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Packing Media for Anaerobic Fixed Film Reactor – A Review

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One of the most important aspects in the anaerobic fixed film reactor design is the selection of efficient support material. It has been reported that the organic matter removal efficiency in these reactors is directly related to the characteristics of the support materials used for the immobilization of anaerobes. Anaerobic fixed film reactors have displayed better performance than any other type of anaerobic reactors. They not only work as anaerobic biological treatment for organic matter in the wastewaters but also trap passage of active biomass out of the reactor. This paper reviews the use of fixed-bed reactors in various fields reported by different researchers using variety of packing media.

Key words: *Anaerobic fixed film, organic loading rate, packing media, wastewater treatment*

Introduction

Recent years have seen marked increase in the worldwide renewable energy installations – annual growth rate varying from 10-60% for different technologies. Research is underway in the field of renewable energy technologies distinctively in the area of biomethanation and biofuels like biodiesel, bioethanol to produce adequate amount of energies which will be the most essential renewable energy source in next few decades until solar, wind and geo-thermal power production offers an economical alternative.

Rapid industrialization has given rise to generation of a large quantity of effluents with high amount of organic composition (biochemical oxygen demand) which has potential to produce bio-energies through biomethanation. Thus, in spite of the fact that there is a negative environmental impact related with industrialization, the effect could be controlled to some extent and energy can be produced simultaneously.

Extensive interest has been paid towards the development of anaerobic reactors for waste treatments leading to conversion of organic molecules into biogas. All modern high rate biomethanation processes are based on the concept of retaining high viable biomass by using different mechanism. Reactors like up-flow anaerobic sludge blanket (UASB) employs sludge granules, expanded/ fluidized bed reactors use fine inert particles and up-flow and down-flow packed bed reactors and hybrid reactors have inert packing media for entrapment of active biomass within the reactor. This paper reviews efficiency of different types of packing material used for anaerobic fixed film reactors handling a variety of wastewaters.

Packing media characteristics

Anaerobic fixed film reactors are biological wastewater treatment systems in which a fixed packing medium provides an attachment surface that supports the anaerobic microorganisms in the form of a biofilm. Treatment occurs as wastewater flows upwards or downwards through this bed and dissolved pollutants are absorbed by biofilm. These were the first anaerobic systems that eliminated the need for solids separation and recycle while providing a high Solid Retention Time to Hydraulic Retention Time (SRT/HRT) ratio. Their resistance to shock loads and inhibitions make them suitable for the treatment of both dilute and high strength wastewaters.

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One of the most important aspects in the anaerobic fixed film reactor design is the selection of efficient support material. It has been reported that the organic matter removal efficiency in these reactors is directly related to the characteristics of the support materials used for the immobilization of anaerobes. Factors affecting biofilm attachment are varied and numerous. It has been found that there are strong correlations between size, shape, porosity of packing media, bulk density and specific surface area of the packing material and the performance of anaerobic fixed film reactors. The ideal packing material for the anaerobic filters has been described as the one that maximizes both specific surface area and porosity.

The choice of packing media depends both on characteristics of effluent or substrate and its own inherent characteristics such as specific surface area, porosity, surface roughness, pore size and orientation of the packing material. High specific surface area and porosity, large pore size and rough surface for packing material improve the performance of an anaerobic fixed film reactor. Oriented and porous packing media show better performances than random and non-porous packing material. The reactor with non-porous packing showed instability above an organic loading rate (OLR) of 4 kg COD/m^3.d, while the reactor with porous packing was still stable at OLRs up to 21 kg COD/m^3.d. [1] Now-a-days synthetic packing media are available with much higher surface/volume ratio in comparison with conventional rock media. Apart from porosity and surface area surface characteristics also affect the biomass retention characteristics. It has been observed that methanogens have difficulty in adhering to the surface like glass and polyvinyl chloride (PVC) due to the surface of glass and PVC are smooth. On the other hand, activated carbon, ceramic and porcelain provide adequate roughness to promote microbial growth on the surface because of that surface is rough.

Review of literature

Performance of fixed film reactors with natural and synthetic media was tested at mesophilic and psychrophilic temperatures by D R Vartak et.al (1997). Eight digesters were maintained in an environmental chamber, with the temperature varied between 37 and 10°C. Two digesters were packed with limestone gravel; two with pieces cut from non-woven polyester matting; two with a combination of limestone gravel and polyester pieces and two had no packing. Digester operation was initiated at a temperature of 37°C. After the digesters reached stable operation at the initial temperature, the temperature was lowered slowly to 10°C. The temperature was held at 10°C for 5 weeks after stabilizing. The polyester medium with its high porosity and surface to volume ratio had the best overall performance for methane productivity at both 37 and 10°C[2].

A number of biofilm support media including foam cubes, bamboo rings, fire bricks, PVC rings and gravels were employed to immobilize biomass for reduction in biological oxygen demand (BOD) , COD and volatile suspended solid (VSS) of dairy wastewater in batch and repeated batch cultivation systems by J I Qazi et.al (2011). Performance data were collected at 1, 2, 4, 6 and 8 d HRT. It was observed that an increase in HRT caused corresponding increase in COD reduction up to 6 d HRT and then on COD reduction was almost constant. It was also apparent from these experiments that the efficiency of COD removal was associated with the nature and properties of support material involved in the attachment of biomass. It was categorized as: fire bricks>gravels >foam cubes>PVC rings>bamboo rings. The same trend was observed in both batch and repeated batch operation. In addition, it was also felt that the performance of support material might be attributed to chemical properties interlinked with its physical properties[3].

H. Patel (2000) studied the anaerobic digestion of waste water from a petrochemical plant, manufacturing Nylon-6 in continuously fed, up-flow fixed-film column reactors using different biomass support materials such as bone char, charcoal, bricks, plastic beads and polyurethane foam under varying hydraulic and organic loading rates. Experimental results showed bone char as the best support material with high biomass-retaining capacity because of its high specific surface area and pore specific volume. This system could treat waste water at hydraulic retention times (HRT) as low as 2.5 days with organic loading rates as high as 21.76 kg COD/m^3 d using acidic feed of pH 2.5 resulting in a 95% COD reduction with biogas production of 11.76 m^3/m^3 of reactor volume day. Total alkalinity of 1700 mg $CaCO_3$ /l and pH of 7.5 of the treated wastewater were observed at 2.5 days HRT, indicating that methanogenesis appear to be alkalizing step and wastewater with pH as low as 2.5 can be treated as such without neutralization with retention of methanogenic biomass on bone char[4].

Ugurlu and Forster (1992) studied two thermophilic anaerobic filters, one with porous media and the other with a non-porous media. The performance of the filters was monitored during and after the application of organic shock. The results show that, in general, the filter with the porous packing had greater stability. They also reported that the filters were less tolerant of organic shocks that were applied at a constant hydraulic retention time than to those in which the hydraulic retention time was also varied. Activated carbon, polyvinyl chloride supports, hard rock particles, and ceramic rings were the film supports which were tried. Reactor configuration and operation (upflow or downflow) also had a marked effect on performance of the reactor[5].

Bodkhe (2008) used a module of inclined tube settlers (ITS) that was incorporated in the reactor to control input of SS to the anaerobic filter to avoid media clogging[6]. Reticulated polyurethane foam (porous media) appeared to be an excellent colonization matrix for an anaerobic filter reactor as it provided a high specific surface area and a high porosity[7]. Zaher et al. (2008), Anderson (2002), Reyes et al. (1999) worked on fixed bed systems and used automobile tyre, straw, waste tyre rubber as packing material and reported satisfactory results [8,9,10].

S A Habeeb et. al (2011) while studying the performance of hybrid reactor using palm oil mill effluent observed an increase of COD removal after day 40th in reactor with palm oil shell as media while the same was lower for reactor with fine gravel as media. The removals were 82% and 78% respectively. Similar trend was observed for TSS and turbidity removal also[11].

Laboratory scale experiments were carried out by S. Ghaniyari-Benis et.al (2009) using a multistage anaerobic biofilm reactor of three compartments with a working volume of 54- L for treating synthetic medium-strength wastewater containing molasses as a carbon source. PVC Pall Rings with nominal size 25 mm, thickness 1 mm, surface area 206 m^2/m^3 and porosity 90% were used as packing media. It proved to be an efficient reactor configuration for the treatment of medium-strength synthetic wastewater. For an OLR of 9 kg COD/m^3 day, the molasses based wastewater was treated with 88.3% COD removal efficiency. This reactor also showed high resistance and good recovery when toxic shock was applied[12].

Han-Qing Yu et.al (2006) performed a lab-scale investigation to examine the effectiveness of a multi-fed upflow anaerobic filter for the methane production from a rice winery effluent at ambient temperatures. They used string shaped three-dimensional plastic fibrous media. The experiment was carried out in two identical 3-liter upflow filters, one single-fed reactor and the other multi-fed reactor. The results showed that the multi-fed reactor, operated at the ambient temperatures of 19–27°C and influent COD varying from 8.34 to 25.76 g/L, could remove over 82% of COD even at an organic loading rate of 37.68 g COD/l d and a short hydraulic retention time of 8 h. This reactor produced biogas with a methane yield of 0.30–0.35 l $CH_4/g\ COD_{removed}$. The multi-fed upflow anaerobic filter was proved to be more efficient than the single-fed reactor in terms of COD removal efficiency and stability against hydraulic shock loading[13].

Attachment, strength and performance of a porous media in an upflow anaerobic filter treating dairy wastewater was studied by O. Ince et.al (2000). The media used was raschig rings of porous sintered glass. The reactor performed well in terms of COD removal efficiency, methane yield and methane percentage. The attached biomass consisted of a mixture of various auto-fluorescent methanogenic populations of rod, cocci and sarcina shaped and filamentous species. The filaments were at low numbers indicating a non-filamentous biofilm. Accumulation of biomass on the media was significant and was not susceptible to high shear stresses. There was approximately 50% reduction in the compressive strength of the sintered glass media after eight months of operation. Consequently, it could be concluded that any kind of material which loses its compressive or mechanical strength or swells over a short duration cannot be considered for use as support medium in any microbial film process[14].

Three types of carriers were studied in methanogenic biofilm reactors by Anthony Manoni Mshandete et.al (2007). The carrier materials were consisted of sisal fibre waste, pumice stone and porous glass beads and the bioprocess evaluated was the methanogenesis of sisal leaf waste leachate. Process performance was investigated by step-wise increasing the organic loading rate. The best results were obtained from the bioreactor packed with sisal fibre waste. It had the highest COD removal efficiencies in the range of 80-93% at OLRs in the range of 2.4-25 g COD/ l d. The biodegradation of the sisal fibre was measured at the end of the experimental period and it was observed that though this media performed well, around 50% of the sisal fibre waste was degraded during the experimental period of about 8 months[15].

Sumi S. and Lea Mathew studied the performance of an upflow anaerobic hybrid reactor (UAHR) for the treatment of synthetic wastewater at different organic loading rates and filter media volumes. The filter media used in the reactor was polyurethane foam (PUF) blocks of size 2.5cm x 2.4cm x 2.3cm. During a nine-month operation, organic loading rate was increased from 0.414 to 1.696 g COD/l d, with corresponding reduction in HRT from 48 hours to 12 hours. The filter media volume was increased from 20% to 40%. The optimum performance of reactor was attained at HRT of 18 hours for 35% filter media volume. The reactor effectively removed 90.50% of COD, 93.27% of BOD and 87.14% of turbidity at optimum condition[16].

M. Wu et.al (2000) studied influence of media-packing ratio on performance of anaerobic hybrid reactors (AHR). Four laboratory upflow anaerobic hybrid reactors, each with a total unpacked volume of 7.85 l, with varying packing depths, were operated at organic loading rates from 1 to 24 g COD/l d. The media-packing ratios were 75%, 60%, 40% and 20% of the total reactor height in the AHRs. The results indicated that 20% media packing ratio was satisfactory even when high organic loading rate was expected. When operated at 1 and 2 g COD/l d, COD profiles along the reactor height from bottom to top showed a plug-flow regime. From 4 to 12 g COD/l d, the COD profiles were distorted in the reactors with 20%, 40% and 60% packing, while at 16 g COD/l d and above, COD profile indicated homogeneity in each reactor, suggesting a perfectly-mixed regime[17].

Two laboratory-scale anaerobic fixed bed reactors were evaluated for treating dairy manure in upflow mode and semicontinuous feeding by Oscar Umana et.al (2008). One reactor was packed with a combination of waste tyre rubber and zeolite (R1) while the other had only waste tyre rubber as microorganism immobilization support (R2). Higher COD, BOD_5, total and volatile solids removal efficiencies were always achieved in the reactor R1. No clogging was observed during the operation period. Methane yield was found to be a function of HRT and of type of support used, and was 12.5% and 40% higher in reactor R1 than in R2 for HRTs of 5.5 and 1.0 days, respectively[18].

G.Sunil kumar (2007) while investigating the treatment of distillery spent wash used anaerobic hybrid and USAB reactors for the treatment . The start-up and granulation study demonstrated that early start-up and granulation were achieved in case of hybrid reactor (45 days) as compared with UASB reactor (60days). The investigation of the effect of HRT on the performance of reactors indicated that at optimum HRT (5 days) and OLR 8.7 kg COD/m^3 d, the COD removal in hybrid and USAB reactor was found to be 79% and 74.5% respectively. The rate of sludge washout was reducing by 25% in hybrid reactor as compared with the USAB reactor. The study on the shock loading capacity of the reactors revealed that hybrid reactor is capable of resisting organic shock load up to two times as compared to the USAB reactor capable of resisting the shock loading up to 1.5 times of normal organic load[19].

Rajesh Babu (2006) studied treatment of sago wastewater using Hybrid Upflow Anaerobic Sludge Blanket (HUASB) reactor, at organic loading rates varying from 10.7 to 24.7 kg COD/m^3.day. Polyurethane foam (PUF) cubes were used as carrier material. After 130 days of start-up, the reactor produced appreciable decrease in COD of wastewater and removed solids efficiently. The COD removal varied from 91-87%. While the removal of total solids was in the range of 61-57%, that of volatile solids varied from 70-67%. The ideal OLR for the reactor was 23.5 kg COD/m^3 d. The reactor could be operated at a considerably higher OLR of 23.5 kg COD/m^3 d, which is twice the loading rate suggested for the treatment in anaerobic filter[20].

R. Rajkumar (2011) performed an experiment on bench scale continuous upflow anaerobic filter (UAF) reactor for poultry slaughterhouse wastewater and the pleated (rough surface) PVC ring was selected as packing media. Because of its pleated surface, it can retain more biomass on surfaces rather than plain surfaces. The reactor took 147 days for complete start-up with removal efficiencies of total COD and soluble COD of 70 and 79% respectively. The maximum total COD removal efficiency of 78% was achieved at an organic loading rate of 10.05 kg/m^3 d and at an HRT of 12 h. The average methane content varied between 46 and 56% and methane yield at maximum removal efficiency was 0.24 m^3 CH_4/kg $COD_{removed}$ day. Sludge granules of 1-2 mm were observed in the interstices of packing media[21].

P. Chaiprasart (2003) monitored performances of three anaerobic hybrid reactors with various nylon fibre densities per packed bed volume (33, 22, and 11 kg/m^3 in R1, R2, and R3, respectively) as supporting media through their ability to remove organic compounds in cassava starch wastewater. The COD removal efficiency was more favourable in R1 (87%)

and R2 (84%) than in R3 (70%). The total biomass in the reactors with greater nylon fibre densities was also higher and increased from 20.4 to 67.3 g VSS and to 57.5 g VSS in R1 and R2, respectively.

The amount and density of the media in an anaerobic hybrid reactors (AHR) considerably affected the wastewater treatment performance since the media played a direct role in retaining the biomass inside the system by either being a place for attachment or acting as a gas/solid separator. As opposed to 11 kg/m^3, the densities of nylon fibre of 33 and 22 kg/m^3 seemed to generate better system stability even though the specific treatment was slightly lower. Also, the COD removal efficiency of more than 80% was readily achieved in higher medium density reactors compared to merely 70% in the least density one in the experiment[22].

D. Ioannis (2006) reported his experience of operating upflow anaerobic filter reactors with ceramic saddles, plastic rings, and crushed stone packing for the treatment of raw municipal wastewater under a wide range of hydraulic and organic loadings and operating conditions. Column profile sampling, draining, and biomass evaluation studies were conducted to ascertain the functioning of the reactors and accumulation of biosolids. The distribution of organics and solids with column height and length of operation was different in the three reactors. Crushed stone packing with lowest void ratio was characterized by a gradual increase in concentration, starting at the 20 cm position and progressing to higher elevations. No signs of clogging were observed in any of the three reactors, indicating that biomass accumulation did not constitute a problem for the long-term operation of an UAF treating raw municipal wastewater[23].

A. Ramakrishnan (2006) performed the treatment of synthetic coal wastewater at the mesophilic temperature of 27±5°C in anaerobic hybrid reactors. Synthetic wastewater with an average COD of 2240 mg/L, phenolic concentration of 752 mg/L and a mixture of volatile fatty acids was fed to three hybrid reactors. The filter media consisted of PVC rings. Hybrid UASB reactors could successfully degrade synthetic coal waste water with an influent phenolic concentration of 752 mg/L at an organic loading rate of 2.24 g COD/l d and an HRT of 24 h at mesophilic temperature (27±5°C). Particle size distribution in the sludge bed revealed that the granules of smaller diameter dominate in the upper portion of the sludge bed while those of larger diameter occupy the lower portion of the sludge bed[24].

G. Srinivasan (2009) studied the Diphasic Fixed Film Fixed Bed (DFFFB) Anaerobic digester for dairy wastewater. The experiment was run for different combinations of influent COD - 8000, 8996, 9956, 10976 and 11981 mg/L and flow rate of 0.006, 0.012, 0.024, 0.036 and 0.048 m^3/d. The overall reactor performance showed maximum removal of COD as 70.40% at a flow rate of 0.006 m^3/d for a OLR of 1.265 kg COD/m^3.d .The maximum yield of bio-gas at 0.330 m^3 of gas/ kg COD removed was observed at an average influent COD of 11981 mg/L corresponding to an OLR of 14.812 g COD/l d[25].

T. Yilmaz (2008) performed an experiment on two anaerobic filters. One mesophilic (35 °C) and one thermophilic (55 °C) reactor were operated with paper mill wastewater at a series of organic loadings. Each filter was packed with raschig rings. The HRT ranged from 6 to 24 h with OLR 1.07–12.25 g COD/l d. At loading rates up to 8.4 g COD/l d, there was no difference in terms of the removal of soluble COD (SCOD) and gas production. At the higher organic loading rate, the SCOD removal performance of thermophilic digester was slightly better compared to mesophilic digester. Similar trend was also observed in terms of the daily methane production[26].

Conclusion

A critical analysis of literature reveals that anaerobic fixed film reactors have displayed better performance than any other type of anaerobic reactors. They not only work as anaerobic biological treatment for organic matter in the wastewaters but also trap passage of active biomass out of the reactor. Packing media when used even in smaller quantity as in case of hybrid reactors could prevent sludge wash-out by 25% higher compared to UASB, which means that the physical filtering action provided by the packing media bed is more effective than the three-phase separator in UASB. A wide range of materials - natural and synthetic, porous and non-porous, heavy and light - have been used as packing material and it has been observed that these packing materials help in reducing hydraulic retention time and ultimately cost of the treatment.

Porous materials have been found better compared to non-porous ones as surface characteristics also play important role in microfilm development. Synthetic media of different kinds offered added advantages in terms of lower bulk densities and easy availability as these are commercially available.

Table 1 : Performance of different packing media

Reactor	Feed	Packing Media	OLR (g COD/l d)	Biogas Yield	COD Removal (%)	Ref.
Hybrid	Distillary Spent Wash	PVC Pipe	8.7	52.37 lit/d	79	[19]
Hybrid	Sago Wastewater	Plastic cut rings	23.4	30.7 cum/d	83	[20]
Hybrid	Cassava starch wastewater	Nylon Fiber	0.5-0.4	--	70-87	[22]
Hybrid	Domestic Sewage waste	Reticulated Polyurethane foam (RPF)	(influent COD) 518 ppm	--	55	[7]
Hybrid	Synthetic wastewater	Polyurethane foam (PUF)	0.4-1.7	--	90.50	[16]
Hybrid	synthetic coal wastewater	PVC rings	2.24	0.5 m^3 CH_4/kg COD	88±1	[24]
Anaerobic filter	Paper mill wastewater	Rashing rings, 35°C	7.93 ± 1.40	0.295 m^3 CH_4/kg CODr	> 70%	[26]
		Rashing rings, 55°C	8.41 ± 0.48	0.317 m^3 CH_4/kg CODr		
Up flow anaerobic filter	Poultry slaughter house wastewater	Pleated PVC ring	14.3	0.24 m^3 CH_4/kg CODr	78	[21]
Up flow anaerobic filter	Dairy Wastewater	Sintered glass rasching ring	21	0.32 m^3 CH_4/kg CODr	80	[14]
Up flow fixed film anaerobic bio reactor	Low pH petrochemical wastewater	Bone char	27.2	0.01 m^3 CH4/kg COD	45	[4]
		Charcoal	18.1	0.02 m^3 CH4/kg COD	49	
		Plastic beads	18.1	0.01 m^3 CH4/kg COD	51	
		Bricks	6.0	0.08 m^3 CH4/kg COD	56	
		Polyurethane foam	4.1	0.02 m^3 CH4/kg COD	44	
Anaerobic Fixed Film	Dairy Wastewater	Gravels	--	--	96	[3]
Fixed bed Ananerobic digester	Flush Dairy Manure	Automobile tires	--	--	40 - 60	[8]
Fixed bed Ananerobic digester	Screened Dairy Manure	Tyre Rubber + Zeolite	12	--	46.2	[18]
		Tyre Rubber			41	
Packed bed Reactor	Sisal leaf waste leachate	Sisal fiber waste	25	--	80-93	[15]
Packed Bed	Dairy Cattle Wastewater	Limestone Gravel, 37°C	0.12	0.19 m^3 CH_4/kg CODr	94	[2]
		Limestone Gravel, 10°C		0.06 m^3 CH_4/kg CODr	82	
		Non-woven Polyester Matting, 37°C		0.21 m^3 CH_4/kg CODr	94	
		Non-woven Polyester Matting, 10°C		0.06 m^3 CH_4/kg CODr	77	
		Combination, 37°C		0.19 m^3 CH_4/kg CODr	94	
		Combination, 10°C		0.05 m^3 CH_4/kg CODr	76	
HUASB	Palm oil mill effluent	Palm shell	1.85	--	78	[11]
		Fine gravel			76	
		Palm shell 37°C			82	
Multistage anaerobic filter	Low strength wastewater	Waste tyre rubber	(COD less than 1000 ppm)	--	60	[10]
Multistage anaerobic bio film reactor	Synthetic medium strength wastewater containg molasses	PVC pall rings	9	--	88.3	[12]
Multi-fed upflow anaerobic filter	Rice winery effluent	Plastic fibrous media	37.68	0.30 -0.35 m^3 CH_4/kg COD	82	[13]
DFFFB	Dairy wastewater	---	14.812	0.330 m^3 of gas/kg COD	75%	[25]

References

1. Burak D, Orhan Y. and Turgut T. Onay, Anaerobic treatment of dairy wastewaters: a review, *Process Biochemistry*, 40, 2583 – 2595 (2005).

2. Vartak D. R., Engler C. R., McFarland M. J. & Ricke S. C., Attached-Film Media Performance in Psychrophilic Anaerobic Treatment of Dairy Cattle Wastewater, *Bioresource Technology*, 62, 79-84 (1997).

3. Qazi J. I , Muhammad N., Shagufta S. B., Shahjahan B. and Quratulain S., Anaerobic Fixed Film Biotreatment of Dairy Wastewater, *Middle- East Journal of Scientific Research*, 8(3), 590-593 (2011).

4. Patel H. and Datta M., Biomethanation of low pH petrochemical wastewater using upflow fixed film anaerobic bioreactors, *World Journal of Microbiology and Biotechnology*, 16, 69-75 (2000).

5. Ugurlu A. and Forster C. F., The impact of shock loadings on the performance of thermophilic anaerobic filters with porous and non-porous packings, *Bioresource Technology*, 39(1), 23 – 30 (1992).

6. Sandeep B., Development of an improved anaerobic filter for municipal wastewater treatment, *Bioresource Technology*, 99, 222 – 226 (2008).

7. Tarek.A.E., Vladimir S., Grietje Z. and Gatze L.e, Low temperature pre-treatment of domestic hybrid or an anaerobic filter reactor, *Bioresource Technology*, 82, 233 – 239 (2002).

8. Zaher U., Frear C., Pandey P. and Chen S., Evaluation of a new fixed-bed digester design utilizing large media for flush dairy manure treatment, *Bioresource Technology*, 99, 8619 - 8625, (2008).

9. Andersson J. and Björnsson L., Evaluation of straw as a biofilm carrier in the methanogenic stage of two-stage anaerobic digestion of crop residues, *Bioresource Technology*, 85, 51 – 56 (2002).

10. Reyes O., Sanchez E., Rovirosa N., Borjac R., Cruz M., Colmenarejod M. F., Escobedo R., Ruiz M., Rodroguez X. and Correa O., Low-strength wastewater treatment by a multistage anaerobic filter packed with waste tyre rubber, *Bioresource Technology*, 70, 55 – 60 (1999).

11. Habeeb S. A., AB. Aziz A. L., Zawawi D., Zulkifli A., A Biodegradation and Treatment of Palm Oil Mill Effluent (POME) Using A Hybrid Up-Flow Anaerobic Sludge Bed (HUASB) Reactor, *International Journal Of Energy And Environment*, 2(4), 653-660 (2011).

12. Ghaniyari-Benis S., Borja R., Ali Monemian, Goodarzi V., Anaerobic Treatment of Synthetic Mediu-Strength Wastewater Using a Multistage Biofilm Reactor, *Bioresource Technology*, 100, 1740–1745 (2009).

13. Han-Qing Y., Zhao Q.B and Tang Y., Anaerobic treatment of winery wastewater using laboratory-scale multi- and single-fed filters at ambient temperatures, *Process Biochemistry*, 41, 2477 – 2481 (2006).

14. Ince O., Kasapgil Ince B. and Donnelly T., Attachment, Strength and Performance of a Porous Media in an Upflow Anaerobic Filter Treating Dairy Wastewater, *Water Science and Technology*, 41(4-5), 261–270 (2000).

15. Anthony M. M., Lovisa B., Amelia K. K., Mugassa S. T. R., Bo M., Performance Of Biofilm Carriers In Anaerobic Digestion Of Sisal Leaf Waste Leachate, *Electronic Journal of Biotechnology*, 11(1), 1-9 (2008).

16. Sumi S., Lea M., Influence of Media Packing Depth and HRT on Performance of Anaerobic Hybrid Reactors, Proceedings of 10th *National Conference on Technological Trends* (NCTT09) held at College of Engineering Trivandrum, 6-7 (2009).

17. M. Wu, F. Wilson, J.H. Tay, Influence Of Media-Packing Ratio on Performance of Anaerobic Hybrid Reactors, *Bioresource Technology*, 71, 151-157 (2000).

18. Oscar U., Svetlana N. , Enrique S. , Rafael B., Francisco R., Treatment of Screened Dairy Manure By Upflow Anaerobic Fixed Bed Reactors Packed With Waste Tyre Rubber And A Combination Of Waste Tyre Rubber And Zeolite: Effect Of The Hydraulic Retention Time, *Bioresource Technology*, 99, 7412–7417 (2008).

19. Sunil G., Gupta S.K., and Singh G., Anaerobic Hybrid Reactor – A Promising Technology for the Treatment of Distillery Spent Wash, *Journal of Indian School of Mines*, 11(1), 25-38 (2007).

20. Rajesh B. J., Sudalyandi K., Dieter B., Treatment of Sago Wastewater Using Hybrid Anaerobic Reactor, *Water Quality Research Journal Canada*, **41(1)**, 56-62 (2006).

21. Rajkumar R., Meenambal T., Rajesh B., I.T.Yeom, Treatment of Poultry Slaughterhouse wastewater in Upflow ananerobic Filter under Low Upflow Velocity, *International Journal Environment Science Technology*, **8(1)**, 149-158 (2011).

22. Pawinee C., Worakrit S., Benjaphon S., Morakot T., Sakarindr B., Nylon fibers as supporting media in anaerobic hybrid reactors: its effects on system's performance and microbial distribution, *Water Research*, **37(19)**, 4605-4612 (2003).

23. Ioannis D., Manariotis and Sotirios G. G., Anaerobic Filter Treatment of Municipal Wastewater: Biosolids Behavior, *Journal of Environmental Engineering*, 132**(1)**, (2006).

24. Anushyaa R., Gupta S.K., Anaerobic biogranulation in a hybrid reactor treating phenolic waste, *Journal of Hazardous Materials*, **B137**, 1488–1495 (2006).

25. Srinivasan G., Subramaniam R. and Nehru Kumar V., A Study on Dairy Wastewater Using Fixed-Film Fixed Bed Anaerobic Diphasic Digester, *American-Eurasian Journal of Scientific Research* **4(2)**, 89-92 (2009).

26. Turan Y., Ahmet Y., Mesut B., A comparison of the performance of mesophilic and thermophilic anaerobic filters treating papermill wastewater, *Bioresource Technology*, **99**, 156–163 (2008).