Badr El-Din E. Hegazy, Hanan A. Fouad, Al-Motaz M. Kamel. Moving bed biofilm reactor with activated sludge for treating paper industrial wastewater. International Journal of Academic Research Part A; 2013; 5(4), 155-160.
***DOI:** 10.7813/2075-4124.2013/5-4/A.22*

MOVING BED BIOFILM REACTOR WITH ACTIVATED SLUDGE FOR TREATING PAPER INDUSTRIAL WASTEWATER

Badr El-Din E. Hegazy*, Hanan A. Fouad, Al-Motaz M. Kamel

Department of Civil Engineering, Faculty of Engineering - Shoubra, Benha University **(EGYPT)**
***Corresponding author:** Badrhegazey@yahoo.com

DOI: 10.7813/2075-4124.2013/5-4/A.22

ABSTRACT

Pulp and paper industry is one of the most polluting industries all over the world that uses significant amount of fresh water and produces substantial amount of solid and liquid waste. Wastewater resulting from paper industry in Upper Egypt was treated using activated sludge process but all chemical and biological parameters were high, thus, in the present study, activated sludge process followed by moving bed biofilm reactor were used in treating paper industrial wastewater with special microorganisms such as *Pediococcus* sp., *Bacillus* sp. and *Pichia* sp. The results showed that COD, BOD, TDS and TSS values of raw paper industrial wastewater were 2929.4 mg/L, 676 mgO_2/L, 2584.5 mg/L and 1666.3 mg/L as average respectively. While COD, BOD, TDS and TSS values of final effluent after using moving bed biofilm reactor were 36 mg/L, 27.5 mgO_2/L, 1077.5 mg/L and 33 mg/L, respectively. The removal efficiencies of COD, BOD, TDS and TSS using activated sludge after adding the special microorganisms were 95.8%, 94.1%, 38.5% and 95.2%, respectively. Moving bed biofilm reactor has an impact on removal of TSS, COD and BOD. The removal efficiency increased using this technique with special microorganisms. The removal efficiencies of COD, BOD, TDS and TSS were 98.7%, 95.9%, 58.3% and 98%, respectively using activated sludge process followed by moving bed biofilm reactor system with special microorganisms. Also, coliforms removal efficiencies were 94.6% for total coliforms and 99.5% for fecal coliforms. From this study, it can be concluded that, the final effluent was suitable for reuse in irrigation and industrial purposes after biological treatment. Biological treatment is more economic and eco-friendly due to its low running and maintenance cost.

Key words: moving bed biofilm reactor; activated sludge; paper wastewater; microorganisms

1. INTRODUCTION

Paper manufacturing is a highly capital, energy and water intensive industry that discharge liquid and solid waste of polluting nature (1). However, in order to meet out the statutory standards for discharge of industrial wastewater into water bodies as prescribed by Egyptian standards, treating the wastewater becomes necessitated. Discharge into the environment, these effluents cause considerable environmental impact that contain toxic compounds to aquatic organisms. Moreover, these effluents are strongly colored owing to the presence of lignin, resins, tannins and chlorophenolic compounds that are resistant to biodegradation (2).

The biological wastewater treatment offers one of the major steps in eliminating biodegradable organic matter present in pulp and paper mill wastewater besides offers energy by regenerating fuel (3). Biological wastewater systems are widely used in municipal and industrial applications including pulp and paper (4). These systems use aerobic bacteria to remove organic matter in wastewater by converting it to carbon dioxide, water and biomass (5). Wastewater treatment with aerobic microorganisms has been performed for many years (6).

Pulp and paper industry wastewater contains organic and other matters that can cause serious environmental problems if sent directly to natural bodies of water (7). In aerobic biological treatment systems, the wastewater is pumped into a tank or pond that contains a suspension of aerobic microorganisms which oxidize the organic matter forming carbon dioxide, water and more microorganisms. The activity of microorganisms depends on the concentration and biochemical composition of biologically active sludge and the amount of biologically degradable biomass (8).

The main microorganisms degrading waste are heterotrophic and are adverse set of bacteria that breakdown a wide variety of organic matter (Bongards, 2001). Pulp and paper industry wastewater contain organic and other matters that can cause serious environmental problems. The chemical composition of pulp and paper industry wastewater was 0-23% carbohydrates, 22-52% proteins, 2-10% lipids, 2-8% cellulose and 38-58% lignin (9).

In Upper Egypt, pulp and paper mills require large volume of water and in turn release huge amount of effluent about 25000 m^3/day in the form of black liquor loaded with many pollutants effluents of most agro-industries can be characterized with residual chemical oxygen demand (COD) levels and color (10).

The activated sludge process has been widely applied for domestic and industrial wastewater treatment due to its highly efficiency operational flexibility, possibility for nutrient removal among other advantages (11). In case of paper industrial wastewater was treated using two biologically methods such as activated sludge process followed by trickling filter or biological anaerobic treatment with activated sludge process (11-13).

The moving bed biofilm reactor process uses small plastic carrier elements to provide sites for bacteria attachment in a suspended growth medium. The carrier elements allow a higher biomass concentration to be maintained in the reactor compared to a suspended growth process, such as activated sludge. This increases the biological treatment capacity for a given reactor volume. The carrier elements can be installed in either an anoxic reactor or aeration basin (14). Moving bed biofilm reactor either be used as a pre-treatment system ahead of an existing activated sludge system for increased organic matter removal, stand alone biological treatment process for BOD removal, nitrification and/or denitrification or a retrofit of an existing activated sludge processes to help increase overall capacity of the existing system (15).

The trickling filter process is one of the oldest and most commonly applied methods of wastewater treatment. A trickling filter is a fixed-film reactor with non submerged medium over which wastewater is disturbed (16). Wastewater treatment occurs when wastewater passes through the biofilm attached to the medium (17).

Trickling filters are used for organic matter removal. Thus, industrial wastewater should be treated to recovery and reuse which is an important feature of the total quality management for industrial activities. Biological processes are more economical and eco-friendly than advance wastewater treatment due to its low running and maintenance cost (5).

In this study, paper industrial wastewater was treated using activated sludge process followed by moving bed biofilm reactor with specific microorganisms for removing organic matter.

2. MATERIALS AND METHODS

The main objective of this study is evaluating the effect of special microorganisms such as *Bacillus* sp., *Pediococcus* sp. and *Pichia* sp. in girandoles material on improving the paper industrial wastewater. The existing industrial wastewater treatment plant in Upper Egypt consists of two primary sedimentation tanks, two aeration tanks seeded by municipal wastewater activated sludge, and two final settling tanks. This activated sludge process industrial wastewater treatment plant of daily discharge 25000 m^3. The physical and chemical properties of paper industrial wastewater are presented in Table (1). Biological characterization of paper industrial wastewater is shown in Table (2).

Table 1. The physical and chemical properties of paper industrial wastewater

Chemical parameters	Unit	1st week	2nd week	3rd week	4th week	Average
pH		7.1	7.8	7.4	7.2	7.4
COD	mg/L	2918	3100	2900	2800	2929.4
BOD	mgO_2/L	659	740	660	645	676
Oil & grease	mg/L	54.7	64.5	58.2	45.8	55.8
TDS	mg/L	2475	2871	2535	2457	2584.5
TSS	mg/L	1580	1870	1620	1595	1666.3
Sulfide	mg/L	10.4	12.2	13.1	11.4	11.8
Total phosphate	mg/L	3.2	4.1	3.8	3.6	3.7
Nitrate	mg/L	0.3	0.4	0.5	0.4	0.4
phenol	mg/L	0.0	0.0	0.0	0.0	0.0

Table 2. Biological characterization of paper industrial wastewater

Biological parameters	MPN-index/100 ml				Average
	1st week	2nd week	3rd week	4th week	
Total coliforms	$1.1x10^2$	$2.3x10^2$	$4.8x10^2$	$4.6x10^2$	$3.2x10^2$
Fecal coliforms	$1.0x10^2$	80	$1.1x10^2$	$1.0x10^2$	97.5

In this study, the raw paper industrial wastewater was treated using special microorganisms such as *Bacillus* sp., *Pediococcus* sp. and *Pichia* sp. in girandoles material from Alkonnova Company. The amounts of special microorganisms were added to the aeration tanks as follows 66 kg (11 kg/day) for the first week, 40 kg (6.6 kg/day) for the second week and 18 kg (3kg/day) for the third and the fourth weeks. To reactivate the special microorganisms every one kg was added to 10 liters of industrial wastewater obtained from the effluent of the aeration tank of the wastewater treatment plant in a container for at least 4 hours. The solution of special microorganisms were added in the influent and the middle of the aeration tank besides the surface aerator to have a good distribution of the special microorganisms in the aeration tank as shown in Figure (1). The addition of special microorganisms was during four weeks to reach the stationary phase of microorganism's growth to make up for the decline of some of the special microorganisms due to the toxicity of the paper industrial wastewater. These special microorganisms were added to increase the removal efficiency of the activated sludge process. The activated sludge process was followed by moving bed biofilm reactor.

Fig. 1. *Photos of the addition of the special microorganisms to the aeration tank*

To model the moving bed biofilm reactor a tank of dimensions (1m x 1m x 1m) made of hard polyethylene is used. A schematic diagram of the moving bed biofilm reactor used in the experiment is shown in Figure (1).

Fig. 2. *A schematic diagram of the moving bed biofilm reactor*

The capacity of moving bed biofilm reactor (a pilot-scale) is 1 m^3 filled with 0.6 m^3 of paper industrial wastewater from the effluent of the aeration tank and plastic media 3 cm each. These media represent 40% of the volume of moving bed biofilm reactor. The air is introduced into the bottom of the moving bed biofilm reactor. In order to enhance biofilm formation on plastic media inoculated and submerged in special microorganisms solution consists of 40 kg of special microorganisms and 40 liters of water for two days at least in room temperature 28 ^{o}c. The moving bed biofilm reactor technology is used on a pilot scale to improve the activated sludge effluent. The contact time in moving bed biofilm reactor is 8 hours of aeration. Wastewater treatment occurs when wastewater passes through the biofilm attached to the plastic media. The industrial wastewater samples are collected in plastic bottles for chemical analysis and sterilized glass bottles for biological tests according to (18). Chemical and biological parameters were carried out according to (18).

3. RESULTS AND DISCUSSION

Biological wastewater treatment systems are widely used in industrial applications including pulp and paper industry. The most commonly used configurations are activated sludge systems and moving bed trickling filters. These systems use special microorganisms to remove organic matter in wastewater by converting it to carbon dioxide, water and biomass. In this study, large volume of wastewater was 25000 m^3/day with paper industry in Upper Egypt, most of this wastewater is currently treated using activated sludge process followed by moving bed biofilm reactor process (0.6 m^3) as a pilot scale with special microorganisms.

The influent industrial wastewater was dark brown in color having pH (7.1 – 7.8), COD (2900 – 3100 mg/L) and Biological oxygen demand (BOD) from 645 to 740 mgO_2/L. Total dissolved solids (TDS) and total suspended solids (TSS) of influent were ranged between 2457 to 2871 and 1580 to 1870 mg/L, respectively. In addition, coliforms counts of influent were ranged between $1.1x10^2$ to $4.8x10^2$ MPN-index/100 ml for total coliforms and 80 to $1.1x10^2$ MPN-index /100 ml for fecal coliforms. The color of influent was due to presence of lignin compounds and nature of chemicals which used for bleaching of the pulp. COD, BOD, TDS and TSS of raw wastewater of paper industry were much higher than the permissible limits. Thus, these influents of paper industrial wastewater should be treated (19, 20). The results of first effluent treated using activated sludge are given in Tables (3 and 4). In addition, COD, BOD, TDS and TSS of first effluent after wastewater treatment using activated sludge process ranged from (115-130 mg/L), (36-46 mgO_2/L), (1540-1640 mg/L) and (75-87 mg/L), respectively.

Table 3. Characterization of paper industrial wastewater treated using activated sludge

Chemical parameters	Unit	1st week	2nd week	3rd week	4th week	Average
pH		7.2	7.1	7.4	7.2	7.22
COD	mg/L	118	130	124	115	121.75
BOD	mgO_2/L	36	40	46	38	40
Oil & grease	mg/L	3.3	4.4	5.1	3.1	3.97
TDS	mg/L	1570	1610	1640	1540	1590
TSS	mg/L	78	82	87	75	80.5
Sulfide	mg/L	2.4	3.1	3.2	2.1	2.7
Total phosphate	mg/L	0.2	0.4	0.5	0.2	0.33
Nitrate	mg/L	0.2	0.4	0.3	0.1	0.3
phenol	mg/L	0.0	0.0	0.0	0.0	0.0

Table 4. Biological wastewater quality of paper industry treated using activated sludge

Biological parameters	MPN-index/100 ml				Average
	1st week	2nd week	3rd week	4th week	
Total coliforms	70	60	80	90	75
Fecal coliforms	30	ND	40	40	27.5

ND: Not Detected.

Coliforms counts ranged from 60 to 90 MPN-index/100 ml for total coliforms and from zero to 40 MPN-index/100 ml for fecal coliforms. With regard to pilot-scale, 0.6 m^3 for activated sludge process effluent (first effluent) was introduced into moving bed biofilm reactor. The results of final effluent of moving bed biofilm reactor are presented in Tables (5 and 6). COD, BOD, TDS and TSS of final effluent ranged from 32-38 mg/L, 26-29 mgO_2/L, 1050-1112 mg/L and 30-36 mg/L, respectively. Total coliforms counts ranged from 10-20 MPN-index/100 ml while fecal coliforms were not detected except in one week (2 MPN-index/100 ml) (21). Table (7) represented the efficiency of paper industrial wastewater treatment. Wastewater treatment in most paper mills using activated sludge process. First consists of settling tanks where solids are removed. This is considered as primary treatment of wastewater and the solids produced are known as primary sludge. After primary settling, the rest of the wastewater was sent to a secondary treatment which is usually an activated sludge system. After aeration, the mixed liquor was sent to a second settling tank where clean effluent is separated from activated sludge that will be recycled (22, 7).

The aerobic microorganisms in activated sludge degrading waste are heterotrophic and are a diverse set of bacteria that breakdown a wide variety of organic matter. The COD (121.75 mg/L), BOD (40 mgO_2/L), TSS (80.5 mg/L) and TDS (1590 mg/L) as average concentrations in the treated effluent (Table 3) using activated sludge process with special microorganisms still too high for disposal, other treatment is needed such as moving bed biofilm reactor. These systems use aerobic microorganisms to remove organic matter in wastewater by biodegradation process (7).

After using moving bed biofilm reactor the reductions of COD, BOD, TSS and TDS are observed in Table (7). COD, BOD, TSS and TDS concentrations of final effluent are 36 mg/L, 27.5 mgO_2/L, 33 mg/L and 1077.5 mg/L, respectively. Fecal coliforms were absent after using of moving bed trickling filter. Trickling filters or biotowers continue to be an important technology for industrial wastewater treatment. With biological aerobic treatment using activated sludge and moving bed biofilm reactor, reductions of TSS and TDS were 71.34 and 64.22%, respectively during aerobic digestion major portion removed by sedimentation of sludge in clarifier (23). It may be consumed by microbes as nutrients (24). Reduction of oil and grease may be due to biological growth and destroying the emulsifying agent which has sufficient adsorptive power to hold oil and grease for its oxidation (22). Several aerobic biological processes are used for industrial wastewater treatment in which oxygen is supplied to microorganisms and in the rate at which microbes metabolize the organic matter (20).

Table 5. Chemical wastewater quality of final effluent after the second stage of moving bed biofilm reactor

Chemical parameters	Unit	1st week	2nd week	3rd week	4th week	Average
pH		7.1	7.2	7.0	7.1	7.1
COD	mg/L	36	38	38	32	36
BOD	mgO_2/L	26	27	29	28	27.5
Oil & grease	mg/L	0.3	0.4	0.2	0.3	0.3
TDS	mg/L	1050	1100	1112	1048	1077.5
TSS	mg/L	30	34	36	32	33
Sulfide	mg/L	1.1	1.2	1.0	1.1	1.1
Total phosphate	mg/L	0.1	0.12	0.1	0.1	0.1
Nitrate	mg/L	0.1	0.2	0.1	0.1	0.13
phenol	mg/L	0.0	0.0	0.0	0.0	0.0

Table 6. Biological wastewater quality of final effluent of treated industrial wastewater after moving bed biofilm reactor

Biological parameters	MPN-index/100 ml				Average
	1st week	2nd week	3rd week	4th week	
Total coliforms	20	10	20	18	17
Fecal coliforms	2	ND	ND	ND	0.5

ND: Not Detected.

Table 7. The removal efficiency of paper industrial wastewater treatment

Parameters	With activated sludge process				With activated sludge process followed by moving bed biofilm reactor		
	Raw	1st effluent	Reduction value	(%)	1st effluent	Reduction value	(%)
COD	2929.5	121.8	2807.7	95.8	36	2893.5	98.77
BOD	676	40	636	94.1	27.5	648.5	95.9
TDS	2584.5	1590	994.5	38.5	1077.5	1507	58.3
TSS	1666.3	80.5	1585.8	95.2	33	1633.3	98
Oil & grease	55.8	3.9	51.9	93	0.3	55.5	99.5
Phosphate	3.7	0.33	3.42	91.9	0.1	3.6	97.3
Nitrate	0.4	0.3	0.25	62.5	0.13	0.28	70
Total coliforms	3.2x102	75	245	76.6	17	303	94.6
Fecal coliforms	97.5	27.5	70	71.8	0.5	97	99.5

4. CONCLUSION

Biological methods are used for treating industrial wastewater by conversion of dissolved and suspended substrates into biomass which is separated and removed from the wastewater. The activated sludge process followed by moving bed biofilm reactor with special microorganisms in treatment of paper mill wastewater showed higher reductions for COD, BOD, TDS and TSS than using activated sludge only. Final chemical and biological results of final effluent made it suitable for reuse in irrigation and other industrial purposes.

ACKNOWLEDGEMENT

We would like to thank water pollution research department staff, national research center, Egypt for help in analysis and experimental techniques. Also, we would like to thank ELCON NOVA Company for providing special microorganisms in granules. Finally, we would like to thank paper industrial company in Upper Egypt for their support and help.

REFERENCES

1. Hendriks A.T.W.M.; Zeeman G. (2008). Pretreatment to enhance the digestibility of lignocellulosic biomass. *Biores. Technol.*, 100: 10-18.
2. Bishnoi N.R.; Khumukchan R.K.; Kumar R. (2006). Biodegradation of pulp and paper mill effluent using anaerobic followed by aerobic digestion. *J. Environ. Biology*, 27(2): 405-408.
3. Balasubramanian N.; Muthukumar M. (2012). Performance of HUASB reactor for treating paper and pulp wastewater using effective microorganisms (EM). *Inter. J. Engin. Sci. Technol.*, 4(06): 2453-2461.
4. von Sperling M.; Freire V.H.; de Lemos Chernicharo C.A. (2001). Performance evaluation of a UASB - activated sludge system treating municipal wastewater. *Wat. Sci. Technol.*, 43(11): 323–328.
5. Kirjanova A.; Rimeika M.; Dauknys R. (2011). Start-up of trickling filters using novel filter medium under low temperature conditions. Environmental Engineering, 8th international conference 19-20 May, Vilnus Lithuania, p. 578-583.
6. Bongards M. (2001). Improving the efficiency of a wastewater treatment plant by fuzzy control and neural network. *Wat. Sci. Technol.*, 43(11):189-196.
7. Nicholas W. (2008). Pretreatment of pulp mill wastewater treatment industries to improve their anaerobic digestion. Master thesis, department of chemical engineering and applied chemistry, University of Toronto.
8. Koyuncu I.; Sevimli M.F.; Ozturk I.; Aydin A.F. (2001). Application of membrane and ozonation technologies to remove color from agro-industry effluents. *Wat. Sci. Technol.*, 43(11): 233-241.
9. Kylömen H.L.; Lappi M.K.; Thun R.T.; Mustranta A.H. (1988). Treatment and characterization of biological sludges from the pulp and paper industry. *Wat. Sci. Technol.*, 20: 183-192.
10. Lerner M.; Stahl N.; Galil N. (2009). Pretreatment of pulp mill secondary sludge for high-rate anaerobic conversion to biogas. *Biores. Technol.*, 100: 5729-5735.
11. Möbius C.H. (2006). Water use and wastewater treatment in paper mills Norderstedh (ISBN 978-3-8334-4).
12. Möbius C.H. (1989). Biological treatment of paper mill wastewater in an activated sludge reactor. *Wat. Sci. Technol.*, 21: 1828-1889.

13. Möbius C.H. (1999). Inside wastewater biofilters used for advanced treatment of paper mill effluent. *Wat. Sci. Technol.*, 40(11-12): 101-108.
14. Zimmerman R.A., Richard D., Lynne S. and Lin W. (2005). Is Your Moving Bed Biofilm Reactor (MBBR) Running on All Cylinders? WEFTEC 2005.
15. Metcalf and Eddy (2003) Inc., *Wastewater Engineering: Treatment, Disposal and Resue,* 4th Ed.; Tchobanoglous, G., Burton, F.L., and Stensel, D.H..; McGraw-Hill: New York, 2003.
16. Möbius C.H. (2009). Wastewater in the pulp and paper industry today and in retrospect paper presented at PTS water & environmental technology symposium 10/11 November, 2009 in Munich.
17. Orantes J.C.; Gonzales-Martinez S. (2003). A new low-cost biofilm carrier for treatment of municipal wastewater in moving bed reactor. *Wat. Sci. Technol.*, 48(11-12): 243-250.
18. APHA (American Public Health Association) (2005). Standard methods for the examination of water and wastewater, 21st ed., Washington, D.C.
19. Iqbal S.; Mehta S.C. (1998). Characterization and treatment of sugar industry. *J. Indian Pollut. Cont.*, 14(2): 151-161.
20. Sonune, A.; Ghate, R. (2004). Development in wastewater treatment methods. *Desalination*, 167:55-63.
21. Möbius C.H.; Helble A. (2004). Combined ozonation and biofilm treatment for reuse of paper mill wastewaters. *Wat. Sci. Technol*, 49(4): 319-323.
22. Sawyer C.N.; MoCartly P.L.; Parkin G.F. (1994). Chemistry for environmental engineering. MC. Graw Hill Inc.
23. McCarthy P.L.; Brown G.J.; Bilirs S.G.; Cocci A.A.; Landine R.C. (1991). Two stage pilot study on anaerobic/aerobic BNR treatment of fermentation based pharmaceutical wastewater. *J WPFC*, 63(3): 569-578.
24. Hulmes J.; Chymoweth D.P.; Turick C.E.; Owen J.M.; Peck M.W. (1993). Biochemical methane potential of biomass and waste food stock. *Biomass Bioenergy*, 5(1): 95-111.