Recent Patents on Immobilized Microorganism Technology and Its Engineering Application in Wastewater Treatment

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Abstract: Compared with suspended microorganism technology, immobilized microorganism technology possesses many advantages, such as high biomass, high metabolic activity, and strong resistance to toxic chemicals, and so on. This review presents the state of the art of various immobilized microorganism methods as well as immobilization microorganism carriers whose engineering applications are mainly focused on bioreactors including fluidized bed reactor (FBR) and packed bed reactor (PBR). This review covers the patents which emphasize the characteristic of the immobilization carriers as well as bioreactors from the year of 2000 up to date. In the last part of the review, the future developing trend in immobilization microorganism technology and the potential engineering applications in wastewater treatment were also proposed tentatively.

Keywords: Immsobilization microorganism, carrier, bioreactor, wastewater treatment.

INTRODUCTION

With the development of society and economy, the exploitation of natural resources has increased rapidly and results in the worsening of water environmental pollution. So it is extremely essential to develop new wastewater treatment methods to deplete and reduce water borne contaminants. Recently, many physical and chemical methods such as advanced oxidation [1], electro-coagulation [2] and flocculation [3] have been proposed and applied in wastewater treatment. However, most methods encounter with secondary pollution or high cost problems [4]. On the contrary, the cost of biological treatment is much lower than that of physical and chemical methods. Especially, the biotechnology has been employed extensively for organic borne wastewater treatment during the past few decades. Generally speaking, biological treatment processes include two types: the one is suspended system i.e. activated sludge, and the other is immobilized microorganism technology [5]. However, the activated sludge technology possesses several inherent disadvantages, such as low biomass concentration, easy washout, and so on. More recently, many novel technologies such as, acoustic cavitation [6], ultraviolet irradiation [7], magnetic field [8] were successfully applied to improve the bioactivity of the activated sludge, but there are far away the engineering application in wastewater treatment due to complex construction and high operation cost. Compared with conventional suspension system, the immobilized microorganism technology offer a multitude of advantages in wastewater treatment, for instance, higher biomass loading, higher microbe retention time, easier operation of solids–liquid separation, higher biodegradation rates, higher metabolic activity and better operation stability [9]. Therefore, immobilized microorganism technology has been exploring as a promising technology for wastewater treatment in the past few decades and in the near future.

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IMMOBILIZATION MICROORGANISM TECHNOLOGY

An immobilized microorganism is defined as a microbe that prevented from moving independently of its neighbors to all parts of the aqueous phase of the system by natural or artificial means [10]. Several methods can be applied to immobilization microorganism on the carriers by using artificial way, these methods including: adsorption, covalent bonding, cross-linking of microorganism, and encapsulation into a polymer-gel and entrapment in a matrix, and so on [11]. Different immobilized methods of microorganism onto the carrier can offer various merits and demerits. The adsorption of microorganisms onto the carriers is one of the simplest immobilization methods, which is based on the physical interaction between the microorganism and the carrier surface. This is a reversible process and can lead to the peeling off adsorbed microorganisms during the operation [12]. The covalent coupling is one of the most widely applied methods which immobilize the microorganism with bonding reaction of reactive groups (e.g. -NH_2 or -COOH groups) at the surface of biological cell, for instance protein. After the coupling immobilization, the stability of the microorganism will increase significantly, but the bioactivity of microorganism will decrease rapidly during the post-operation process [13]. Cross-linking method was often used to link the bio-macromolecular each other with covalent bonds by using multifunctional reagents, such as glutaraldehyde, bisdiazobenzidine and hexamethylene diisocyanate. This mentioned method is very simply, but the procedure is difficult to control properly [14]. The encapsulation method was used to enclose the microorganisms in a polymer-gel. Many synthetic polymers, such as polyacrylamide (PAM), polyvinyl alcohol (PVA), etc., and a lot of natural polymers, for example collagen, agar, agarose,

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cellulose, alginate, carrageenan, etc. are often used as encapsulated carriers [15]. This method is one of the most frequently used method in laboratory experiment up to now and there is far away engineering application for wastewater treatment [16]. Compared with other immobilization methods, the diffusion limitation is one of the inevitable drawbacks associated with encapsulation method. Entrapment of the microorganisms in porous polymer carrier was often used to capture the microorganisms from suspended solution and then obtain the immobilized microorganisms. The polymer matrix used in this method confining microorganisms has porous structure, and thus the pollutants and various metabolic products could easily diffuse through into the matrix. In this method, a lot of porous poly-mers can entrap microorganisms under ambient conditions. What's more, the achievement of higher active biomass concentration, enhanced tolerance to toxic compounds, shock loads and greater plasmid stability of genetic engineered microorganisms offer a lot of merits, and make this method as excellent options for microorganism immobilization [17]. Although many methods can be used to prepare high performance immobilized microorganisms, the design and synthesis of novel immobilized carriers should be a research hot topic in the area of immobilized microorganism because these works would also play very important role in immobilized microorganism processes.

RECENT PATENTS OF NOVEL IMMOBILIZED CARRIER

The selection of a proper immobilization carrier depends upon many factors including non-toxic and nonpolluting, good mechanical strength, light weight, flexibility in overall shape, as well as cost-effective [18]. Frequently used carriers are mainly grouped as two categories: one group is the inorganic carrier material and the other is the organic polymeric carriers. Inorganic carrier materials, one kind cost-effective carrier, were usually selected to immobilize microorganisms by electrostatic attachment between the microorganisms and the carrier material [11] because they not only can resist to microbial degradation, but also has good thermostability performance. Porous glass, ceramics, clay, activated charcoal, anthracite, zeolite and so on are the frequently used inorganic carriers [17]. A new porous inorganic carrier with microelement and an inorganic nutrient salt was prepared by the mixing of the ceramic with a high-molecular weight PVA in nutrient solution [19]. By the use of this carrier, the microorganism density on the immobilized carrier can be improved significantly. For example, there is 20-40 g dry cells/liter compared with the conventional methods with about 1-5 g dry cells/liter [20]. In order to improve the microbe loading and the reproducibility, inorganic carriers often been improved with the surface reaction of active groups with various coupling agents. A novel organo-functional porous ceramic was synthesized by the covalent attachment reaction with microorganism in one recent patent [21] to reduce the biomass loss of the immobilized microorganisms during the operation process. This kind modification promises a good solution to the conventional inorganic carrier for further applications of the immobilized microorganism technology.

Compared with inorganic carriers, the organic polymeric carriers are much more abundant. They also can be divided into two subgroups: natural and synthetic polymeric carriers. Among of the most used natural polymeric carriers, alginate was one of the well known excellent carriers for immobilized microorganism. But the performance significantly depends upon the Ca^{2+}concentrations inside. The higher of Ca^{2+} concentration is, the lower of the mechanical strength of the carrier is. Thus, the alginate carriers can not be maintained for a long period in aqueous solution because the encapsulation immobilized microorganism can easily be broken during the operation [11]. Chitosan was also used as immobilized carrier due to its inexpensive, non-toxic property and possessing potentially reactive amino functional groups which can enhance the affinity of the carrier with the microorganisms. However, the mechanical stability of the carrier would decrease dramatically because of the biodegradability in the course of usage. Chemical linked reagent was often used to improve the mechanical strength of chitosan gel to get much better immobilized carrier. For example, Turtakovsky *et al.* [22] reported that formaldehyde was used to link chitosan gel matrix with microorganisms to improve the stability of immobilized microorganisms. Besides alginate and chitosan, many other natural gels, such as agar, collagen, agarose, and carrageenan, also can be frequently used as microbial encapsulation carriers. But compared with synthetic polymeric carrier, these carriers are less extensively studied in the more recently. Thus the research advances in these kind natural carriers were not specialized in detail in this review.

Unlike natural carriers, a lot of organic polymeric carriers were synthesized and applied as novel carriers of immobilized microorganisms in recently years. Synthetic polymeric supports are not easily biodegradable and have much better mechanical performance compared with nature carrier. Most investigations on the synthesized carriers mainly focused on man-made gel materials and synthetic plastics. Many gel materials, such as PAM, PVA, polyethylene glycol (PEG) and polycarbamoyl sulphonate (PCS) were synthesized as encapsulation carriers [23]; yet, all these gel carriers have various limitations during the applications in the immobilized microorganism technology. For example, the mechanical strength and the stability of these new prepared gels will decreased significantly due to their good water-solubility, which results in the limited usage in large-scale industrialization application [15]. In order to improve the stability of gel carrier, various synthetic plastics, for example polypropylene (PP), polyethylene (PE), polyvinyl-chloride (PVC), polyurethane (PU) and polyacrylonitrile (PAN) have been explored extensively as immobilized microorganism carriers more recently [18]. Among the various extensively used plastics carriers, PU (the schematic view was showed in Fig. (**1**)) is one kind of outstanding carrier for entrapping microorganisms in piloted applications in practical waste-water treatment [24], which offers several advantages including high mechanical strength, excellent resistant to the attack of organic solvents and microbial, easy handling and wonderful regeneration ability as well as cost-effective expense [25]. PU foams mixed with activated carbon, diatomite and zeolite were used as immobilized

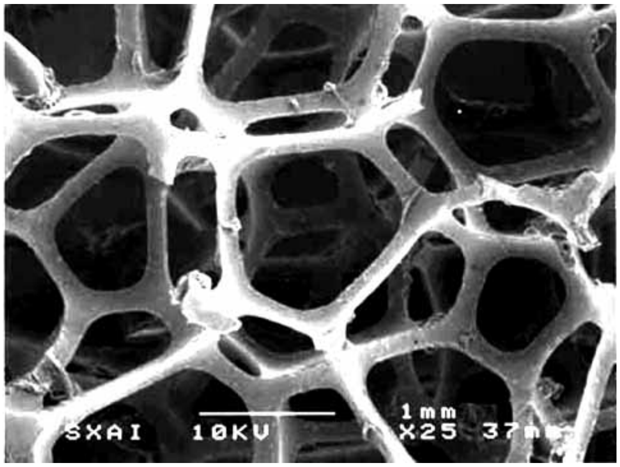

Fig. (1). The schematic view of PU foam [24].

microorganism carrier to treat a synthetic wastewater containing acid orange 7, and the results demonstrated the color of wastewater was reduced effectively from 2500 ADMI (The water color value based on American Dye Manufactures Institute) to less than 550 ADMI [26]. The mixed carriers have excellent porous structure and are capable of trapping and intercepting the microorganism efficiently, so that the start-up period would be shorten, and the decomposition of the contaminants was effectively depleted in the bioreactor. Kallenbach *et al*. [27] developed a light weight carrier based on PU foam for growing immobilized microorganism. The carriers were made from the core of PU and the outer region of inorganic materials including sand, rock chips, limestone, aluminum oxide, clay etc. The physical, electrical and chemical properties of these assembled carriers can be optimized by selecting the appropriate material, and thus all these prepared carriers have high adsorption capability for the microorganisms. DeFilippi *et al*. [28] manufactured a biologically active carrier, i.e. carbon "coated" PU foam. This carrier was made by bounding many particulate adsorbents such as powdered activated carbon, zeolite, and ion exchange resin etc. to PU foam using latex adhesive. The concentration of phenol in the feed stream decreased from as high as about 1584 ppm to as low as 1 ppm with composite PU foam as immobilized carrier, while the concentration of phenol reduced to 40-60 ppm in same conditions when PU foam only was used as immobilized carrier. This is because that the new prepared composite carrier can adsorb excess pollutant when the pollutant concentrations were high, and then release the pollutant to the solution when the concentration of phenol decreased. Thus, it would maintain the pollutant concentrations at medial constant levels which do not inhibit the microorganism growth. A series of novel PU foams were also synthesized by combining with activated carbon [29], modified SiOx nanoparticle [30], and active carbon fiber [31]. These prepared carriers possess strong adsorption ability for microorganism (both adsorption and covalence) due to the macroporous structure and active chemical groups, such as -OH, -COOH, $-CONH_2$, and $–NH_2$ distributed on the surface of the carrier. In addition, they also had eminent biological compatibility and stability. Thomson [32] synthesized a hydrophilic PU foam scaffold bonding hydrophobic PU core with the hydrophilic polysaccharide hydrogel or acrylic hydrogel shell. The resulted composite foam exhibited highly hydrophilic, excellent biocompatible and good absorption performance for microorganism. Thus, from above mentioned, we can conclude that these composite carriers with porous structure can easily be impregnated with nutrients, and also can be easily installed in a bioreactor to colonize with resident microorganisms. Besides appropriate carriers, the design and assembling of the bioreactor configuration is also another important factor influencing the engineering applications of the immobilized microorganism technology in wastewater treatment.

RECENT PATENTS OF BIOREACTORS AND THEIR APPLICATION

With the rapid development, the design and fabrication of novel bioreactor employed with a variety of conventional or new-prepared immobilized carriers become a hot topic within the area of environmental engineering and applications in the wastewater treatment. Two types of bioreactors, for instance fluidized bed bioreactor and packed bed bioreactor were often applied to wastewater treatment [33]. Herewith, we just focus on current development of bioreactors in patents and their engineering application in wastewater treatment from the year of 2000 up to date.

FLUIDIZED BED BIOREACTOR

Due to their high mixing effect and much better mass transfer characteristics, fluidized bed reactors (FBR) are frequently used to treat high-concentration toxic organic wastewater. A typical schematic diagram of FBR is shown in Fig. **2** [34], in which the microorganism was immobilized onto 0.4–0.5 mm carrier particles with large specific surface area. And fluidization was achieved by liquid injection or simultaneous liquid and gas injection at the bottom of the bioreactor.

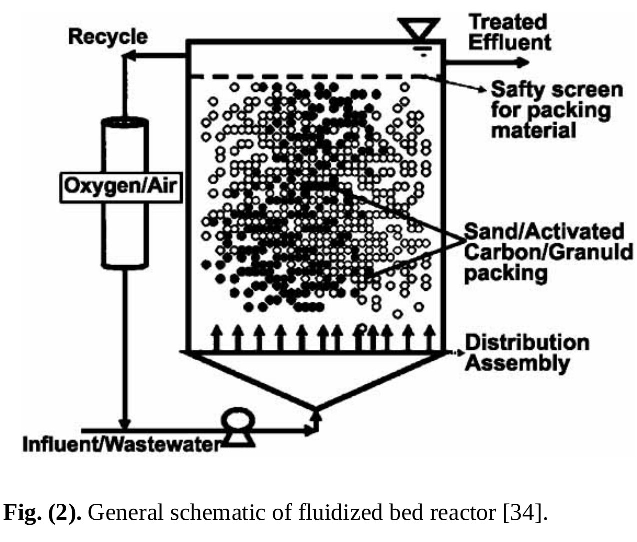

Fig. (2). General schematic of fluidized bed reactor [34].

Traditionally, inorganic particles such as sand, activated carbon were extensively used as fluidized medium in fluidized bed bioreactors in past few decades [35]. However, the density of inorganic carrier is very high, which lead to the increase of operational cost. So more and more low density organic supports were selected or synthesized to replace inorganic carriers for improving the fluidizing performance of immobilized microorganism and the removal efficiencies of wastewater. Rajasimman and Karthikeyan [36] choose light PP particles (density of 0.87 g/cm^3) as an immobilized carrier to treat starch wastewater in a FBR. The optimum chemical oxygen demand (COD) removal of 93.8% occurred at an initial concentration of 2250 mg/L with the hydraulic retention time of 24 h. The results revealed that the removal efficiency of FBR with low-density carriers was improved significantly due to easy control of bioflim thickness within a narrow range. Haridas and Majumdar [37] designed a novel fluidized bed bioreactor, i.e. a reverse fluidized loop reactor (RFLR), for continuous conversion of soluble sulfide in wastewater to solid sulfur particles, which is helpful for the separation of different constituents in suspended solution. The scheme of RFLR is shown in Fig. **3**. This bioreactor consisted of a vessel containing low density float biological carrier (0.90-0.99 g/cm^3), internally fixed both-end-opened drafted tube and a pressured air nozzle located the bottom of bioreactor for the fluidization of the liquid reactants. The drafted tube positioned above the bottom of the vessel and restricted within the level of liquid in the vessel. The mixture gas was introduced into the bottom of drafted tube in order to form an upward flow of the liquid through the constraining of the drafted tube. This design enable much better mixing and mass transfer of bed particles with gas bubbles and the liquid stream, and also enable the easy separation of biocarriers from solid sulfur particles due to the density difference between biocarriers and solid particles in the bioreactor. The detailed results illustrated that at the concentration of 20 kg/m^3/d sulfide loading rate, the removal efficiency of sulfide was up to 99%. The sulfide contained in the wastewater was converted to solid sulfur to evaluate the biological oxidation efficiencies of RFLR. Shechter and Levy [38] fabricated a new FBR which was mainly composed of nozzles, air lift enclosure and a series of light plastic supports, such as polyolefin, polystyrene, PVC and PU Fig. (**4**). In this FBR, the pressurized air ejected from the nozzle equipped at the bottom of the vessel was employed to generate an upward flow of wastewater through air lift enclosures, and then caused the biofilm supports to be inversely fluidized in wastewater. Thus, the resulted FBR would provide enhanced turbulence and excellent mass transfer for wastewater treatment. However, this FBR also revealed many draw-backs, for example outflow of carrier from air lift enclosure, floating of the carrier caused by pressurized air. In order to overcome these limitations, Maekawa and Kuroshima [39] developed an original magnetic FBR which employed magnetic carriers in fluidized bed bioreactor for wastewater treatment. The bioreactor was composed of four parts, such as magnetic carrier, metal core, magnetic coil and treatment chamber Fig. (**5**). A magnetic field was generated by sending electric current into magnetic coil where the magnetic carriers were aggregated around the metal core. When the eclectic current was stopped, the magnetic carriers were dispersed again into the suspension. By repeating this operation intermittently, the magnetic carriers were aggregated and dispersed again and again to form a fluidized bed. Thus

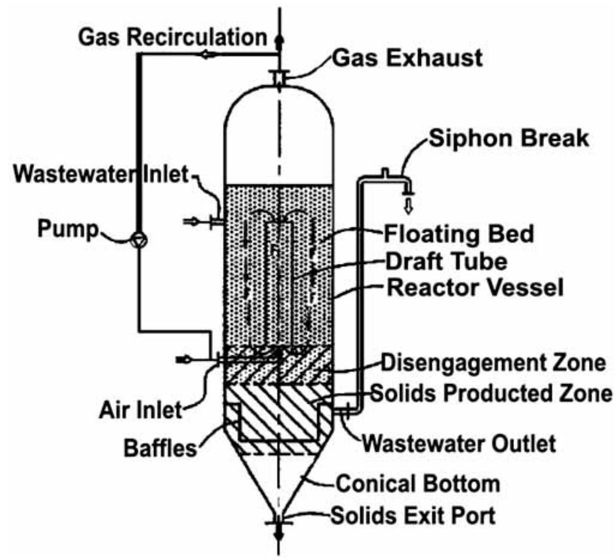

Fig. (3). The schematic of reverse fluidized loop reactor [37].

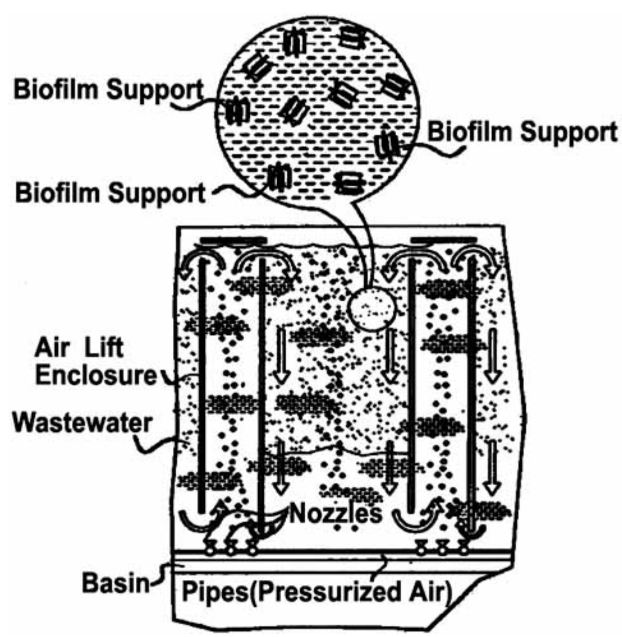

Fig. (4). The schematic of fluidized bed bioreactor employing biofilm carriers [38].

the fluidization of these carriers was controllable in a treatment chamber with magnetic force, and the magnetic carrier could also be maintained in a treatment apartment by generating downward magnetic force in the continuous upward wastewater stream. Although many new fluidized bed bioreactors were manufactured for the application in wastewater treatment in the past few decades. However, their commercial applications are still impeded due to their limitations, such as sophisticated construction, difficult scale-up, and complex operation.

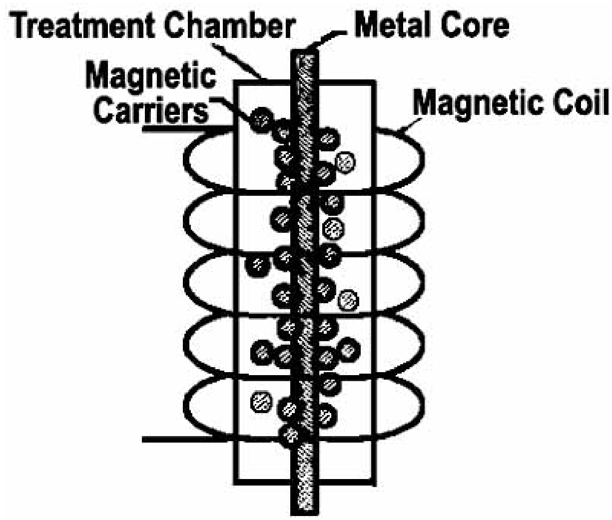

Fig. (5). The schematic of magnetic fluidized bed reactors having magnetic carriers [39].

PACKED BED BIOREACTOR

Compared with fluidized bed bioreactors, the operation cost are very low when packed bed reactors (PBR) were applied in the wastewater treatment. And this technology has already been used extensively to accomplish wastewater treatment through microorganisms attached to the immobilized carrier matrix. Figure **6** presents the schematic diagram of a typical packed bed bioreactor [40]. In this bioreactor, wastewater from the primary clarifiers is uniformly distributed onto the surface of the carriers and purified by the microorganisms immobilized onto the carriers. Generally, the packed carrier is the basic unit of PBR, and the surface area of the packed carrier provides bioactive centre for enhancement of reaction rate in the bioreactor. Therefore, lots of research works have been concentrated on various packed bed bioreactor configurations and the assembling of immobilized carriers. Byers *et al*. [41] developed a novel functional packed bed bioreactor adopting activated carbon as the immobilized carrier by means of a rigid tubular instrument with a plurality holes in bioreactor. This design aim to provide local mixing, thus make it easy to push the rigid tubing through the granular activated carbon (GAC) bed for treating groundwater contaminated with methyl-butyl ether (MTBE) and/or t-butyl alcohol (TBA). The results revealed that the influent MTBE/TBA concentration reduced from about 2 mg/L MTBE and 0.5 mg/L TBA to less than 10 μg/L and 5 μg/L respectively, when the flow rate of the groundwater was set as 454 L/h. Razavi-Shirazi [42] developed another pioneer packed bed bioreactor in order to resolve the pollution of the real organic chemicals contaminated groundwater. In his method, immobilized microorganisms carriers such as, PVA-immobilized cells or 3% GAC-immobilized cells/sand were filled in hole or trench excavated in the ground to intercept the stream of the groundwater Fig. (**7**). The contaminated groundwater flowed across the packed immobilized microorganism carriers and then the contaminants were depleted completely. Compared with conventional groundwater remediation technologies [43], this bioreactor may exhibit many advantages, for example simple and quick installation, low operation maintenance, less surface disruption, less labor and energy, no by-products and sludge, effective interception of the contaminants from the groundwater. Two different employed columns, PVA and GAC immobilized cells were compared to treat trichlorophenol (TCP) contaminated groundwater in the reactor. The results presented that PVA-immobilized cells still maintained good permeable and sound structure over 240 days and obtained up to 91% removal efficiency of TCP loading up to 600 mg/L per day with corresponding hydraulic retention time of 12.3 minutes, while 3% GAC-immobilized cells/sand offered 100% removal efficiency for TCP loading up to 1200 mg/L per day. This obvious enhancement indicated that the GAC carrier was superior in adsorption capacity and biological degradation activity to the PVA-immobilized cells system. Therefore, 3% GAC immobilized carrier would be a better immobilized microorganism carrier than PVA-immobilized carrier for the removal of contaminants from groundwater.

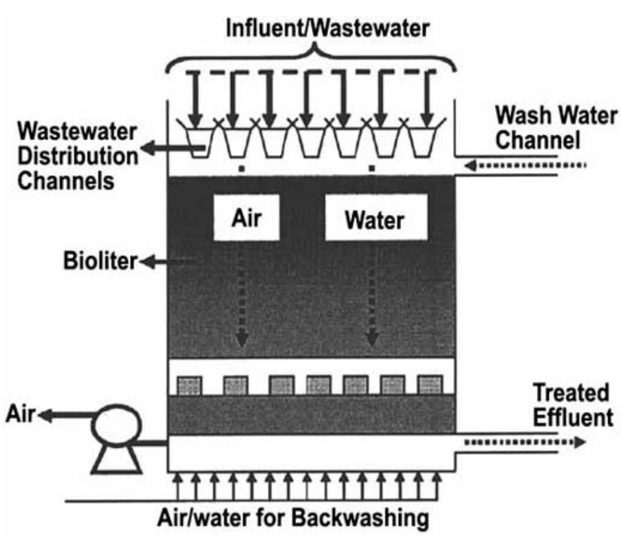

Fig. (6). Schematic diagram of packed-bed reactor [40].

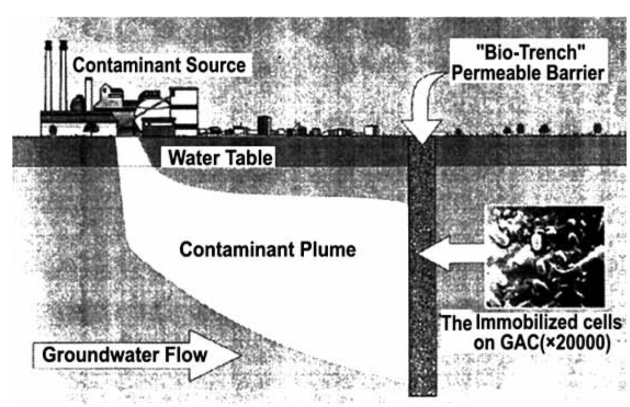

Fig. (7). The schematic of a biological permeable barrier for removal groundwater contaminations [42].

Compared with activated carbon, porous polymer foam carriers have less density, high surface area and plurality holes, and thus were frequently employed in the packed bed bioreactor. Lupton [44] developed a layered packed bed bioreactor having a lot of advantages, such as lower pressure drops, shorter channeling, and less residence time. The bioreactor comprised a biologically active bodies containing PU immobilized microorganism, a open body packing layer, i.e. rigid open cylinders plastic (Jaeger Products, Inc., the profile was showed in Fig. (**8**)), a gas diffuser, a fluid feed distributor, a porous screen, a air exhaust and a exit port Fig. (**9**). Biologically active bodies and open body packing were alternatively packed layer by layer inside the bioreactor. The synthesized wastewater containing 100 mg/L sodium n-cocyl-n-methyltaurate, 100 mg/L Igepal CO-630 (nonyl-phenol ethylene oxide), 1000 mg/L urea, 200 mg/L creatinine, 20 mg/L caprolactam, 50 mg/L ethanol, 20 mg/L benzyl alcohol, and 25 mg/L sodium dihydrogen phosphate were fed to the reactor to compare the removal efficiencies of COD and urea with two different bioreactors, the randomly mixed packed bed bioreactor and layered packed bed bioreactor. The results showed that the removal efficiencies of COD and urea were 89% and 99% respectively by using the layered packed bed bioreactor at 12 h resident time. While the removal efficiencies of COD and urea were 70% and 95% respectively by using the randomly mixed bed bioreactor in same conditions. The experiments verified that the layered packed bed reactor has much better performance than that of the random packed bed reactor. Sato *et al.* [45] designed another new-pattern packed bed bioreactor where the microorganisms were immobilized onto thermoplastic PU carrier to removal nitrogenous components from the wastewater. By using PU carrier, this bioreactor can keep autotrophic nitrifying bacteria at a high concentration, and enhance the nitrification performance compared with standard activated sludge process. Synthesized wastewater containing 100 mg/L biological oxygen demand (BOD), 30 mg/L total nitrogen (T-N), and 24.4 mg/L NH_4-N was fed into the bioreactor to evaluate the removal efficiencies of these test compositions. The results showed that the outlet concentrations of NH_4-N and NO_3-N were less than 1 mg/L respectively, and the removal efficiency of T-N is more than 90% at 6.0 h the hydraulic retention time. In addition, the excellent performance was still warranted after 60 days usage, and the bioreactor didn't appear any trouble such as floating or collapse of carriers throughout the operation period. In order to improve the treatment efficiency of the high concentration of ammonium nitrogen in landfill leachate, Xu *et al.* [46] also designed a novel packed bed bioreactor which combined an anaerobic baffled reactor (ABR) with hybrid biofilm reactor (HBR). The bioreactor was divided into several independent zones where different porous materials, such as PU, sponge, plastic, rubber and ceramic particles were filled with as an immobilized carrier. Meanwhile, the concentration of dissolved oxygen in HBR was controlled and the effluent of HBR was recycled to the inlet of the ABR in a larger proportion, so the concentrations of ammonium oxidizing bacteria were enhanced greatly. It helps to improve the removal efficiency of ammonium nitrogen in wastewater. In the fieldwork, the bioreactor was introduced to treat 500 m^3/d of landfill leachate (Datianshan,

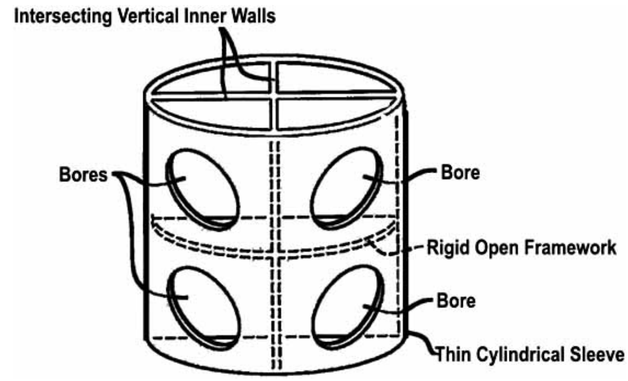

Fig. (8). The schematic view of rigid open cylinders [44].

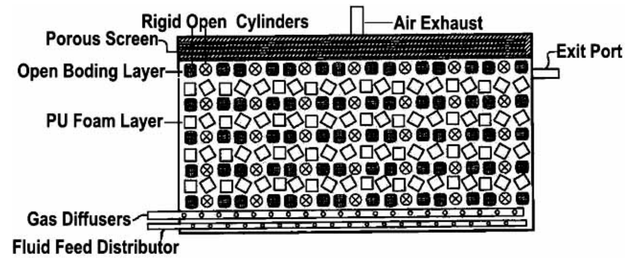

Fig. (9). The scheme of layered packed bed bioreactor [44].

Guangzhou city, China). The final effluent NH_4-N concentration was under 25 mg/L and the removal efficiency of T-N was above 80% when the influent concentration of ammonium nitrogen was 700-1000 mg/L. These results indicated that this combined bioreactor can be successfully applied in the treatment of landfill leachate [47]. Furthermore, Christodoualatos and Korfiatis [48] also developed a novel bioreactor which combined a typical packed bed bioreactor with a series-wound membrane bioreactor for high organic carbon removal and high ammonia conversion for special usages under the microgravity operation. The schematic diagram of this new-designed packed bed bioreactor was demonstrated in Fig. **10**. The treatment apparatus comprises a packed bed bioreactor filling with the immobilized cell, and a membrane oxygenation module attached to an external recirculation line. The wastewater stream saturated with oxygen was pushed into the packed bed bioreactor by diffusion through a non-porous hydrophobic membrane by a pressure regulator, allowing a high concentration of oxygen and preventing the formation of bubbles. Thus immobilized microorganism bioreactor can obtain a unique oxygenation environment for microbial growth and result in high biomass concentrations. The wastewater containing 600-900 mg/L COD, 350 mg/L ammonium was used to evaluate the removal performance of the bioreactor. The results showed that this bioreactor had high removal efficiencies both for organic carbon and ammonium in high substrate concentration wastewater. Average removal efficiencies of COD and ammonium exceeded 90% and 85% respectively, and still maintained after the bioreactor operated over one year at 6 h hydraulic retention time. The successful application of

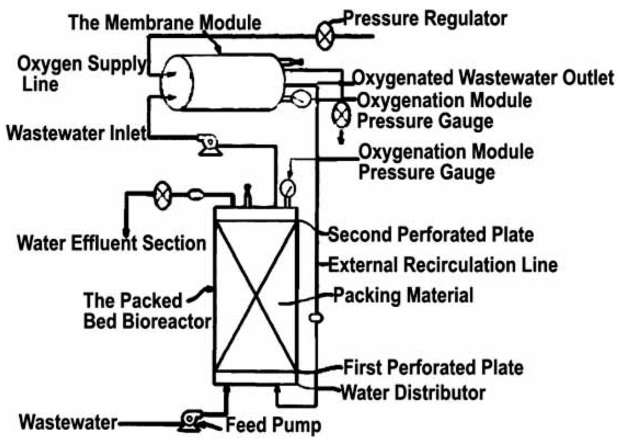

Fig. (10). The schematic of combined packed bed bioreactor with membrane [48].

this new-designed bioreactor in closed systems such as a space station, space craft, or submarine where utilization space was limited or unavailable would be a pilot or lead research work in the field of the packed bed bioreactor.

CURRENT & FUTURE DEVELOPMENTS

Available literatures and patents with a numbers of research works and pioneer engineering applications using the immobilization microorganism technology were proposed successfully for treating synthetic and practical wastewater over past few decades. But the complicated construction, sophisticated operation and the complexity composition of the practical wastewater impeded the commercial engineering application of immobilization microorganism technology in wastewater treatment at a large scale. Enhancing active biomass concentration, prolonging the life of immobilized carrier and improving the stability of immobilized microorganism all play important roles in engineering application of the technology. The selection of suitable immobilized carriers is also an undoubted key step for immobilization microorganism technology. Thus, the design and preparation of the novel immobilized carriers (e.g. by functional modification) containing active groups, porous structure, high surface area, excellent biological compatibility and stable physical-chemical performance would be one of the future research trends for immobilizing microorganism. Of course, the innovation assembling of new-prepared immobilized carriers in the new-design fluidized bed bioreactor or packed bed bioreactor should be another fresh new hot topic to accomplish higher removal efficiency of contaminants, prevent clogging, and reduce the operation costs. Moreover, the combination of conventional bioreactor with other kind reactors, such as membrane reactor, will significantly expand the application range of immobilized microorganism technology in wastewater treatment, and also will lead to industrial scale application in the practical and special wastewater treatment in the near future.

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