The reusability is very impressive and the activities can remain nearly 100% and 93% even after 100 recycling [56]. Not only the porous polystyrene can achieve the goals, but the nonporous polystyrene particles also have a good performance. Dantas et al. studied the nonporous polystyrene particles, compared with the soluble enzymes, the immobilized enzymes showed an improvement in the ester conversion [57].
Polyurethane (nine in Figure 2), a commonly used polymer in daily life, also can be used in enzyme immobilization. Cipolatti et al. immobilized the lipase on the polyurethane nano-supports, which showed higher thermal stability and higher activity [58]. Polyaniline (10 in Figure 2), an environmental stability synthesized conducting polymer [59]. It also has excellent redox recyclability and can allow scientists to build the polymer with significant differences by just with simple acidic or basic treatment [60]. Lee et al. immobilized lipases on the polyaniline nanofibers; the immobilized enzymes can remain more than 80% even after 32 days under room temperature [61]. Poly(lactic acid) (11 in Figure 2) is thermoplastic, high-strength, high-modulus, biocompatible and bioabsorbable polymer [62]. Siqueira et al. used the poly(lactic acid) and chitosan to produce electrospun fiber and it was employed to immobilize lipase [63]. Calzoni et al. prepared poly(lactic acid) film to immobilize the proteases by covalent binding to treat biomass waste [64]. A linear polymer, polyethylene glycol (12 in Figure 2), is neutral polyether that is formed by the reaction of ethylene oxide to an ethylene glycol [65]. It is rarely singly used as the support for the enzyme, but it is used as the spacer between the enzymes and polymers or inorganic supports in the application of the enzyme immobilization wildly. Polyethylene glycol, as the Manta et al. studied the spacer with the beaded thiol–agarose, the polyethylene’s presence led to enzymes’ immobilization yields [66]. Wang et al. studied a polyethylene glycol derivative, the polyethylene glycol diacylchloride as the spacer between the lipase and the ultra-high specific surface cellulose fibers, the immobilized lipases still remain relatively high activity than the free lipases after expose to the organic solvents [67].

4. Applications
4.1. Applications in Food

In this section, we would like to focus on the polymer as the supports in line with the tone of the whole article. Dairy products are one of the primary protein resources for people. However, about three-quarters of the people will have lactose intolerance at some time in their life, which can come with the symptoms such as abdominal pain, diarrhea and flatus when they have milk, cheese and other dairy products [68]. Normally, commercial milks have a lactose level of 4–6 g/100 mL. Scientists in food industries used modern biotechnology to produce lactose-free milk with has lactose levels less than 0.25 g/100 mL to fulfill the demand of people [69]. To achieve this goal, immobilized lactase plays an important role. Lactase immobilized on different polymer materials has been reported [70]. Chitosan, the natural polymer and its derivatives were widely used in the dairy industry. The usage of chitosan-grafted hydrogels has been reported [71]. The chitosan hydrogel can help the lactase reused without losing the activity. The combination with inorganic material also has a good performance. Ke et al. created a novel magnetic chitosan microsphere with Fe₃O₄ as the enzyme support. The immobilized lactase by this material has better pH and thermal stability and it also showed higher activity than the free enzyme [72]. In their study, immobilized enzyme reached the highest activity at pH = 8, while the free enzyme only could remain about 20% of its activity [72]. In addition, dairy products, juices are also popular items in the markets, the immobilized enzymes are also used wildly in this area. For example, pectinases can be in the wine making industry, there are roughly four steps in the entire process, the first step is pressing and maceration, followed by the fermentation, clarification and the final step will be the stabilization and aging [73]. Several different kinds of enzymes are involved in different steps. Many of them can be immobilized by polymers. For example, in the maceration, Ruiz et al. used hollow alginate beads to immobilize glucose oxidase in the model must, which can be reused seven times with final 37% efficacy [74]. In the rest of the steps, immobilized glycosidase, pectinases and lysozyme have also been well studied with the polymer [75–77]. Ureases have also been reported to be immobilized covalently by chitosan-based material in the wine application (Figure 3a) [78]. In addition, to the purpose of helping food obtain a better flavor, immobilized enzymes can also help food keep fresh. Niu et al. prepared the lysozyme-N-succinyl chitosan, which makes the activity of immobilized lysozyme
increased by 256% compared with free lysozyme, more importantly, it can help the shelf life of strawberry extend by 3 days (Figure 3b) [79].

Figure 3. (a) The scheme of acid urease immobilization on GO-CS composite beads [78]; (b) the scheme of preparation process of lysozyme-N-succinyl chitosan [79].

4.2. Application in Biomedical

Im mobilized enzymes are enjoying the rising interest in the food industry and the pharmaceutical industry. These biocatalysts can meet the increasing requirement of drug’s regio-, stereo- and enantioselectivity of drugs in modern society [80]. According to Torchilin, the possible methods for immobilized enzymes in the biomedical industry can be divided into two principal groups [81]. The first method would use enzymes for prolonged circulation in the body within bloods, tissues and organs [81]. The second one would use enzymes for local depositions, such as specific organs or tissues [81]. Both of those methods require polymer support. The different support methods for the Poly(ethylene glycol) can be used as typical examples shown in Figure 4 [82].

Enzyme therapy is one of the most investigated and promising applications of immobilized enzymes. Enzymes naturally regulate biochemical processes and are highly specific, making them grouped into different therapeutic applications [81]. Enzymes can be used in surface modifications on prosthetic devices, artificial apparatuses and other structures like dressings to heal wounds [81]. Bio-catalysis is becoming applicable at both the industrial and laboratory levels for the synthesis of chiral compounds. One of the most utilized enzyme types is lipases as they can perform esterification, transesterification and aminolysis and are high in stability and activity [80]. Chiral diols and optically active alcohols are also for the production of fine and chiral chemicals and some pharmaceuticals [80]. Urease is one of the recognizable enzymes in the biomedical field. It can be used to determine of amount of urea in the blood and urine. Polyaniline, cellulose and poly(methyl- methacrylate) were reported as the supports for the immobilized urease by adsorption and it can help the enzyme maintain stability after a long storage period [83]. One of the problems
that can arise from the utilization of immobilized enzymes in biomedical applications is the high costs of the enzymes themselves and the preparation materials and processes. Another problem that arises is difficulties due to the nature of the enzymes themselves [81]. Other issues that may arise can be attributed to unwanted waste products of the immobilization processes in manufacturing APIs, thus causing toxicological issues [80].

![Diagram of carrier systems for drug delivery](image)

**Figure 4. Overview of carrier systems for drug delivery [82].**

### 4.3. Applications in Biofuel Industry

Petroleum is a non-renewable resource. Biodiesel fuel prepared from biomass is more environmentally friendly with less sulfur oxide production than conventional diesel. In recent years, the demand for biodiesel fuel has grown exponentially due to environmental and economic factors. Even though the chemical process of producing biodiesel has been studied a lot, the removal of the catalyst and the tremendous energy are the major drawbacks of the chemical process [84]. The polymer immobilized lipase has also been introduced as a biocatalyst for biodiesel since the late last century and is essential for many possible applications. When being compared to free lipase, the immobilized lipase had a higher activity (Iso). Different feedstocks and usages of polymers have been reported. Some of the substrates for transesterification processes being investigated are safflower oil and sunflower, soybean and waste cooking oils [84,85]. Lipase also can be immobilized on copolymer support by the adsorption method to hydrolysis of palm oil in a lecithin/isooctane system, which also has about 70% activity of the free lipase [86]. Lipase can also be immobilized onto other supports such as chitin by chemical binding and hydrophobic sol-gel support by entrapment [85]. Lipase can also be immobilized on the Fe₃O₄-poly(GMA-co-MAA) composite, as shown in Figure 5a, the immobilized enzymes can remain 79.4% of biodiesel yield after 5 cycles [87]. By this method, the immobilized enzyme could remain about 60% activity at 80 °C, where the free enzyme was almost completely deactivated [87]. Sometimes, one kind of enzyme loaded on the polymer are not sufficient for the designated mission. Therefore, two or more enzyme species can be co-immobilized together on the support to achieve the goal [88]. Wang et al. reported a single enzyme of β-glucosidase and cellulase loaded on the polyethylene [89]. Compared with the single enzyme system, the presence of β-glucosidase can quickly convert the intermediate product cellobiose into glucose, which is the important raw material of biofuel [89]. Furthermore, this system showed a high catalytic activity band the reusability. Therefore, they thought this system has a promising potential for applications in biofuel [89]. Membrane bioreactor is one of the innovative systems for biofuel production [90]. Li et al. utilized the modified polyacrylonitrile hollow membrane for lipase immobilization [91]. By
this method, the immobilized lipase can remain the activity at 50 °C, while the free lipase began to lose the function [91]. Meanwhile, the acid resistance of immobilized enzyme was also enhanced [91]. When pH was as low as 3, more than half of immobilized enzymes were still functional [91].

![Figure 5](image_url)

**Figure 5.** (a) The immobilization procedure of Fe₃O₄-poly(GMA-co-MAA) composite and subsequent immobilization of lipase onto the magnetic support [87]; (b) The scheme of immobilization of β-glucosidase and cellulase on low-density polyethylene [89].

### 4.4. Environment Treatment

Heavy metal, dye and phenolic pollution are one of the most critical environmental problems in the world. Due to being highly toxic and hardly being degraded in nature, they are extremely dangerous to the humans and mother earth. Many traditional methods like physical adsorption and chemical oxidation have been deployed, but they have very low efficiency and high cost [92]. Immobilized enzymes have drawn a lot of attention to be used as a treatment for the wastewater treatment. Along with other support candidates, polymers also maintain high standard performance in this field of application. Peroxidases and polyphenol oxidase immobilized in alginate-coated magnetic nanocatalysts were utilized to remove the phenolic pollution in the water [93]. Laccase, as shown in Figure 6a, can be immobilized by the hydrogels. By this method, it can help to reduce the persistent trace compound [94]. The commonly used synthetic polymer, polystyrene, is also reported in wastewater treatment usage [95]. The polystyrene with a layer of polydopamine can immobilize the horseradish peroxidase via covalent bonds, shown as Figure 6b, the immobilized horseradish peroxidase can maintain about 53% of activity in the high pH solution (pH = 10), while the free enzyme only has 25% [95]. Meanwhile, when the concentration of H₂O₂ changed from 2 mM to 5 mM, the decolorization efficiency could still maintain over 60% [95]. Like other applications, the co-immobilized enzymes on the same support in the environment treatment also attracted such attention. More than one kind of en-
zymes/catalysts are immobilized on the surfaces of supports, the pollutants are catalyzed to form the intermediate products, the rest enzymes continue to catalyze the intermediate products to next level intermediate products until to the degraded products [96,97]. Sometimes, the second material immobilized on the supports not necessarily to be the enzymes. Some mediators may be added on the surface of the support, to expand the oxidative range of the enzyme [98]. For example, as shown in Figure 6c, Qiu et al. immobilized the laccase and 2-binamine-di-3-ethylbenzothiazolin-6-sul-thonic acid (ABTS) on the magnetic chitosan nanoparticles, which not only improve the removal capability for pollutants, but also can avoid the potential pollution of ABTS [99]. A biocatalytic membrane reactor can also be used in water treatment [100,101]. Vitola and Mazzei et al. innovatively designed an enzyme-loaded membrane reactor to remove the organophosphate pesticides in vegetative waters [102]. Phosphotriesterase were loaded on the regenerated cellulose membrane [102]. They proved the ability of that novel biocatalytic membrane reactor to remove pesticide selectively and the immobilized enzyme was more stable than the free enzyme [102].

**Figure 6.** (a) The scheme of the In Situ Preparation Process of Hydrogels Containing Itaconic Acid-Immobilized Laccase [94]; (b) The scheme of coating of expanded polystyrene foam (EPS) with polydopamine layer followed by HRP immobilization to realize HRP@PDA/EPS [95]; (c) The scheme of preparation of the immobilized laccase and its modes of action [99].

5. Conclusions

Enzymes as the promising biocatalysts both in research laboratories and industries with so many advantages, such as high efficiency and specificity. Those characteristics make the enzymes as the powerful competitor of conventional chemical synthesis catalysts. Even though the low thermal stability and narrow pH range limit the enzymes’ application in the industry, the immobilization technologies give the enzyme the opportunities to overcome its own weakness. There are three different immobilization methods mentioned in this review. The usage of physical adsorption is first mentioned, which can maximum keep the activity of an enzyme. Using covalent binding is the second method in this review. It can provide a relatively strong interaction between polymer supports and enzymes. However, the configuration may be reduced during the process due to the formation of a covalent bond. The third method is called entrapment. The enzymes are physically confined in the polymer matrix and protected by the outsider polymer material. However, it still has a chance for enzyme leakage due to weak interaction between polymers and enzymes. In addition, several different kinds of nature and synthesis polymer and their
application in enzyme immobilization are introduced in this review. We need to know that there is no single polymer and no single technology can immobilize all the enzymes. To develop a biocatalyst, more attention should be paid to the protein structure-properties before selecting carriers [103], which means choosing the preparation method should be the priority.

Even though we know the immobilized enzyme has a lot of advantages, such as high stability in extreme pH and temperature, increase reusability. However, maintaining good uniformities and activities is still a huge challenge [104]. The modified and new polymers should be studied more to find better support candidates for further effort. The more effective and eco-friendlier immobilization methods are desired. Meanwhile, storage and transportation are also costly for those bio-products. With the dedicated works of scientists and engineers, we believe the polymer immobilized enzyme will be more reliable, reusable and affordable and widely used in labs and industries.

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