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Microbial Fluidized Bed Reactor Removing Pharmaceutical Contaminants from Wastewater – Review

Mays Abbas[1], Ghayda Yaseen Al Kindi[1], Amal Ali Hussein[2*]

[1] Department of Civil Engineering, University of Technology, 52 Alsinaa St., PO Box 35010, Baghdad, Iraq
[2] Department of Applied Sciences, Biotechnology Branch, University of Technology, Baghdad, Iraq
* Corresponding author's e-mail: 40126@uotechnology.edu.iq

ABSTRACT

Pharmaceutical contaminants are difficult to remove with standard treatment techniques and are one of the current problems in wastewater treatment. These bioactive substances are considered emerging pollutants due to their persistence and potential impact on aquatic ecosystems. They will continue to function even in small amounts. Efficient wastewater treatment methods are needed to address this issue. As a result, the efforts to develop more efficient wastewater treatment methods have recently intensified. Fluidized bed reactors offer a special opportunity for efficient treatment of wastewater containing recalcitrant pollutants. This article discussed FBBR and covered its advantages, disadvantages, modifications, and applications. Additionally, the FBBR design was briefly discussed.

Keywords: bio-treatment, fluidized bed reactor, pharmaceutical wastewater, polymer.

INTRODUCTION

Medicines are widely used in the treatment as well as prevention of diseases in humans and animals. Due to their long lifetime in aquatic ecosystems, these bioactive compounds are considered new pollutants. These pharmaceutical contaminants (PHCs) include analgesics, anti-inflammatory drugs, anti-epileptic drugs, and antibiotics, most of which are endocrine disruptors, and continuously enter the aquatic environment in very small quantities (Tiwari et al., 2017). It continues to work even at low doses, as shown in Figure 1. Ecosystems are drugged. Direct or through indirect leaching (treatment and discharge of wastewater treatment plants) becomes wastewater. Veterinary facilities also provide drugs to protect animals from disease and promote growth (Martnez-Carballo et al., 2007; Kim et al., 2011, Ji et al., 2012). These pharmaceuticals (PHCs) can harm humans and ecosystems if released into the environment. Several studies have investigated PHC in rivers. However, they use different analytical techniques, measure PHC differently, and ignore several countries around the world. Therefore, it is difficult to judge the scale of the problem from a global perspective (Wilkinson et al., 2022).

Various strategies such as oxidation, biodegradation, photodegradation and adsorption have been used to remove pharmaceutical contaminants from wastewater. According to Homem and Santos (2011) and Al-Obaidi (2015), different methods depend on the chemical nature of his PHC, the abundance of his PHC in the wastewater, and the treatment costs. Wastewater treatment plants (WWTPs) use physical separation methods such as screening and gravity settling to remove bulk solids at the primary treatment stage. In the secondary treatment stage, biological treatment methods are used (Amal A. Hussein, 2015). Microbial growth within bioreactors consumes contaminants through metabolic processes for bioremediation. If necessary, the process is chemically disinfected along with the wastewater. Wastewater treatment plants cannot completely remove pharmaceuticals (Petrovi et al., 2003; Saussereau et al., 2013; Kim et al., 2014). Depending on the chemical, removal efficiency varies from 0% to

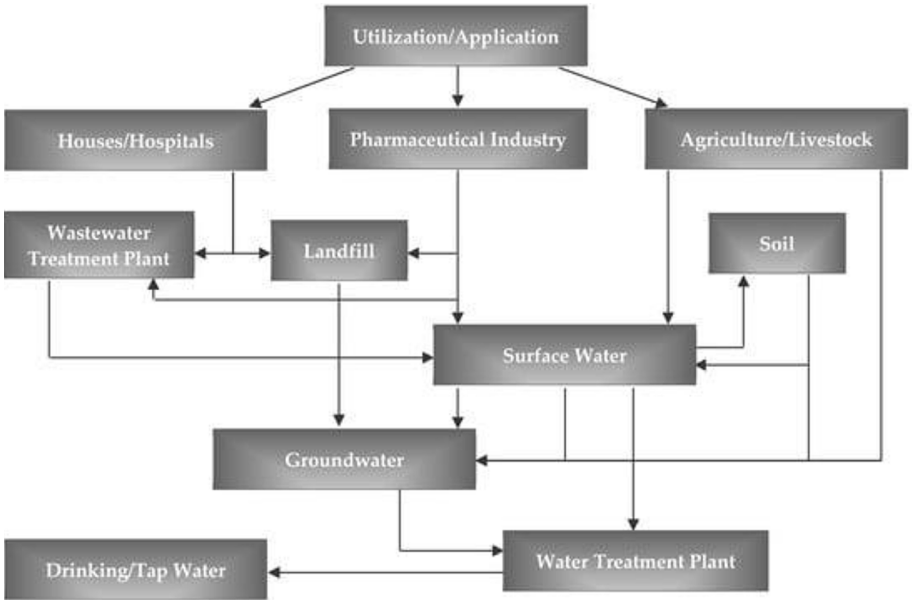

Fig. 1. Pharmaceutical highway in environment (Silva et al. 2019)

100% (Hörsing et al., 2011). Due to the nature of the compounds, the removal rate for most compounds is less than 50% (Verlicchi et al., 2012). Various physical, chemical, and biological treatments have been tried in wastewater treatment plants, but none have completely eliminated them (Benotti et al., 2009). Tertiary treatments, such as advanced oxidation processes and membrane technologies are often more effective than primary and secondary treatments in removing these trace contaminants (Pomati et al., 2006; Joss et al., 2008). Tertiary biological wastewater treatment outperforms other technologies in terms of efficiency, affordability and environmental friendliness. Numerous studies have been conducted on the removal of pharmaceuticals from wastewater. These include a study using Moringa oleifera seeds as an environmentally friendly sorbent to remove ibuprofen drug residues from municipal wastewater (Ghayda, 2021a) and a study using activated charcoal to remove diclofenac (Ghayda 2021a, 2021b), as well as removal of tetracyclines from wastewater by flocculation and adsorption (Ghayda, 2021c; 2022). The use of specific microorganisms is becoming increasingly important in applied environmental microbiology (Wu et al., 2012). It has been suggested that the drug remediation approaches based on fungi and algae have potential. Figure 2 shows studies focused on drug removal by fungi (white rot fungi) and algae (Chlorella vulgaris) using bioremediation and/or biosorption processes (Maity et al., 2014; Silva et al., 2019).

Both physical unit operations and chemical and biological unit processes are used in wastewater treatment. A "reactor" is a commonly used tank or vessel (Burghate and Ingole, 2013). The main types of reactors used to treat wastewater include batch reactors, mixed reactors (also known as continuous stirred tank reactors or continuous stirred tank reactors or CSTRs), plug flow reactors, in-line mixed reactors, fixed bed Reactors and Fluidized Bed Reactors. During operation, electricity is fed into batch reactors where it is

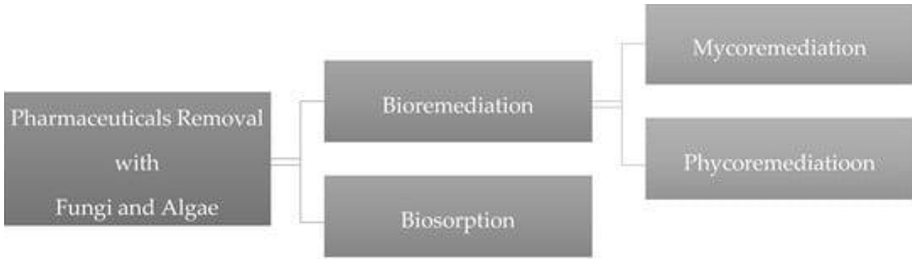

Fig. 2. Pharmaceuticals removal process with *fungi* and *algae* (Silva et al., 2019)

processed and released again. A continuous flow stirred tank reactor thoroughly mixes all liquids in it. Immediate homogeneous mixing is expected throughout the reactor (Metcalf and Eddy, 2003). In a plug flow reactor, there is little longitudinal mixing and the order of the particles upon entry is preserved. The particles maintain their presence and uniqueness in the reactor for the duration of the theoretical residence time. A series of fully mixed reactors was used to simulate the flow regime between idealized hydraulic flow patterns corresponding to fully mixed and plug flow reactors (Burghate and Ingole, 2013).

The fixed-bed reactor is filled with fillers such as rocks, slag, ceramics, and plastics. Fixed bed reactors can be operated in both upflow and downflow modes (Silva et al., 2019). A fluidized bed reactor has many similarities to a fixed bed reactor; however, the packing in a fluidized bed reactor expands as the liquid (air or water) rises through the bed. The liquid flow rate can be varied to alter the increased porosity of the fluidized bed packing material (Makhathini, 2020; Özkaya et al., 2019.) This article discussed the fluidized bed biofilm reactor (FBBR), its advantages and disadvantages, variations and applications. A brief overview of the FBBR design was also given.

FLUIDIZATION

As particles flow through a dense particle bed, the friction created by the airflow on the particles tends to lift the particles. This buoyancy increases with the velocity of the fluid until all particles are lifted by the fluid, preventing them from flowing freely and colliding with their neighbors at any velocity. This process is called "fluidization". When a solid is divided into more manageable parts, more surface area is available for heat and mass transfer or chemical reactions compared to the bulky initial state of the solid and surrounding liquid (Patnaik and Sriharsha, 2010). The granular material is fluidized in a fluidized bed reactor. Fluidized beds come in many forms, but generally they all contain the same four main components: plenums, headers, bed sections, and freeboard zones. Before the liquid reaches the bed, it enters the plenum. After initial hydration, hydration is evenly distributed through aeration panels or diffusers at the bottom of the bed. Granular solids are on the bed above the distributor. Above the bed chamber is the freeboard area, which retains particles ejected from the bed (Qiu et al., 2018). As a chemical reactor, a fluidized bed has many advantages. These include uniform temperature distribution, low pressure drop, as well as good heat and mass transfer efficiency. Fluidized beds come in several forms, including fixed fluidized beds (FFB) and circulating fluidized beds (CFB). These particles are contained in a fluidized bed called FFB. CFB, on the other hand, is a fluidized bed in which ions are absorbed by the liquid flow and transferred from the fluidized bed to the circulating bed at the liquid velocity. Figure 3 shows how FBRs can be classified according to reactant phase and flow direction. In addition, there are many applications of fluidized bed in wastewater treatment plants, such as B. Adsorption, biological treatment and pre-oxidation process (AOP), as shown in Figure 4.

Types of fluidizations and its applications

The two main forms are particle liquefaction and aggregate or bubble liquefaction. Fluidization of aggregates occurs in gas-solid and

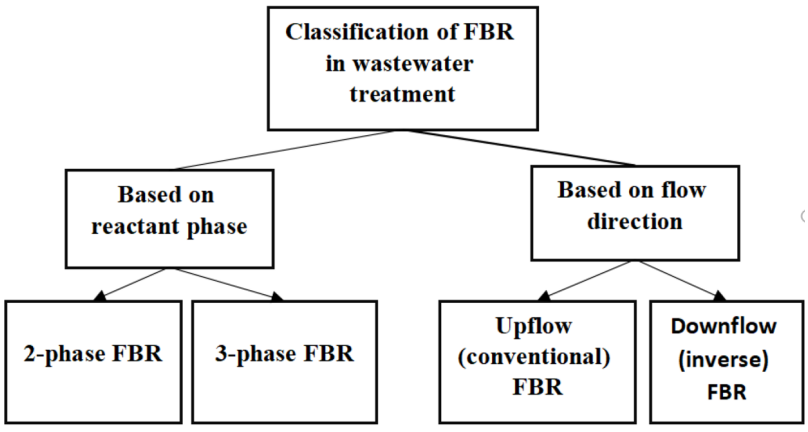

Fig. 3. FBR classification according to reactant phase and flow direction (Özkaya et al. 2019)

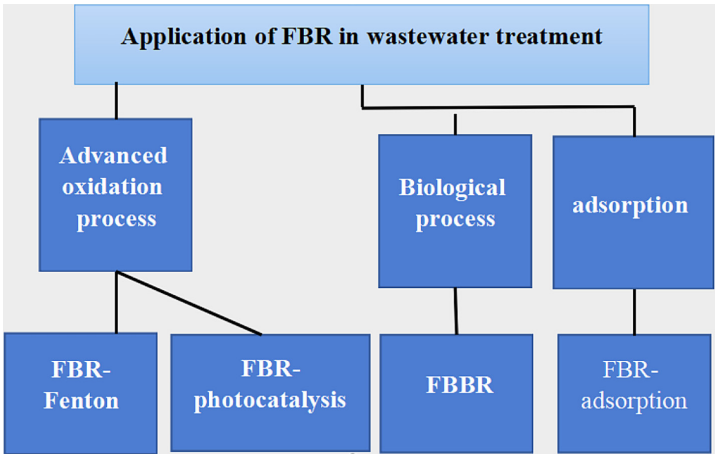

Fig. 4. FBR Application in wastewater treatment (Özkaya et al. 2019)

gas-liquid-solid-gas continuous systems, while particle fluidization occurs more commonly in liquid-solid and liquid-continuous gas-liquid-solid systems. The size of the particles in the liquid-solid mixture has a major impact on what happens in the bed. Efficient fluidization of aggregates requires uniform fluidization, which is only possible with good gas-solid contact. However, some inherent disadvantages of aggregate fluidization, such as bubbling, channeling, and gush formation, lead to gas-solid contact and poor fluidization quality (Zhou et al., 2009).

Three -phase fluidization

Gas-Liquid-Solid 1 Fluidization is the process of suspending a bed of solid particles in a liquid or gaseous medium. This occurs when the net drag of the fluid (liquid or gas) moving in the column opposes the net gravity of the particles. This approach allows close communication between different stages and provides additional advantages for use in chemical, biological and physical processes (Hara Mohan Jena, 2009). The interaction between the gas phase in the form of bubbles as well as the solid and liquid phases liquefies or suspends the solid particles. This interaction between the phases creates the intensive mixing required for chemical reactions and efficient heat and mass transfer (Lee and De Lasa, 1987).

Modes of three-phase fluidization

Depending on the direction of flow, fluidized beds can be classified as liquid or gaseous countercurrent media. This occurs when the net drag of the fluid (liquid or gas) moving in the column opposes the net gravity of the particles. This approach allows close communication between different stages and provides additional advantages for use in chemical, biological and physical processes (Hara Mohan Jena, 2009). The interaction between the gas phase in the form of bubbles as well as the solid and liquid phases liquefies or suspends the solid particles. This interaction between the phases creates the intensive mixing required for chemical reactions and efficient heat and mass transfer.

Flow regimes

Seven featured flow regimes are identified in the co-current fluidized, these are as follows (Jena et al. 2008):

- dispersed-bubble – this sort of flow involves a high-velocity liquid and a low-velocity gas, which results in tiny bubbles that are essentially uniform in size. Despite the great frequency of bubbles, little bubble coalescence happens.
- discrete-bubbles – the majority of the time, this flow happens at low gas and liquid velocities. It is comparable to the dispersed but has fewer bubbles every time.
- coalesced-bubble – larger bubble and wider in size distribution appear in this flow that are achieved at intermediate gas and low liquid velocities and medium gas velocities.
- slug-flow – large bubble has the bullet shape and diameter and length exceeded that of the column this is the characteristics of this mode of flow
- churn-flow – similar to the mode of slug flow, except it is much more chaotic and frothier.
- bridging-flow – a regime transitive between the mix and annular flow, when continuously reformed and broken bridges are formed across the reactor by the solid and liquid.

- annular flow – continuous phase appears in the column core this established at very high gas velocities (Özkaya et al., 2019) as shown in Figure 5**.**

Variables affect the quality of fluidization

According to Chowdhury et al. (2008), some of the variables that affect the fluidization quality in gas, liquid and solid fluidization phenomena are listed below. The liquid flow rate must be high to keep the solids in suspension while maintaining a sufficient level to prevent channeling.

- bed height – bed height indicates how easy it is to achieve good fluidization.
- particle density – since the particle density is similar to gases and liquids, uniform fluidization is easily maintained.
- liquid inlet – when designing a fluidized bed, the liquid distribution within the bed must be considered.

HYDRODYNAMIC PARAMETERS

Minimum fluidization velocity

Hydrodynamic parameters are critical to the design and efficiency of fluidized bed adsorbers (Kareem and Mohammed, 2020). Only at slow fluidization rates, such as those found in fixed beds, does water enter the spaces between the beads. When the flow rate is increased beyond a certain point, the settled beads begin to disperse; after that, the atoms are suspended in the liquid. At this time, the minimum fluidization velocity Umf is given. With an increase above Umf, the fluidization rate increases as the sorbent particles move further. This causes the bed to gradually expand, a process known as steady state fluidization (Yoshida et al., 1969). When the sorbent particles exit the bed at a critical velocity, the additional fluidization causes the bed to become unstable. The maximum fluidization velocity or terminal velocity Ut is the flow velocity at that point, as shown in Figure 6. This velocity can be roughly calculated using Stokes' theorem, which gives the sedimentation velocity of a single particle at infinite dilution. Equation 1 below determines the minimum fluidization ratio (Yoshida et al, 1969):

$$Umf = (\mu/d\ \rho)\ Re \quad (1)$$

Bed expansion

The lowest fluidization velocity is greatly controlled by the void fraction of the bed in addition to other hydrodynamic factors (εv). Bed voidage can be computed using the volume of the whole fluidized bed and particles (Vp).

$$(Vb)$$

$$\varepsilon = V\varepsilon\ Vb = Vb - V\ p\ Vb = 1 - Vp\ Vb = 1 - mp\ \rho p.\ Vb = 1 - mp\ \rho p.A.H \quad (2)$$

$$Vb = A \cdot H2 \quad (3)$$

$$Vp = (\Delta P\ A) + (mp \cdot 9.81)\ \rho g \quad (4)$$

where: A (m^2) – cross-sectional area of the column, H2 – the expanded bed height, P – the actual particle density, and mp – the particle mass.

The Richardson-Zaki equation was applied to find the best fit equation for homogeneous particles connecting U in the fluidized bed. One of the best ways to describe how U and U are related in a normal fluidized bed is the Richardson-Zaki correlation. The formula for this equation is: (Pare 2013; Sulaymon et al., 2014).

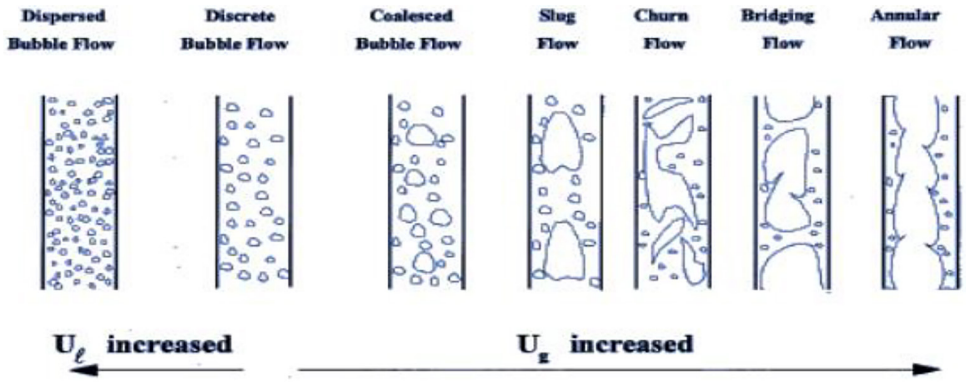

Fig. 5. Seven featured flow regimes identified in the co-current fluidized (Özkaya et al., 2019)

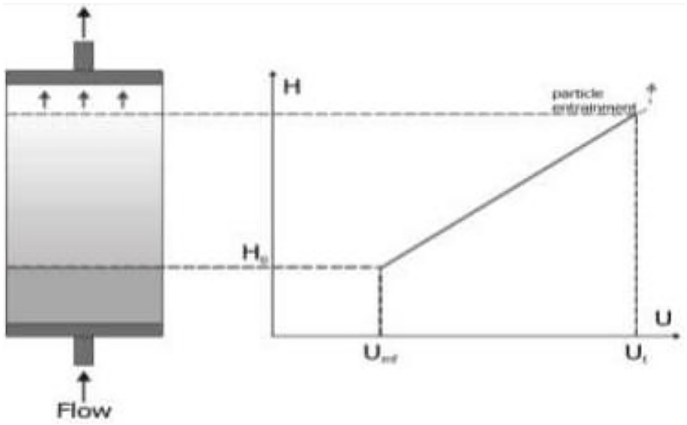

Fig. 6. The operational window of fluidization velocities (Yoshida et al, 1969)

$$U/Ui = \varepsilon n \quad (5)$$

where: U (m/sec) – minimum superficial and fluidization velocities. Ui – the settling velocity of the particle at infinite dilution, and n is a constant.

The Reynolds number (Ret) and the particle's final velocity affect the exponent (n). For the prediction of Ui and n, Richardson and Zaki proposed the following relationship.

$$n = 4.65 + 20\ d / D \ (Ret < 0.2) \quad (6)$$

$$n = (4.4+18\ d/ D)\ Ret\text{-}0.03\ (0.2< Ret< 1) \quad (7)$$

$$n = (4.4+18\ d/D)\ Ret\text{-}0.1\ (1<Ret<Ret<500) \quad (8)$$

$$n = 2.4\ (Ret>500) \quad (9)$$

where: d – the particle size and D – the bed diameter, Ui – sedimentation rate at infinite dilution; Ut – terminal velocity.

$$Log\ Ui = log\ Ut - d/D \quad (10)$$

where: Ut – the terminal velocity of the free-falling body. Ret – is the Reynolds number at terminal velocity.

$$Re = Ut.\ D.\ \rho l\ \mu l \quad (11)$$

$$U = g.\ d2.\ (\rho s - \rho l)\ 18.\ \mu l,\ (Re < 0.2)\ (2.26)\ Ut = 0.153.\ g0.71.\ DP\ 1.14.\ (\rho s - \rho l\ )0.71\ \rho l\ 0.29.\ \mu l\ 0.43,\ (Re > 0.2) \quad (12)$$

where: ρs – particle density, ρl – liquid density, μl – liquid viscosity, Re – Reynolds number.

Mass transfer in fluidized bed

The minimum fluidization velocity must be Similar to surface velocity. At infinite dilution, Ui is the particle settling velocity and n is a constant. The exponent (n) depends on the Reynolds number (Ret) and the terminal velocity of the particle. Richardson and Zaki provide the following correlations for estimating Ui and n: (Al-Musawi, 2012; Mohammed and Najim, 2020). Several in-bed mass transfer studies were performed to predict solid-liquid mass transfer coefficients for various systems. Therefore, the KL value can be predicted using the formula (Wang et al., 2019; Zhou et al., 2020; Li et al., 2020):

$$Dm = 2.74{*}10{-}9\ (Mwt)\ {-}1/3 \quad (13)$$

$$Sh = 0.35\ Re0.6\ Sc1/3 \quad (14)$$

$$Kl = Shz.\ Dm\ dp\ (2.30) \quad (15)$$

where: Dm – a diffusivity coefficient, Sh – a Sherwood number, Sc – a schimidt number.

FLUIDIZED BED BIOFILM REACTOR

A recent innovation in wastewater treatment uses a small fluidized medium for cell fixation and retention: the fluidized bed biofilm reactor (FBBR) (Fig. 7) (Shieh et al., 1989). Both aerobic and anaerobic wastewater have been successfully treated with FBBR (Figure 8). The system consists of an effluent coated with microorganisms and sufficiently agitated to maintain a homogeneous phase mixture. Both aerobic and anaerobic processes have received increasing attention as efficient technologies for treating water and wastewater (Schugerl, 1989; Shieh et al., 2005). By immobilizing microorganisms on the surface of tiny particles, a large surface area is available to react with liquids, resulting in high concentrations of

active microorganisms (Schügerl, 1989). Bacteria form biofilms on surfaces by attaching to the fluidized medium, as shown in Figure 9. With high mixing (low external resistance to mass transfer) and significantly smaller system dimensions, residence time decreases with increasing flow rate. This eliminates the possibility of clogging (Burghat and Ingole, 2013a).

According to Liew et al. (n.d.) The basic premise of the process is to pump wastewater through a dense bed of particles, causing the particles to flow or liquefy. As the effluent rises through the biological bed, the dense biota living on the surface of the bed consumes the biodegradable waste contaminants in the liquid. In the key diagram of the process, a fluidized bed reactor is shown in its entirety, with the effluent flowing up through the fluidized bed to agitate the liquid particles. Particles are separated from the liquid in the pure water zone above the bed (Jamali et al., 2019).

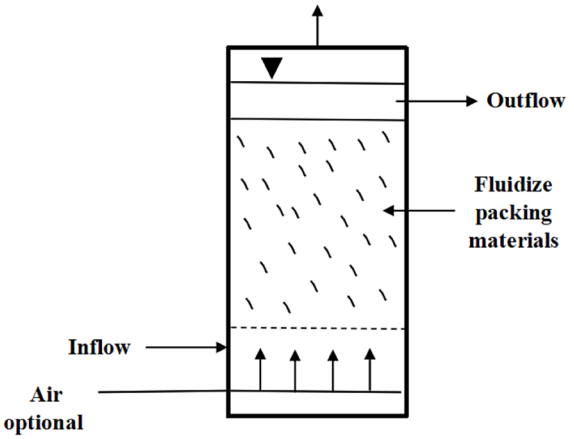

Fig. 7. The Fluidized Bed Biofilm Reactor (FBBR) (Burghate and Ingole, 2013b)

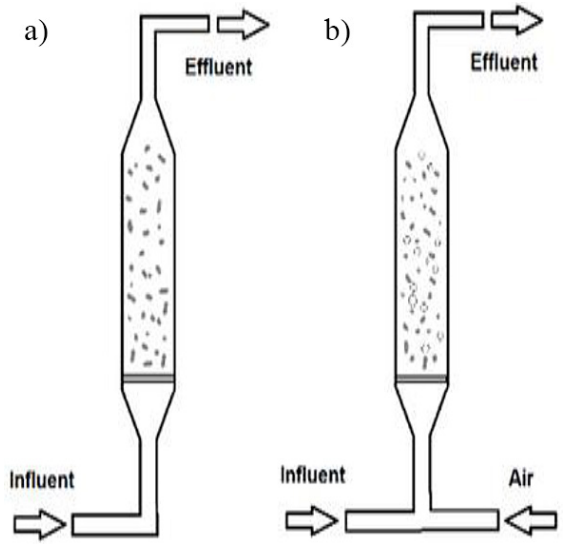

Fig. 8. Aerobic and anaerobic FBBR reactor (Özkaya et al., 2019)

Advantage of FBBR

There are many advantages to using a fluidized bed reactor (Burghate and Ingole, 2013a).

1. Significant flow rates can be achieved in FBBRs because the medium in which microorganisms grow is fluidized and has a relatively large surface area for microorganisms to grow.
2. FBBR has a great potential to eliminate various factors, such as BOD, COD, nitrogen, etc., because there are too many microorganisms.
3. Since the FBBR equipment is smaller than other types of reactors, it takes up less space.
4. Permissible shock loads are used to achieve FBBR.
5. FBBR treatment is affordable.
6. When used properly, the FBBR eliminates the need for a second settling tank, reducing the overall cost of the facility.
7. Since FBBR provides an exceptionally long SRT, microorganisms are required to break down xenobiotic and hazardous chemicals.
8. Easy and reliable to use.

Disadvantages

The primary drawback of FBBR is the amount of pumping power required to run it as well as how well the inlet and outlet arrangements are designed to distribute the flow (Burghate and Ingole, 2013a).

Packing materials

Various media were tested in the FBBR including sand, glass beads, activated carbon, plastic beads/chips, etc. Sand was used as the

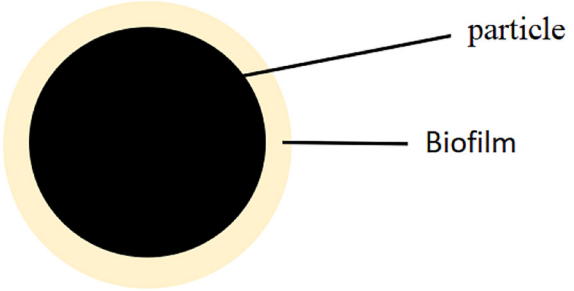

Fig. 9. Microbes attach and form a biofilm on the surface (Nelson et al., 2017)

biofilm host medium in most studies. Majumdar et al. (2019) bioremediation of paper mill waste studied in a fluidized bed reactor (FBR) using *Planococcus* sp. Another industrial waste, PMS, was used as the immobilization substrate. After 60 h of treatment, the PMS bacteria immobilized in FBR eliminated 96%, 74%, 81%, and 85% of phenol, lignin, dye, and COD, respectively (Bustos-Terrones et al., 2022).

Sodium alginate (SA) has been used to immobilize pollutants in wastewater using microbial communities isolated from activated sludge ponds in wastewater treatment plants. The first study investigated the removal of total phosphorus and organic matter from domestic wastewater using microorganisms immobilized on SA, with removal efficiencies of 71% and 93%, respectively, after 12 hours (Kube et al., 2020). Nutrient removal from wastewater in a microreactor was carried out using algal beads embedded in alginate. Secondary effluent to mice contained TP (8.9–0.45 mg/L), TN (18.3–0.7 mg/L), $N\text{-}NO_3$ (5.3–0.4 mg/L) and $N\text{-}NH_4^+$ (9.4–0.2 mg/L) A retention time of 12 hours was performed in a fluidized bed reactor enriched with Scenedesmus or Chlorella vulgaris. The effectiveness of an algae mixture (80% Chrysophyta, 5% Cyanobacteria, and 14% Green algae) for the removal of nickel ions from aqueous solutions was investigated using batch and circulating fluidized bed methods (Mohammed and Najim, 2020). De Melo Pirete et al. (2022) investigated the use of a fluidized bed reactor capable of nitrification and removal of ibuprofen (IBU) and diclofenac (DCF). FBR on an industrial scale using domestic wastewater as input, ethanol (74–100 mg/L) and nitrate (89–136 mg/L). The experiment was divided into four phases. In addition, many studies have found ways to remove various pollutants in wastewater, as shown in the Table 1.

EFFECT OF OPERATION PARAMETERS

Effect of flowrate

Especially in fluidized bed reactor designs, the liquid flow rate has a large impact on the length of time that the particles and contaminant solution remain in contact (Nelson et al., 2017;

Table 1. Previous study identified to remove deferent type of pollutant using FBBR

Pollutant	Reactor and support material properties	Operational conditions	Removal	REF.
Waste activated sludge	Plexiglass rectangular column V: 16 L H: 3.6 m Support: HDPE DP: 600–850 µm Density: 1554 kg/m3	T: 37 o C HRT: 2.2–4 d OLR: 12 -18kg COD/m3 d		(Z. Wang et al. 2016)
Domestic wastewater	V: 0.0125 m3 D: 0.1 m H: 1.8 m Support: LDPE Density: 870 kg/m3 BH: 0.6–1.0 m	HRT: 6.25 – 24 h Q: 10–80 mL/min Ug:0.0016 - 0.00318 m/s	COD: 96.7%	(Haribabu and Sivasubramanian 2016)
Autotrophic denitrification	Glass column V: 580 ml Support media: GAC DP: 0.5–1 mm	pH: 5.8 T: 20–30 o C Q: 800 mL/min, HRT: 10 min OLR: 500 mg/L h Bed expansion: 25%	N: 100%	(Mohamed et al. 2016)
Aquaculture Effluent: Nitrate removal	V: 2.85 L D: 0.31 m H: 3.9 m BH: 0.9 m Support: Sulfur biofilters, DP: 0.3 mm	Phase I: HRT: 3.2–3.3 min, Flowrate: 63–65 L/min Phase II: HRT: 3.2-4.8 min Flowrate: 67–43 L/min 13–42% bed expansion	N: 49 %	(Christianson et al. 2015)
Cu, Ni & Zn	V: 2.5 L D: 0.08 m H: 1.0 m	removal HRT: 24 h pH: 7 & 5 OLR: 1 g COD/L. d 30 % bed expansion	Cu: 97.5 % Ni: 65.9 % Zn: 97.0 % COD: 61.9	(Janyasuthiwong et al. 2015)
Synthetic municipal wastewater: denitrification Plexiglass	column V: 608 ml D: 2.54 cm H: 100 cm Support: zeolite DP: 600–850 µm	T: 20 ± 3 o C HRT: 0.6 h OLR: 5.9–7 kg COD/m3 d Q: 20 ± 2 L/day	N2O: 0.53 %	(Eldyasti, Nakhla, and Zhu 2014)
Currant wastewater:	Plexiglass column V: 3.95 L D: 60 mm H: 140 cm BH: 0.6 m Support: PVC DP: 2 mm	COD T: 35 ± 2 o C OLR: 9.4 to 24.2 kg COD/m3 Umf: 0.75 m/min 30 % bed expansion	COD: 96. 9 %	(Jaafari et al. 2014)
Domestic wastewater	Plexiglass plate V:7.6 L, Support : GAC Loading: 200 – 300 g	T: 15 - 35 o C HRT: 6 h	COD:74%	(Gao et al. 2014)
Sulfide oxidation	Glass column V: 0.6 L D: 0.045 m H: 0.38 m Support: nylon DP: 2–3 mm	T: 30 ± 2 o C HRT: 25–70 min Uup: 14–20 m/h	Degradation: 92 %	(Midha, Jha, and Dey 2012)
Real acid drainage mine water	V: 300 mL Support media: AC DP: 0.5–1 mm	T: 35 o C HRT: 12 – 24 h pH: 2.7–7 15–20 % bed expansion	Sulfate: 90 % COD: 80 % Metal: 99.9 %	(Sahinkaya et al. 2011)

Sureshkumar et al., 2020). Increased effluent flow through the same unit reduces residence time and reduces system cleaning efficiency. Therefore, wastewater contains more contaminants than usual (Wang and Shen, 2020). The fluidization distance is greatly affected by the flow rate of the solution (Zhu et al., 2019).

A high flow rate shortens the contact time, causing the C/Co to approach 1 early (increased bed fatigue) and drains the adsorbate solution from the column before full equilibrium is reached. The liquid phase residence time decreases with increasing liquid velocity (Yang et al. 2021; Mohammed et al., 2022). The shorter the residence time, the higher the contaminant concentration in the raffinate and the shorter the adsorption time are. These results agree with that obtained by Muhammad et al. (2020). Three investigators tested different solution flow rates (18, 21, and 24 L/h) to demonstrate this effect on CFBR removal efficiency and antibiotic removal breakthrough curves. Figure 10 a shows that the breakthrough curve becomes steeper as the flow rate increases. According to (Mohammed and Najim, 2020), the Ce/Ci ratio increased from 0.39 to 0.8 when the liquid flow rate was increased from 6 L/h to 12 L/h.

As shown in Figure 10b, the impurity concentration in the liquid phase increases along with liquid flow rate through the column. This can be explained by the residence time. As the liquid velocity increases, the residence time of the liquid phase decreases. A short residence time results in a short adsorption time and at the same time increases the concentration of impurities in the raffinate stream (Naja and Volesky, 2006; Sahinkaya et al., 2011).

Effect bed high

Bed height is a key design element of the adsorption process, affecting the breakthrough curve and removal efficiency (Dayton et al., 2013; Kareem and Mohammed, 2020). How long it takes to reach saturation depends on the height of the bed. Figure 11a shows how the time required to reach equilibrium increases with bed height. This is due to the high load of pollutants and prolonged contact between particles (Mohammed et al., 2011). The effluent sorbate concentration ratio increased faster at lower bed heights, than at higher

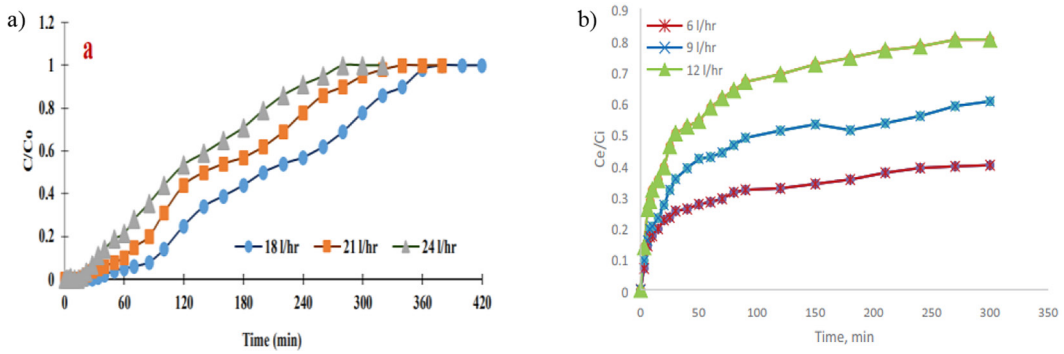

Fig. 10. Effect of flow rate on breakthrough point (Mohammed and Najim 2020; Kareem and Mohammed 2020)

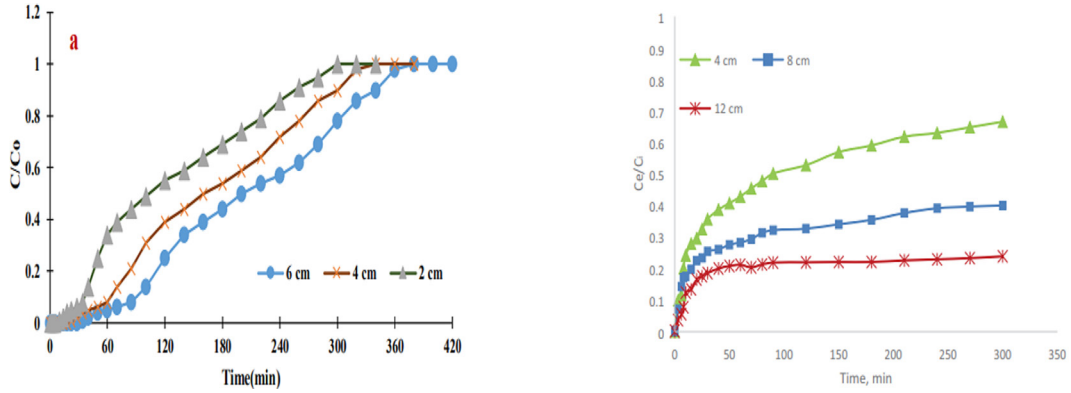

Fig. 11. Effect of bed high on breakthrough point (Mohammed and Najim 2020; Kareem and Mohammed 2020)

bed heights, indicating faster saturation at lower bed heights (Giffin and Mehrani, 2010). In addition, the higher the bed height, the more adsorption sites with larger surface area, which contributes to the improvement of the adsorption process (Sundaresan, 2003). Increasing Hs increases the contact time of the antibiotic solution with the bed at a constant flow rate, thereby increasing the solute removal efficiency.

(Mohammed and Najim, 2020; Hawraa R. Bohan, 2021) showed that the time to equilibrium increases with bed height. At Ci = 50 ppm, the liquid flow rate is 6 l/h and the air flow rate is 250 cm^3/min. Figure 11(b) shows the effect of bed height on the biosorption process at static bed heights of 4, 8 and 12 cm. This is due to the increased contact time of contaminants and particles in the bed. The effluent adsorption concentration ratio increased faster at lower bed heights than at higher bed heights, indicating that saturation was reached earlier for smaller bed heights (Z. Wang et al., 2016). Increasing the bed height creates more surface area or biosorption sites, further enhancing the biosorption process. These results are consistent with those of (Lan, 2002: Gautam et al., 2013). The residence time of particles in the bed increases with the height of the bed (Tran et al., 2016).

Effect of initial concentration

At lower initial pollutant concentrations, it takes longer for the diffusion rate to reach saturation. Furthermore, it is clear that the adsorption capacity decreases with increasing influent concentration (Mohammed and Najim, 2020). This is because the concentration of the solute in the bulk solution is very different from the concentration in the solid phase. A solute will transfer its mass more quickly if it can bind to one or more vacancies in the solid phase. Transport depends on the concentration difference between the solute and the adsorbent in solution. On the other hand, if the initial concentration is high, the bed will saturate faster and the slope of the breakthrough curve will be steeper (Burghate and Ingole, 2013; Kareem and Mohammed, 2020).

Effect of pH

The pH is a key factor in how the process works, because it affects the bacteria in the FBBR. Extremely high or low pH values can affect the efficiency of FBBR, as superacidity and superalkalinity limit the function of bacterial internal enzymes (Jianping et al., 2003: Lin et al., 2010: Ghayda et al., 2019) The biodegradation of reactive blue was studied using Pseudomonas(sp) in a two-stage anaerobic/aerobic FBBR. When the pH value was between 5 and 9, the total COD removal efficiency was 67.7%~90.4%, and the chroma removal efficiency was 13.75.6%~86.9%.

A pH between 6 and 7 is ideal for degradation. (Bello et al., 2017) studied the effect of pH (from 3 to 9) on Geotrichum spp. Calcium alginate restores various colors bleached in FBBR. The most intense color change is achieved at pH 5. When the pH value is higher than 5, the discoloration rate drops sharply. The effect of pH on the denitrification of nitrate-nitrogen effluents with low C/N ratios was studied in a three-phase FBR (Zeroual et al., 2007). Values between 6.5 and 7.5 have been identified as the ideal pH range. It was also observed (Suidan et al., 1996) that increasing the pH from 7 to 7.5 improved the performance of the FBBR.

CONCLUSIONS

This study demonstrates that algal biomass can serve as a powerful biosorbent for removing drugs from aqueous solutions. The fluidized bed biofilm reactor is the latest development in wastewater treatment that uses a microfluidic medium to trap and contain microorganisms. The FBBR degradation process can be anaerobic or aerobic. The breakthrough point is affected by several manipulated variables such as initial contaminant concentration, bed height, flow rate, and pH. At higher initial concentrations, the bed saturates on the breakthrough curve sooner, increasing bacterial inhibition. FBBR performance can be affected by pH, hyperacidity, and hyperbasic intracellular enzymatic activity. A high flow rate will drain the adsorbate solution from the column before full equilibrium is reached, thus shortening the contact time and allowing the C/Co to reach the unit sooner (increased bed fatigue). Bed height affects the time to reach saturation. As the bed height increases, so does the time it takes to reach equilibrium. This is due to increased contact time between contaminants and particles in the bed. FBBR has many advantages that make it an excellent choice for removing various wastewater contaminants, especially pharmaceuticals.

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