PERFORMANCE OF BIOLOGICAL FILTRATION PROCESS FOR WASTEWATER TREATMENT: A REVIEW

Shuokr Qarani Aziz[1, *]

[1,*]: Department of Civil Engineering, College of Engineering, Salahaddin University–Erbil, Erbil, Iraq; Corresponding author, shuokr.aziz@su.edu.krd, shoker71@yahoo.com

Sazan Mohammed Ali [2]

[2]: Department of Dams and Water Resources Engineering, College of Engineering, Salahaddin University–Erbil, Erbil, Iraq, sazan.ali@su.edu.krd

***Abstract*-Among all biological processes for treatment of wastewater, biological filtration method is used as a secondary treatment technology for improving certain kinds of wastewaters. The present work was aimed to illustrate several types of biofilters such as trickling filter (TF), rotating biological contactor (RBC), fixed bed filters, moving bed biofilm reactor (MBBR), and fluidized bed filters (FB). An overview of each technique, operational parameters, typical standards, advantages and shortcomings of each method were revealed as well. Moreover, applications suitability of various attached growth processes for the treatment of different wastewaters of other investigators were outlined. Published works reported that applications of biofilm technology are efficient for treatment of weak wastewaters such as municipal wastewater with low strength rates. In addition, biological filtration process particularly TFs are unproductive for treatment of strong wastewaters which contains high concentrations of organic matter, nitrogen compounds, heavy metals, phenols, grease and oil, and low biodegradability ratio. Suggestions were outlined for enhancing efficiency of biological filtration process for treatment of high organic loading rate wastewaters.**

Keywords: Wastewater; dairy; biofilm; filtration; attached growth; biological treatment

I. INTRODUCTION

Increase of human population and urbanization growth results in producing huge amount of wastewaters which creates the most challenging environmental safe and economic problems in today's world civilization [1]. Adequate treatment of wastewater to provide sufficient level of treated water becomes the major concern for many communities [2]. Selection of a suitable treatment technology for wastewater are related to the characteristics of wastewater and the purpose for the treatment process [3-5]. The overall objective of biological wastewater treatment is that wastewater contains high rate of microorganisms to be treated biologically especially nutrients and phosphorus [3-6]. Biofiltration is a very important treatment process in biological wastewater treatments for degradation of organic substances which are attached onto the filter media [7]. Applications of biological filtration systems have been a common practice worldwide because of its cost effective and simpler operation [4]. However many researchers worked on various biological filtration techniques for various wastewater treatments [1, 3-4, 6]. In addition, Wastewaters that are generated from food processing industries have different characteristics in comparing with the municipal wastewater, for instance constituents of dairy effluent contains higher concentration of five day biochemical oxygen demand (BOD_5) , chemical oxygen demand (COD), suspended solids (SS), and inorganic compounds[6-8]. In practice, there are a number of biological treatment methods such as activated sludge system, aeration lagoon systems, trickling filters, and anaerobic biological processes are applied for the treatment of municipal and dairy wastewaters; among these process the anaerobic treatments is interested by the researchers to be more attractive for treatment of high organic content wastewaters since its demand for energy is low and the system has source for energy and minimum sludge production [9]. On the other hand, in attached growth system design, the organic loading rate (OLR) and hydraulic retention time (HRT) of the reactors and characteristics of the media type are playing an important role in the performance of biological filtration systems [9]. The present study was aimed to fill and overcome the gap of knowledge in the applications of different biological filtration treatment processes with their advantages and drawbacks of each technique. In addition, this work discussed the role of wastewater characteristics in selecting an appropriate wastewater treatment technique.

II. CHARACTERISTICS OF DIFFERENT KIND OF WASTEWATERS

Wastewater is characterized by its physical, chemical, and biological compositions. The constituents of wastewaters are depend on the source of the wastewater, function, and the activity of particular industries; For example municipal wastewater which originated from homes, businesses, schools, and public buildings have less severe wastewaters (weak wastewaters) since it contains low ranges of BOD_5, COD and heavy metals. In contrast, industrial wastewaters such as tannery industry, complex food processing industries and landfill leachate contain high amount of organic, inorganic materials, and heavy metals. Moreover, there are many factors influencing the variation in characteristics of wastewaters among them the seasonal variation particularly temperature is the most important parameter because it effects on the chemical reactions, and suitability of the wastewater for beneficial uses [3]. In reference [10], author was studied the main sewage channel in Erbil City and its matching for irrigation purpose in different seasons, it illustrated that Erbil municipal wastewater in main sewage channels is can be used for irrigation purposes only in winter season due to increasing in the amount of bacteria in other seasons. Researchers studied changes of the municipal wastewater characteristics during conveying in sewers. They investigated that the characteristics of wastewater (such as COD and nitrogen compounds) changes in the sewage system, not at the wastewater treatment plant [5].

As mentioned, domestic, municipal and dairy wastewater regard as weak waster. Table I illustrates most widely used biological treatment methods for treatment of weak wastewaters. Table 2 shows removal efficiencies for weak wastewaters using common attached growth processes. Information about typical characteristics of municipal and dairy wastewaters are given in Table III.

TABLE I. APPLICATION OF BIOLOGICAL TREATMENT METHODS FOR DIFFERENT TYPES OF WASTEWATERS

Wastewater type	**Treatment Technique**	**References**
Synthetic Salinity wastewater	Membrane Bioreactor MBR	[9]
Dairy wastewater	Trickling filter	[11]
Abattoir wastewater	Trickling filter	[12]
Dairy wastewater	Sequencing Batch Biofilm reactor SBBR	[13]
Automotive Industry wastewater	Sequencing batch biofilm reactor SBBR	[14]
Municipal wastewater	Submerged fixed bed biofilm reactor FBBR	[15]
Domestic wastewater	Constructed wetland system	[16]
Domestic wastewater	Multimedia Trickling filter	[17]
Coffee grain processing ww	Anaerobic fixed bed reactor	[18]
Synthetic milk wastewater	Anaerobic sequencing batch biofilm reactor ASBBR	[19]
Sewage ww	Combined Fixed film bioreactor and sand filter	[20]
Municipal & Landfill ww	Air suction flow-biofilm reactor ASF-BR	[21]

TABLE II. REMOVAL EFFICENCIES FOR ATTACHED GROWTH PROCESSES

Wastewater Type	**Treatment Technique**	**Removal Efficiencies %**	**HRT**	**References**
Domestic ww	Bio-cache attached growth system	BOD_5 88 , COD 78, TSS 72, NH_3-N 75, chloride 9, phosphate 40	2 hr	[1]
Dairy ww	Bio-trickling filter	COD removal > 85	10 days	[11]
Municipal ww	Biological filter with bio filling	BOD_5 76	18-24 hr	[22]
Synthetic dairy ww	Sequencing batch biofilm reactor SBBR	COD 99.5	18 hr	[13]
Municipal ww	Fixed bed biofilm reactor	COD 91, turbidity 92, TSS 94, NH_3-N 97	2.48-3.73 hr	[15]
Municipal sewage ww	Upflow anaerobic filter	COD 46-72	48 hr	[23]

TABLE III. THE TYPICAL QUALITY OF MUNICIPAL AND DAIRY WASTEWATERS [3, 24]

Contaminants	**Typical Values**	
	Municipal ww	***Dairy ww***
BOD_5 (mg/l)	110-400	1,748-3000
COD (mg/l)	250-1000	2660-4550
TKN (mg/l)	20-85	370-640
T.S.S (mg/l)	100-350	3,800-6,500
FOG (mg/l)	50-150	560-960
Total Phosphorus (mg/l)	4-15	0-80
Total Sodium (mg/l)	N/A	200-600

III.BIOLOGICAL TREATMENT TECHNIQUES

Biological wastewater treatment processes use microorganisms to remove (degrade) wide range of contaminants from wastewater, Table II. Basically in biological wastewater treatment, there are two main treatment processes including suspended growth processes, and attached growth (or biofilm) processes [4]. In suspended growth process, the microorganisms which are responsible for the degradation of organic substances in the presence of oxygen into gases and cell tissues are maintained in suspension within the wastewater by adequate mixing methods. Many applications on suspended growth are operated under aerobic condition in the presence of oxygen [3]. The biological activated sludge is the most common technology treatment of suspended growth used for removing organic substances, the mechanism of this process is to provide mixing and transfer oxygen into the process by achieving aeration in the process [3]. The success performance of the activated-sludge process depends on the microorganism separation in the final clarifier, when microorganisms do not settle out as expected so the sludge is called to be bulking sludge [5]. An alternative of activated sludge process is attached growth process with its more reliable removal efficiency for contaminants [25]. Biological filtration is a secondary treatment technology in attached growth system to produce effluent of domestic and industrial wastewaters with the high quality which later can be used for various purposes such as for irrigation [1]. In the attached growth systems the selection of supporting media to provide large surface area and high void ratio are the most important and critical steps for the design operation parameters so as to facilitate the microbial growth (biofilm layer) [8]. However, optimization for the performance of each wastewater treatment system is more effective and important in environmental engineering design, hence many researchers now make optimization for the design parameters of various wastewater treatments. Various wastewater treatment techniques for a number of reserchers that they used response surface methodology (RSM) for wastewater operation variables are reported in [26]. They explained different treamnet methods, and attached growth is a sample, for removal of pollutants from wastewaters.

IV. BIOFILM SYSTEMS IN BIOLOGICAL WASTEWATER TREATMENT

Wastewater treatment with biofilm has several benefits compared to suspended growth system because of its operational flexibility, low space requirement, as well as enhancing reaction rates and population dynamics in wastewater influent [27]. Removal efficiencies of constituents from wastewaters using different biofilm processes are given in Table III. The ability to form biofilm to the surface of the filter media and its growth is very complex process in biological filtration in which its strength of the attachment depends on environmental conditions, surface media properties, type of microorganisms, and fluid characteristics [28-29]. The attachment of microorganisms onto the surface of the media is divided into five stages shown in Fig. 1, including bacterial development on a surface, transportation cells to a surface, adhesion, surface colonization and detachment [23-28]. There are numerous types of biofilm configuration is applied in wastewater treatment system such as trickling filter (TF), rotating biological contactor (RBC), fluidized bed reactor (FB), and membrane bioreactor (MBBR), in which they are all have the same concept in the result of treatment wastewater by utilization of microorganisms that are attached to the filter media to form a biofilm layer [2]. Authors studied the performance of biofilm in fluidized bed reactor using 400-500 basalt support particles, results indicated the density and thickness of biofilm associated with the shear stresses in the reactor while the composition of the biofilm related to the properties of supporting media and the activity of microorganisms in wastewater [29]. Details for the biofilm processes are illustrated in the following sections.

A. Trickling Filter

Trickling filter is one of the treatment technologies for wastewater treatment in which the filter is unsubmerged and the influent wastewater is normally applied at the top of the filter media. Many conventional trickling filters using rock as a fixed-film packing material but now the trickling filter media is constructed with synthetic plastic media packing [3]. In TF system, the microorganisms which exist in wastewater consume the organic materials to form a biological layer called slime (biofilm) layer around the surface of the media along time [30]. Each trickling filter has several components include a dosing rate system, a structure contains filter media, an underdrain system to collect the treated wastewater, and a settling system to settle the sludge and separate from the effluent [6], Figs. 1 to 3.

Moreover, the TF is a common technology used for municipal and industrial wastewaters and hence it reduces the BOD_5, nutrients, removing dissolved solids in wastewater, and bacteria [31]. Many TFs can be operated with different filter packing material depending on the characteristics of the filter media such as high surface area per unit volume, high durability (types of the media), higher porosity, and roughness of the filter media, Figs. 2 to 3 show typical filter packing types for TF [3]. Many studies were carried out on the performance of TF under different filter packing media hence it is the main component of the TF to obtain the higher removal efficiency. A research carried out on multimedia filters (Aerocon stone, brick bats, and plastic srubber) using up and down flows filtration for treatment of domestic wastewater. Removal efficiency for BOD_5, COD, and total solids were 58.54 %, 52.15 %, and 82.31 %, respectively [17]. Anaerobic TF for the treatment of high organic municipal sewage was used [32]. Plastic material was examined as filter media. Removal of COD in the sewage at hydraulic retention time (RRT) of 48 h and at temperature of 15-20 C° was varied from 46 to 72 %; while concentrations of NH_4, PO_4, $SO_4^{=}$ in the effluent were high [32]. Authors reported that some operational drawbacks of the TF (such as performance fluctuations, and biofilm maintenance) and high strength wastewater loading rates affected on effluent quality. But it can be noticed from literature that TFs had ability to remove more than 85 % of COD from dairy wastewater, as explained in Table III.

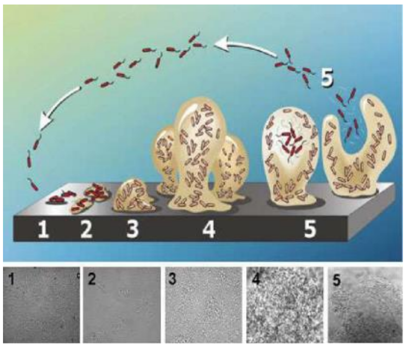

Figure1 The stages involved in biofilm formation [6]

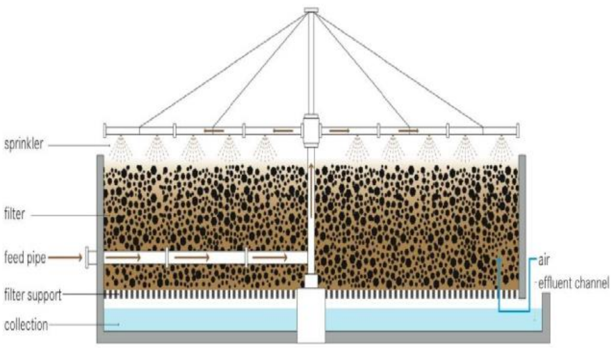

Figure 2 Typical trickling filter [6]

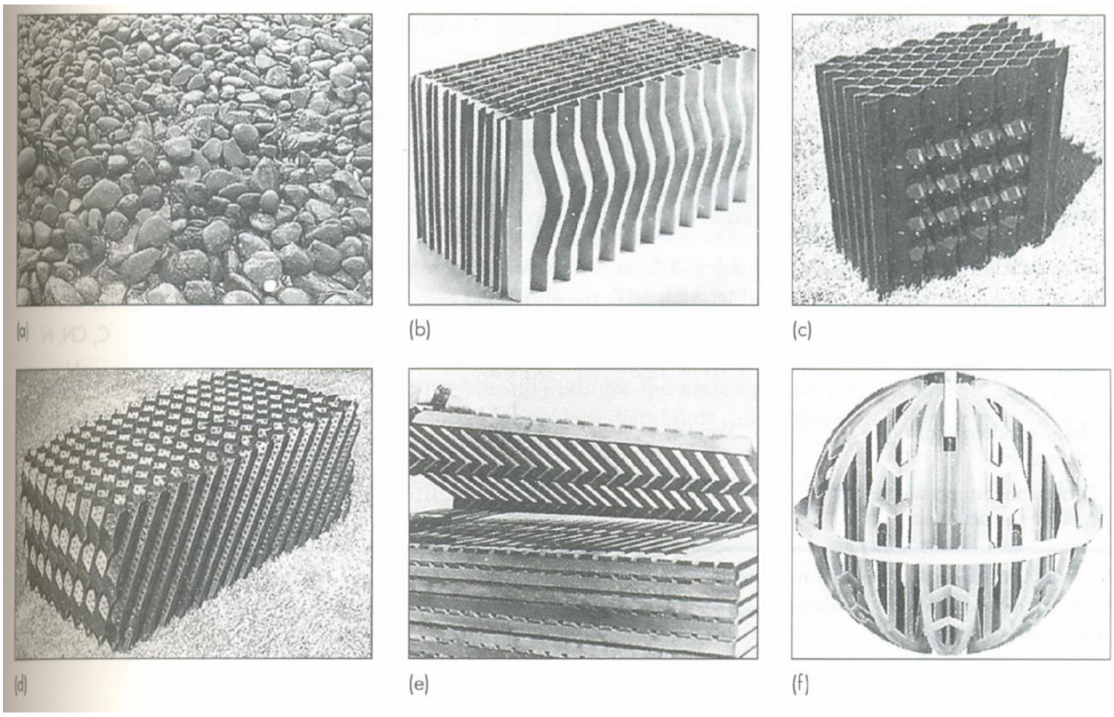

Figure 3 Typical packing material for trickling filters: (a) rock, (b) and (c) plastic vertical-flow, (d) plastic cross-flow, (e) redwood horizontal, and (f) random pack. [3]

B. Rotating Biological Contactor (RBC)

Now the application of RBC for biological wastewater treatment has been developed widely. An RBC is consist of a series of closely spaced circular disks of polystyrene or PVC that partially submerged in wastewater and rotated through it. The aeration in RBC is accomplished by exposure discs to the atmosphere and bacteria grow on the medium surface (discs) to remove substrates in wastewater [3]. Fig. 4 shows the operation process of the RBC.

The RBC consist of a number of parallel discs mounted perpendicularly on a shaft rotate slowly (about 1 to 1.6 revolutions per minute) in a tank contains the wastewater to be treated, and the RBC units are partially submerged in the tank (typically 40%) [33]. Main design parameters for the RBC design are hydraulic loading rate, and organic loading rate. However increasing in stages of RBC results in high efficiency effluent but it needs higher cost of energy demand due to excessive rotation speed of the shafts. Reference [6] recorded the results of other investigators on applying RBC system at high loading rate and low loading rates, the results indicated the removal efficiency of the nitrate-nitrogen for high and low organic loading rates respectively were 79.2%, 83.4%, The authors concluded that the removal efficiency for the RBC system will be high at low organic loading rate.

C. Fixed Bed Filters

The application of fixed bed filter is widely used in wastewater treatment system because it requires much less volume and space with the high load system operations compared to other conventional systems [34]. Nowadays, there are different configurations of reactors used for operation of this system which directly associated with the flow regime, submergence of the support media, support material, aerobic and anaerobic conditions. Fig. 5 illustrates some of the configurations of this system. The basic objective and mechanism of the fixed bed process is the immobilization of bacteria on the solid surface to form a biofilm layer either in aerobic or anaerobic systems [6]. However, anaerobic applications of this system are relatively new, many researchers worked on this system. Removal of COD from medium-strength wastewater using anaerobic fixed bed reactors with 24 h HRT was 88.3 %. The removal efficiency was decreased when HRT of 8 h was applied [6]. Moreover, good performance of this system relies on many factors such as temperature, properties of filter media, and direction of flow (up and down flow). Results indicated the use of rough filter media in the reactors resulting in the accumulation of biomass and can easily adhere to the surface of the media with the high rate followed by a good removal efficiency [34-3 5]. Besides, less efficiency of this technique at high temperature, high cost of support media, and sophistication operation controller are some of the disadvantages of fixed bed reactors. In literature and as explained in Table III, fixed bed biofilm removed 91 % of COD, 92 % of turbidity, 94 % of total suspended solids, and 97% of ammonia-nitrogen from wastewater [14].

D. Fluidized Bed Filters (FBR)

It is a modern technology for the treatment of wastewater with high shock loading influent of wastewater. Fluidized bed consists of a reactor with the supporting media heavier than water and small in diameter. Different supporting media is used such as sand, slag, and plastic balls,…etc. The microorganisms grow on the surface of the media to consume organic contaminants exist in wastewater resulting a biofilm layer on the media at a sufficient velocity to fluidize the filter media and retain at high solid retention time SRT [35]. The system can be operated under aerobic or anaerobic conditions with floated or submerged support media. Fig. 6 displays the different FBRs. The system aims to form a biofilm layer by microorganisms when the wastewater mixes with the filter media. In addition, there are many advantages using this system for the wastewater treatment comparing to other biological filtration processes. A study on fluidized bed biofilm reactor (FBBR) was carried out [35]. The novelty of this technology for wastewater treatment was FBBR combine both activated sludge and TF in one process. The removal efficiency for FBBR was 10 times more than that of the activated sludge process. The main disadvantages of this process were required power for pumping, and the cost of packing material.

E. Moving Bed Biofilm Reactors (MBBR)

The operation mechanism of the MBBR is like activated sludge process with the addition of small cylindrical shaped carrier for biofilm growth. The small carrier elements inside the reactor will continuously mix in terms of suspension with the wastewater either in aerobic or anaerobic basins. The typical sizes of small cylinder filter carrier are about 10 mm in diameter and 7 mm in height [3]. Fig. 7 shows the mechanism operation of two typical system design of MBBR. In the former case, the suspended packing material is moved inside the aerobic reactor in terms of aeration, while in the latter case, the biofilm supporting material is agitated in an anoxic reactor using mechanical mixer.

The MBBR has many benefits compared to other conventional systems in removing organic materials such as removing of BOD_5 and COD with high organic loading rates. Researchers carried out a study on characteristics of biofilm carrier elements of MBBR. They indicated that carrier biofilm elements with high specific surface area allow higher biomass concentration in small reactors and good control for system's efficiency on which the concentration of biofilm is between 3000 and 4000 g TSS/m^3 which is the same rate as in the activated sludge process [6]. However the cost of operation and the settleability of biosolids in the reactor are the main drawbacks of this system.

V. CONCLUSIONS

Wastewaters are categorized as weak, medium and strong wastewaters. The overall biofilm systems in biological processes are efficient for treatment of weak to medium wastewaters. More than 85 % of organic matters (in particular COD) could be removed in biological filtration process. Modifications of attached growth process such as FBBR enhanced removal efficiencies of pollutants. Shortcomings of the attached growth techniques can be minimized by combining extra physical/chemical methods with the attached growth processes.

REFERENCES

[1] V. Alireza , M. T. Seyed , K. R. Venkatraman , B. G. Gagik , J. Shervin and H. Nazanin, “An Approach on Attached Growth Process for Domestic Wastewater Treatment,” Env. Eng. and Manag., Romania, vol. 13, pp. 145-152, January 2014.

[2] Primer for Municipal Wastewater Treatment Systems, “Environmental Protection Agency EPA, United states: office of water and wastewater management,” Washington DC, September 2004.

[3] Metcalf & Eddy, Wastewater Engineering: Treatment and Reuse. Fifth edition, McGraw-Hill, New York, 2014.

[4] F. J. Cervantes, S. G. Pavlostathis and A. C. van Haandel, “Advanced Biological Treatment Processes for Industrial Wastewaters: Principles and Applications”, IWA publishing, UK: London, 2006.

[5] O. Qteishat, S. Myszograj, and M. S. Kisielewicz, “Changes of Wastewater Characteristic during Transport in Sewers”, J. of Wesas Trans. on Env. and Dev., Vol. 7, November 2011.

[6] K. Shahot, A. Idris, R. Omer, and H. M. Yusoff, “Review on biofilm Processes for Wastewater Treatment”, Life Sc. J., Malaysia, ISSN: 1097-8135, 2014.

[7] D. Chaudhary, S. Vigneswaran, H. H. Ngo, W. Shim, and H. Moon, “ Biofilter in Water and Wastewater Treatment”, Korean J. Chem. Eng., 20(6), ISSN: 1054-1056, 2003.

[8] O. Cristian, “Characteristics of the Untreated Wastewater Produced by food Industry”, Analele Universității din Oradea, Fascicula: Protecția Mediului, Vol. XV, 2010.

[9] G. D. Bella, D. D. Trapani, G. Freni, M. Torregross, and G. Viviani, “Analysis of Biomass Characteristics in MBR and MB-MBR Systems Fed with Synthetic Wastewater: Influence of a Gradual Salinity Increase”, Chem. Eng. Trans., vol. 38, 2014.

[10] U. H. K.Bapeer, “A study on the main sewage channel in Erbil city: Destiny and its matching to irrigation purpose”, J. of Kirkuk Univ. – Sc. Studies, Iraq, vol.5 (.2), 2010.

[11] S.T., and S. M., “Assessment of Bio-Trickling Filter Startup for Treatment of Industrial Wastewater”, Int. J, Environ. Res., 9(2):769-776, Iran, Spring 2015.

[12] G.H.D. Pty., “Trickling Filter Technology for Treating Abattoir Wastewater," Austr. Meat Proc. Corp., April 2015.

[13] A. A. L. zinatizadeh, Y. mansouri, A. akhbari, and S. pashaei, “Biological Treatment of a Synthetic Dairy wastewater in A Sequencing Batch Biofilm Reactor: Statistical Modeling using Optimization using Response Surface Methodology”, Chem.l Industry & Chem. Eng. Quarterly (CI&CEQ), Iran, 17 (4), pp. 485−495, 2011.

[14] P. Thury, L. Bartha, G. Gulyas, V. Pitas, B. Fazekas, and A. Karpat, “Improvement of Biofilm Carries for the Treatment of Automotive Industry Wastewater”, Hungarian J. of Ind. and Chem., Veszprém: Hungary, Vol. 40(1) pp. 1–4, 2012.

[15] W. Zahid, and S. El-Shafai, “Performance of Submerged Fixed-bed Biofilm Reactor Packed with Black Scoria for Municipal Wastewater Treatment”, Civil Eng. Dept., College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia.

[16] S. Sirianuntapiboon, M. Kongchum, and W. Jitmaikasem, “Effects of Hydraulic Retention Time and Media of Constructed Wetland for Treatment of Domestic Wastewater”, African J. of Agr. Res., vol. 1 (2), pp. 027-037, September 2006.

[17] M. Gulhane and A. Charpe, “Multimedia Filter for Domestic Wastewater Treatment”, Environ. Research and Develop., India, vol. 9 (3A), January-March 2015.

[18] F. R. L. Fia, A. C. Borges, A. T. de Matos, I. C. S. Duarte, R. Fia, and L. C. de Campos, “Development of Biofilm in Anaerobic Reactors Treating Wastewater From Coffee Grain Processing”, Revista Brasileira de Eng. Agrícola Ambiental, vol.14 (.2), pp.210–217, 2010.

[19] A. T. Dawood, A. Kumar, and S. S. Sambi, “Study on Anaerobic Treatment of Synthetic Milk Wastewater under Variable Experimental Condition”, Int. J. of Environ. Sc. and Develop., Vol.2 (1), February 2011.

[20] I. Naz, Z. U. Khan, N. Ali, and A. Ahmed, “Removal of pollution indicators from sewage by fixed film bioreactor and sand filter at low temperature", Revista Brasileira de Engenharia Agrícola e Ambiental”, Global J. on Adv. in Pure & App. Sc., vol. 1, pp. 259-270, 2013.

[21] P. Forde, and B. MIEI, “Treatment of wastewater using an innovative biofilm reactor – the air suction flow-biofilm reactor”, National Univ. of Ireland, Galway, in fulfilment of the requirement for the Doctor of Philosophy. October, 2013

[22] S. J. B. Al-Maliky, “Performance of Biological Filter with Bio Fillings for the Treatment of Municipal Waste Water”, J. of Sust. Develop., vol. 4 (1) February 2011.

[23] L. Przywara, B. Mrowiec and J. Suschka, “Municipal sewage treatment in upflow anaerobic filter,” unpublished.

[24] B. S. Shete, and N. P. Shinkar, “Dairy Industry Wastewater Sources, Characteristics & its Effects on Environment”, Int. J. of Current Eng. and Tech., vol.3 (5), December 2013.

[25] J. J. Peirce, P. A. Vesilind, and R. F. W. Peirce, “Environmental pollution and control”, 4th ed., Elsevier Sc. & Tech. Books, November 1997.

[26] M. J K. Bashir, S. S. Abu Amr, S. Q. Aziz, “Wastewater Treatment Processes Optimization Using Response Surface Methodology (RSM) Compared with Conventional Methods: Review and Comparative Study”, Middle-East J. of Sc. Res., vol. 23 (2), pp. 244-252, 2015.

[27] S. Anderson, “Characterization of bacterial biofilms for wastewater treatment”, Royal Instit. ofTech. School of Biotech., Stockholm 2009.

[28] J. Kandasamy, S. Vigneswaran, T. T. L. Hoang and D. N. S Chaudhary, “Adsorption and Biological Filtration in Wastewater Treatment”, Water and wastewater Treatment Technologies, EOLSS. Unisco publications, 2009.

[29] V. Holá, F. Růžička, and M. Votava., “The Dynamics of Staphylococcus Epidermis Biofilm Formation in Relation to Nutrition, Temperature and Time”, Scripta Medica (BRNO), vol. 79 (3), pp. 169–174, July 2006.

[30] C.F. Alves , L.F. Melo , M.J. Vieira, “Influence of Medium Composition on the Characteristics of Adenitrifying Biofilm Formed by Alcaligenes Denitrificans in Afluidised bed reactor”, Proc. Biochem. J., portugal, August, vol. 37, pp. 837–845, 2002.

[31] B. Lesikar and R. Persyn, “On-site wastewater treatment systems”, Texas Agricultural Extention Service: the Texas A&M University system.

[32] N. Dabi, “Comparison of Suspended Growth and Attached Growth Wastewater Treatment Process: A case Study of Wastewater Treatment Plant at MNIT, Jaipur, Rajasthan, India”, Europ. J. of Adv. in Eng. and Techn., , vol. 2(2), pp. 102-105, 2015.

[33] [1] H. Jördening, and K. Buchholz, “Fixed film stationary bed and fluidized bed reactors”, chapter in Biotechnology: Environmental Processesl, Book vol. 11a, second edition, Weinheim, Germany. 1999.

[34] F. Galluci, M. V. Sintannaland, and J. A. M. Kuipers, “Comparison of packed bed and fluidized bed membrane reactors for methane

[35] reforming”, 6th Inter. Sympos. on Multiphase Flow, Heat Mass Transfer and Energy Conversion, Xi’an, China, 11-15 July 2009.

[36] S. P. Burghate, Dr. N. W. Ingole, “Fluidized Bed Biofilm Reactor – A Novel Wastewater Treatment Reactor”, Int. J. of Res. in Env. Sc. and Tech., India, November 2013, ISSN: 2249-9695.

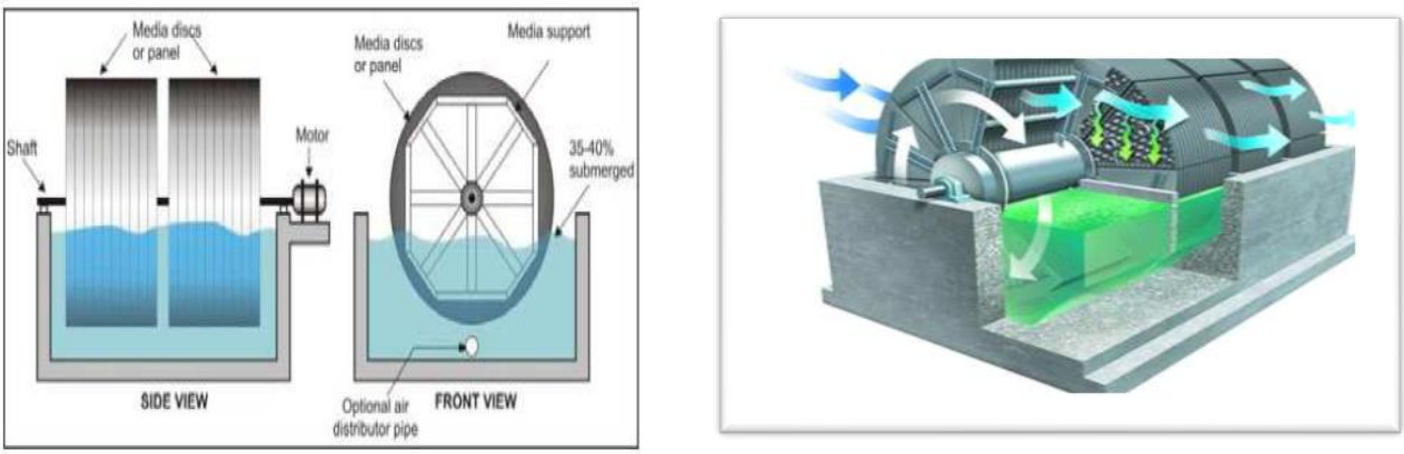

Figure 4 The rotating biological contractor RBC

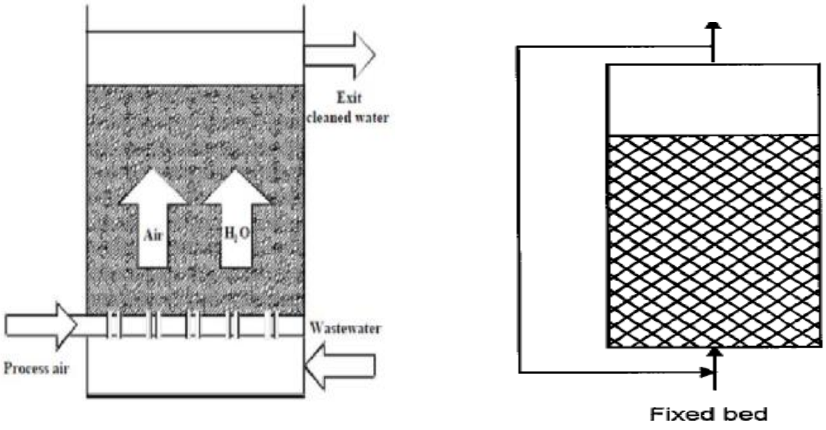

Figure 5 The fixed bed configurations [3, 6]

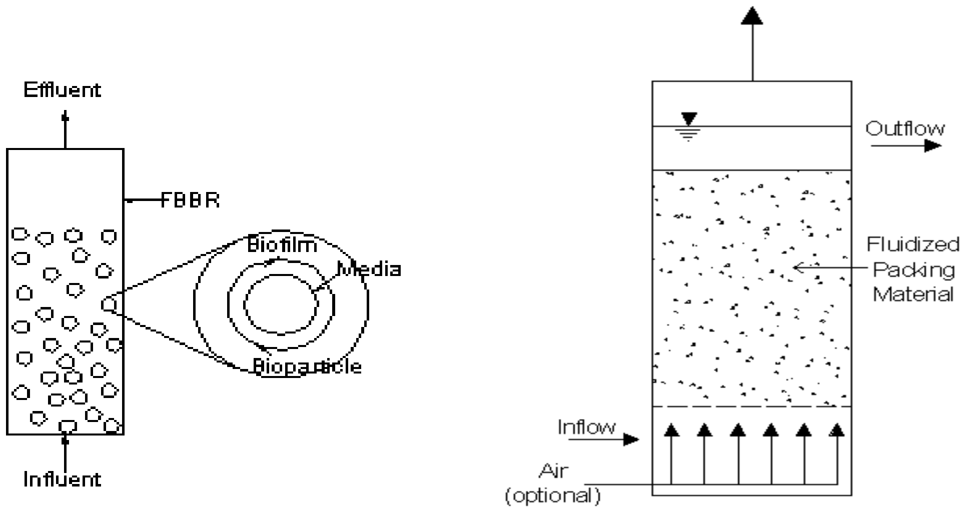

Figure 6 schematic fluidized bed reactors a) anaerobic FBR   b) aerobic FBR [3, 35]

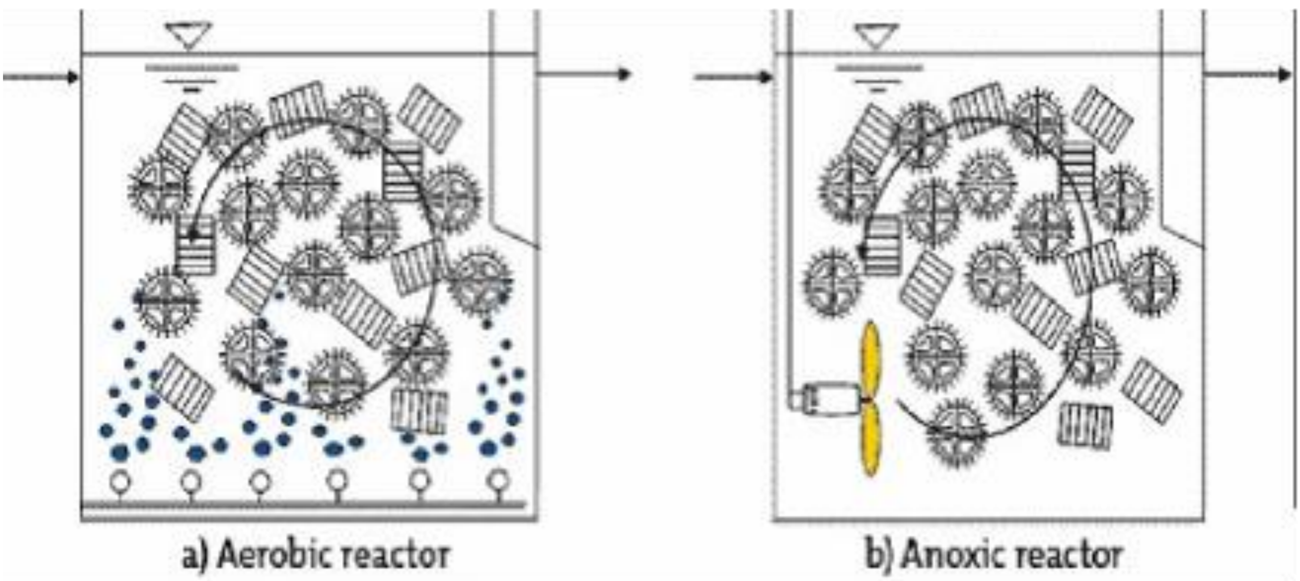

Figure 7 The typical reactors of MBBRs with submerged and suspended packing material [3, 6]