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Pollutants Removal Performance of Anaerobic Baffled Reactors, Septic Tank and Anaerobic Digesters in Myung Sung Christian Medical Center and Bethel Teaching General Hospital, Ethiopia

Risko Assefa[a]; Serawit Handiso[b*];Tesfaye Alemu[a] and Mekbib Dawit[a]
[a]*Addis Ababa University, Department of Microbial, College of Natural Sciences, Cellular and Molecular Biology, Po Box: 1176, Addis Ababa, Ethiopia.*
[b]*Wolaita Sodo University, College of Agriculture, Department of Plant Sciences, Po Box: 138, Wolaita Sodo, Ethiopia.*

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Corresponding Author:
Serawit Handiso
Wolaita Sodo University, College of Agriculture, Department of Plant Sciences, Po Box 138, Wolaita Sodo, Ethiopia.

Abstract
The aim of this study was to evaluate the treatment performance of effective microorganisms (EM) for treatment of hospital wastewater in Bethel Teaching General Hospital (BTGH) and Myung Sung Christian Medical Center (MCM). The EM solution was applied in Anaerobic Baffled Reactors (ABRs) and Anaerobic Digester (AD) based on the average quantity of raw wastewater influent. The result revealed that pollutants removal efficiencies of the two hospitals WWTP were in the same range for turbidity (23%-28%), TDS (23%-27%) and FC (41%-48%). The ABRs showed a higher achievement for COD (66.40%) and BOD5 (75.90%) while, AD showed higher TC removal (94%) with a lower COD (58.75%) and BOD5 (40%) removal efficiencies. After addition of EM in BTGH wastewater, the ABRs showed 3% boost in turbidity removal efficiency with no statistically significant difference ($p = 0.246$), the NH3-N removal efficiency of ABRs was 5% (without EM) and 1% (with EM) reveled to no significant difference removal ($p>0.05$). Application of EM in MCM anaerobic digester showed drop in turbidity from 26% to 7% with no statistically significant difference of ($p=0.250$) and a higher BOD5 treatment efficiency was observed after addition of EM (55%) than before addition of EM (40%) but the COD removal efficiency decreased from 59% to 45% after addition of EM in MCM wastewater. From eighteen physico-chemical and bacteriological parameters considered, addition of EM in the hospitals WWTP improved the pollutants removal performance of ABRs for only three parameters and for seven parameters in the case of AD removal performance. Therefore, it is concluded that the treatment performance of EM on the hospitals wastewater were not significant for removal pollutants. Hence, further studies should be carried out for better treatment efficiencies of EM by combining with supplementary treatment methods.

***Key words**: Anaerobic Baffled Reactors, Anaerobic Digester, Effective Microorganisms, Hospital Wastewater.*

Introduction

Many of the healthcare wastewater chemical compounds resist normal wastewater treatment. They end up in surface waters influence the aquatic ecosystem and interfere with the food chain which could have potential negative effect on biological balance of the natural environments (Emmanuel *et al.*, 2001). The extent to which photogenic microorganisms can be removed depends on the type of treatment process used. A simple settling tank process can remove 50– 60% of viruses in a 3 h retention period by the removal of suspended solids to which virus particles are absorbed (Rao *et al.*, 1981). The trickling filter method can remove 40% of intestinal viruses through adsorption and subsequent inactivation (Kelly and Sanderson, 1960). An activated sludge system can remove as many as 90–99% of coliforms through precipitated adsorption (Tsai *et al*., 1998).

WHO (1999) states the health-care establishment should be connected to a sewerage system. Where there are no sewerage systems, technically sound on-site sanitation should be provided. Discharging of hospital wastewater to municipal sewers without pretreatment is not recommended. An on-site treatment or pre-treatment of hospital wastewater comprises primary treatment (screening, grit chamber, sedimentation tank), secondary treatment (biological treatment processes, such as activated sludge, trickling filters, lagoons), tertiary treatment (physical, biological, or chemical processes to remove nutrients such as nitrogen and phosphorus, and carbon adsorption to remove chemicals); chlorine disinfection and sludge treatment (anaerobic digestion, natural drying beds and incineration) should be available. A study conducted by Bista and Khatiwada (2000) on Dhulikhel hospital in Nepal, the hospital wastewater treatment units consist of a settling tank with a horizontal flow bed and vertical flow bed constructed wetlands. The mean organic matter removal efficiency in wetlands of the hospital was 85%, NH3-N and TP removal efficiency were observed to be 61% and 33 % respectively. In Dong Thap general hospital in Vietnam an aero-tank was transformed to activated sludge combined with biological contactor. The transformed WWTP expressed a higher pollutants removal performance of 87.8% with COD, 71.2% with TN, 83.6% with TP, 99.98% with TC (Greentech, 2011). In Abdel and Aly (2011) study four governmental hospital wastewater was treated in laboratory scale of activated sludge unit and the results indicated about 90.5% of the COD, 85% BOD5 and 99% of TC was removed within the national permissible level.

The ABR initially developed by McCarty and Bachmann, consists of a series of baffled compartments where the wastewater flows upward through a bed of anaerobic sludge. ABR is a low cost treatment technology compared to aerobic systems and does not require external energy. Bacteria within the reactor gently rise and settle due to flow characteristics and gas production but move down the reactor at slow rate (Barber and Stuckey, 1999). Anaerobic decomposition reduces the volume of accumulated solids on the bottom of the tank by 40 – 50% producing methane, carbon dioxide, water and reduced sulfur gases (Seabloom *et al.,* 1982).

ABR has numerous advantages, including good resilience to hydraulic and organic shock loads, long biomass retention times, low sludge yields, simple design, cheap construction, and the ability to separate the various phases of anaerobic catabolism longitudinally down the reactor (Barber and Stuckey, 1999). Krishna and co-workers reported that compartmentalization in ABR served to separate acidogenic and methanogenic activities longitudinally along the reactor, with the highest portion of acidogenic activity occurring in the first compartment (Krishna *et al*., 2007). The separation of two phases causes an increase in protection against toxic material and a higher resistance to changes in environmental parameters such as pH, temperature and organic loading (Wang *et al.,* 2004).
Barber and Stuckey (1999) concluded that the ABR is capable of treating a variety of wastewaters of varying strength (0.45–1000 g COD/l) over a large range of rates (0.4–28 kg COD/m3/d) and with high solids concentrations with satisfactory results. A three chamber ABR was used to evaluate the treatment of low strength synthetic wastewater, the COD and TSS removal was ranging from 82.6-91.9% and from 79.7%-92.2% respectively (Manariotis and Grigoropoulois, 2002). In Fayza *et al.* (2009) study treatment and reuse of domestic wastewater using an ABR, the performance of the ABR at the four HRTs gave satisfactory results, COD removal was between 68-82%, BOD 78% removal at 24 hours HRT and 62% at 8 hours. Total suspended solid percentage removals were 82% at the HRT of 24 h. However, most of the studies on ABR have been looking at industrial wastewater treatment in lab-scale units only and very little research has been conducted on the applicability of baffled reactors for the treatment of hospital wastewater.

AD is the breakdown of organic materials by the action of microorganisms in the absence of oxygen that produces biogas and digestate. It is an effective biological method for treating many organic wastes by employing facultative and strictly anaerobic bacteria to decompose organic material in a wastewater (Sbieb and Nguyen, 2000). The industrialization of AD began in 1859 with the first digestion plant in Bombay and in 1895 biogas was recovered from a sewage treatment plant in Exeter, England for fuel in street lamps. From there, it continued to be widely used as a way to stabilize sewage sludge, as it is today (Mahony and O'Flaherty, 2002). A wide variety of wastewaters have been treated by anaerobic processes include alcohol distillation, breweries, chemical manufacturing, dairy and cheese processing, domestic wastewater, fish and seafood processing, landfill leachate, pharmaceuticals, pulp and paper, slaughterhouse and meatpacking, soft drink beverages, sugar processing and others (Dwaraka and Jayaraju, 2010; Mi Jung *et al.,* 2010; Wong, 2007).

The process of anaerobic digestion occurs in a sequence of stages involving distinct types of bacteria. Hydrolytic and fermentative bacteria first break down the carbohydrates, proteins and fats present in biomass feedstock into fatty acids, alcohol, carbon dioxide, hydrogen, ammonia and sulfides. This stage is called "hydrolysis" or "liquefaction". Next, acetogenic (acid-forming) bacteria further digest the products of hydrolysis into acetic acid, hydrogen and carbon dioxide. Methanogenic (methane-forming) bacteria then convert these products into biogas (Pena-Varo, 2002). The combustion of digester gas can supply useful energy in the form of hot air, hot water or steam. After filtering and drying, digester gas is suitable as fuel for an internal combustion engine, which, combined with a generator, can produce electricity. Future applications of digester gas may include electric power production from gas turbines or fuel cells. Digester gas can substitute for natural gas or propane in space heaters, refrigeration equipment, cooking stoves or other equipment. Compressed digester gas can be used as an alternative transportation fuel (Ezekoye and Okeke, 2006). In spite of numerous wastewater treatments available in Ethiopia, only few practical applications of pollutant removal mechanisms were recorded. Furthermore, studies on the treatment of hospital wastewater with anaerobic digester, their performance to remove pollutants and pathogens are very limited. Therefore, the main objective of this research is to examine the pollutants removal performance of Aerobic Digester (AD) and Anaerobic Digester (ABR) in MCM and Bethel Teaching General Hospital wastewater treatment plant

Materials and methods

Description of the Study Area

This study was conducted in Bethel Teaching General Hospital and Myang Sung Christian Medical Center (MCM), Addis Ababa, Ethiopia. Bethel Teaching General Hospital was commissioned in 2000 at Kolfe Keranyo Sub City. Myung Sung Christian Medical Center is found in Gerji area, Bole Sub City (BTGH, 2011; and MCM, 2011).

Study Design

A descriptive study design was employed during October 2010 – September 2011 to gather data by laboratory analysis. A preliminary survey was carried out to be familiar with different aspects of the study area and major data acquisition by laboratory analysis of the selected hospital wastewater samples for determination of the various physico-chemical and bacteriological parameters.

Sampling Sites

The main source of the sample is wastewater from MCM and BTGH, samples were collected from influent and effluent of the hospitals WWTP for physico-chemical and biological parameters analysis based on standard methods for the examination of water and wastewater (APHA, 1998). Samples were also taken from septic tanks influent and effluent to evaluate the pollutant removal efficiency of septic tanks and to determine the effect of EM in domestic wastewater treatment.

Sampling Equipment and Interval

All samples for physicochemical were collected using a sterilized sampling plastic bottle and for bacteriological analysis sample were collected by sterilized glass bottle. Filtering Apparatus and all laboratory equipments for bacteriological analysis were first autoclaved, at 121 0C for 15 minutes including the sampling bottles (APHA, 1998). From each sampling site triplicate samples were collected, raw influent sample was collected at the point before it enters to the treatment plants and raw effluent of wastewater were collected at the point before discharge to municipal drainage system. EM solution was directly poured as indicated in instruction, 1 liter of EM in 1000 liter of wastewater in to inlet point of the hospitals WWTP. Two samples were collected from the wastewater after addition of EM solution from inlet and outlet points based on the interval of the hospitals wastewater HRTs. Samples were collected for three rounds from each hospital. Therefore, a total of 18 samples from both hospitals and MCM guest house wastewater were collected and analyzed. With consideration of Quang (2000b) study, EM was added each day at the dilution rate of 1:1000 in the studied hospitals WWTP for five days.

Sampling Volume and Techniques

From each sampling point for bacteriological analysis, a composite sample of 300mL water samples were taken in sterile glass bottles and transported to the laboratory with ice box. For the physicochemical analysis composite water samples of 500mL were collected in plastic bottles, labeled and transported to the AAU Environmental Science Research Laboratory with ice box. Before sample collection the bottles was washed with distilled water and repeatedly rinsed with the wastewater at each sample site. Moreover, for prevention of cross contamination and infection from the hospital wastewater all the necessary personal protective equipments: gloves, mask, gown and goggle were worn during sample collection and analysis as necessary.

Laboratory Analysis

The influent and effluent of the hospital wastewater sample collected for determination of physico-chemical and bacteriological parameters were analyzed in AAU; Environmental Science, Mycology and Microbiology laboratories. Samples were characterized in terms of its physical, chemical and biological composition. The laboratory analysis was done by HACH (2004) procedures, Standard Methods for the Examination of Water and Wastewater (APHA, 1975; 1998) and USEPA (1983) accepted procedures for reporting wastewater analyses.

Results and discussion

Pollutants removal performance of BTGH Anaerobic Baffled Reactors

The overall pollutants removal efficiencies of the two ABR's was TSS (13.7%), TDS (26.6%), TN (21.8%), NH3-N (4.5%), NO3-N (76.1%), NO2-N (36%), PO4-3 (28%) and TP (49.5%), respectively (Figure 1).

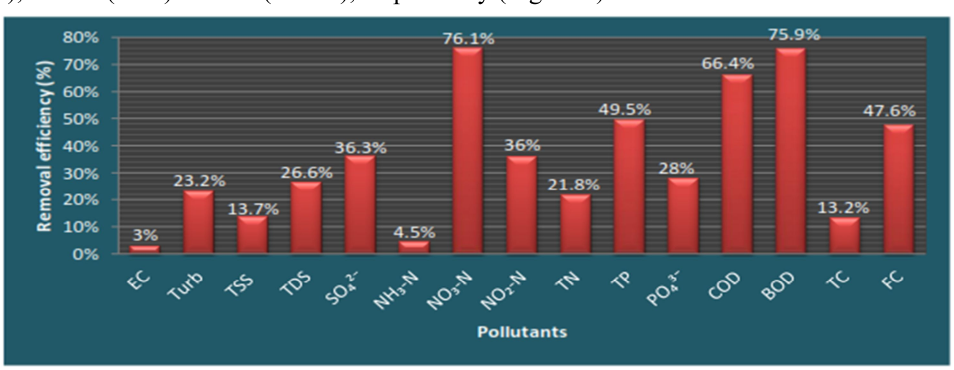

Fig 1: Pollutants removal performance of BTGH Anaerobic Baffled Reactors**.**

The overall performance of the system has showed 66.4% of COD removal and 75.9% of BOD5 removal efficiency, similar COD removal has been seen in a study carried out in treating wheat flour starch industry wastewater by ABR the efficiency of COD removal was 67% (Movahedyan *et al.,* 2007). The mean efficiencies for the ABR treating swine wastewater BOD5 removal was

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76.2%, while for COD removal was 65.2%, respectively (Erlon *et al.,* 2010). The study of Foxon *et al.* (2004) showed the performance of a 3000 L pilot ABR treating domestic wastewater to remove between 58% and 72% of COD entering in the feed and to reduce TSS and pathogen indicator organisms in the domestic wastewater.

The influent SO42- has been reduced in 36.3% whereas S2- has increased its concentration in the effluent with the ABRs removal performance being lowered down in 51% for S2-. Increase in sulfide levels down the reactor indicated that sulfide preferentially redirected electron equivalents to hydrogen sulfide rather than methane. Hydrogen sulfide is a strong inhibitor of methanogenesis and sulfate reduction promotes competition between Sulfate Reducing Bacteria (SRB) and Methane Producing Bacteria (MPB) because of substrate utilization (Moosa *et al.,* 2002). Also temperature and pH value increased in the effluent than the influent because the treatment plant is complete anaerobic system. The ABRs performance showed EC (3%) and TC (13.2%) removal efficiency. The FC and turbidity of the influent was removed in 47.7% and 23.3%, respectively (Figure 1).

Pollutants removal performance of MCM septic tank

The MCM guest house septic tanks remove 32.6% of TSS influents, which is within a typical TSS removal efficiency range of (30-81%) a septic tank as reported by Seabloom *et al.* (1982). The residential wastewater TDS removal in the septic tank was 41.8% which might cause by changes to the solubility of inorganic compounds and degradation of organic molecules into soluble salts in the effluent. The septic tank EC removal efficiency was 14.3% might caused by an input of relatively clean water from showers and toilet use with low chemical input. 39.5% of the influent sulfate might removed by SRBs (sulfate reducing bacteria) which use the oxygen from sulfates as part of the process of breaking down waste constituent. MCM guest house septic tank FC removal was 93.9% and TC removal was 10.7% respectively, as shown in Figure 2.

The septic tank shows analogous FC removal and lower TC removal when it is compared to Stewart (2005) study, the septic tanks at Pisgah Public School reduced TC by 82% and FC by 88% while the retrieve septic tank reduced TC by 95% and FC by 97%.

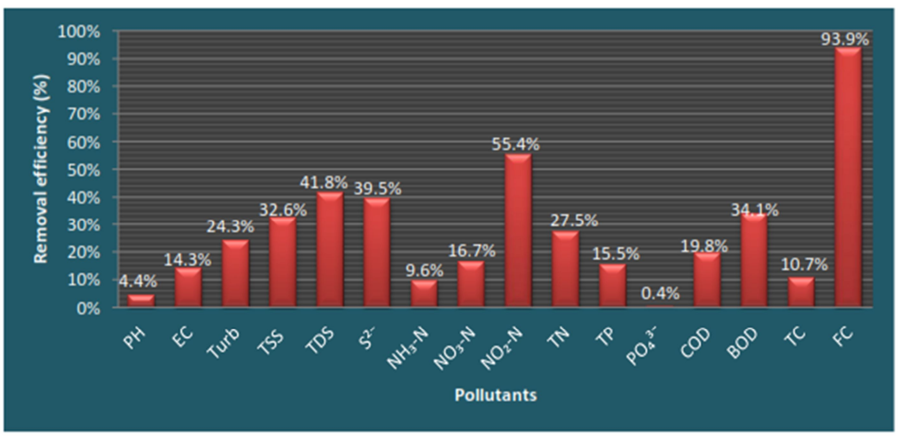


Fig 2: Pollutants removal performance of MCM guest house septic tank.

The TP influent removal in the septic tanks was 15.5%, which is lower than the Jamaica Public School septic tank removal of 25% (Stewart, 2005). The septic tank alone is not expected to affect the phosphorus concentrations in the wastewater but a smaller phosphorus removal could be expected within the septic tank due to adsorption of solids (Seabloom *et al.,* 1982). A lower removal of orthophosphate (0.4%) can be caused by the chemical precipitations reaction that can occur within the septic tank (Seabloom *et al.,* 1982). The septic tank removal efficiency of BOD5 was determined to be 34.12%, which is within the typical septic tank BOD_5 removal efficiency range 30-50% of U.S.EPA (2002), BOD5 is mostly reduced in a septic tank by primary settling of organic solids. The COD removal in septic tank was 19.8%, a lower removal can be caused by household bleach in waste water. In Washington *et al.* (1998) study the septic tank COD removal prior to laundry wastewater addition was 40-50% whereas 25-35% COD removal was attained after the addition of laundry wastewater. As shown in Figure 2, the septic tanks removal competence of TN, NH3-N, NO3-N, NO2-N were 27.5%, 9.6%, 16.7%, 55.4%, respectively. In Andreoli *et al* (1979) study 20% of TN discharged from a home attenuated in septic tank accumulated seepage sludge, with possible identification or volatilization. The study conducted in two public schools found in Jamaica in Pisgah School septic tanks removed 11% of influent TN and 24% of influent NH3-N while, in Retrieve School septic tank removed 66% of influent TN and 55% of influent NH3-N (Stewart, 2005).

Pollutants removal performance of MCM Anaerobic Digesters

The temperature of the AD increased in the effluent 230C than the influent 200C, in order to achieve reasonable methane production, the temperature should be above 200C (Pena-Varo, 2002). A higher removal of TC bacteria 93.7%) are shown in the AD and lower removal of FC (41.2%) as showed in Figure 3.

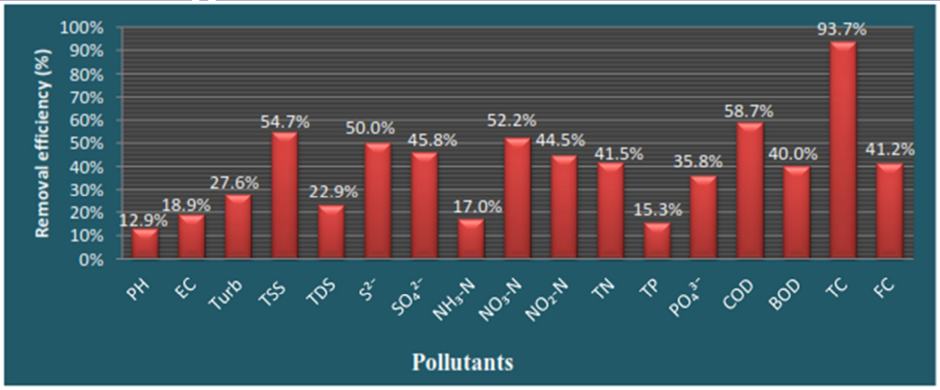
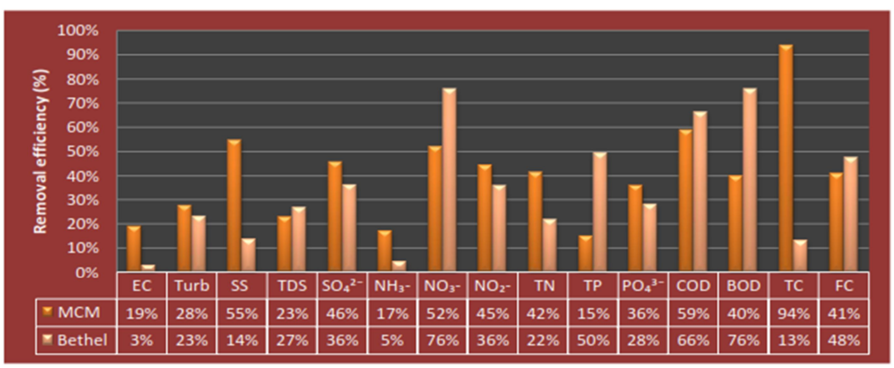


Fig 3: Pollutants removal performance of MCM Anaerobic Digesters.

The study of Tewodros Tilahun (2009) point out AD significantly reduces the coliform bacteria: 98.6% for FC and 98.4% for TC of sewage silage. Since the organic matter is the main substrate for anaerobes to degrade TDS removal rates in AD was 22.9% and TSS was 54.7%. The overall performance of the AD for various nutrients was 41.5% (Total N), 44.5% (NO2-N), 52.2% (NO3-N), 17% (NH3-N), the digester performance with respect to TP and PO43- was 15.3% and 33.8% respectively (Figure 3). The low treatment efficiencies observed for TP and TN are not surprising since microorganisms in the digester do not consume TP, Some TP can be converted to $PO_4$3- but the total mass remains constant and organic nitrogen compounds are converted to ammonia (Van *et al.,* 1997). The pH has been removed in 12.9% as the wastewater undergoes the anaerobic digestion process, organic solids are reduced to volatile fatty acids, and as these organic acids accumulate the pH initially tends to decrease. The COD and BOD5 rate of the influent has been decreased in 58.7% and 40%, the main reason for lower removal efficiency can be due to high organic loading rate in to system which leads to organic shock and also microorganism's death by drugs and antibiotics in raw wastewater.

Overall Treatment Performance

The overall treatment efficiencies in terms of turbidity, TDS and FC of the two hospitals reactors were in the same range as mentioned in Figure 4. The results show that ABRs remove the hospital wastewater organic matters more effectively than the AD (66% comparing to 59%).



	EC	Turb	SS	TDS	SO_4^{2-}	NH_3-	NO_3-	NO_2-	TN	TP	PO_4^{3-}	COD	BOD	TC	FC
MCM	19%	28%	55%	23%	46%	17%	52%	45%	42%	15%	36%	59%	40%	94%	41%
Bethel	3%	23%	14%	27%	36%	5%	76%	36%	22%	50%	28%	66%	76%	13%	48%

Fig 4: Comparisons of the removal efficiency (%) of the hospitals WWTPs

Also in terms of BOD_5, NO_3-N and TP removal BTGH ABRs achieved higher removal competency 76%, 76% and 50% respectively, when compared to that of MCM digester with a lower PO43-(28%) and TN (22%) removal rates. Furthermore, AD showed higher removal efficiencies in terms of FC, TSS, EC, SO_4-2, NH_3-N and NO_2- N than the ABRs for treatment of the hospital wastewater (Figure 4), which might be cause by the difference in the wastewater HRT, the longer a substrate is kept under proper reaction conditions, the more complete its degradation.

Conclusion

From this study it is concluded that the pollutant removal efficiency of ABRs after addition of EM solution showed achievements on only three parameters of turbidity, TSS and TC in reverse the treatment plant removal performance was decreased for fifteen parameters (temperature, pH, EC, TDS, SO4-2, S2, NH3-N, NO3-N, NO2-N, TP, TN, PO43, COD, BOD5 and FC). In the case of MCM, anaerobic digester after addition of EM in the AD there was enhancement in removal efficiency for seven parameters of the wastewater (SO4-2, NO2-N, NH3-N, TN, PO43-, BOD5 and FC). While, the efficiency decreased for eleven parameters: EC, turbidity, temperature, pH, TDS, TSS, S2, NO3-N, TP, COD and TC, respectively. Domestic wastewater contaminates removal efficiency of the septic tank after application of EM increased for seven parameters (EC, turbidity, S2, NH3-N, NO2-N, TP, PO43) and decreased for eleven parameters (temperature, pH, TSS, TDS, TN, SO4-2, NO3-N, COD, BOD5, TC and FC), there was no statistical significant decrease in wastewater parameter before addition of effective Microorganism and after addition of EM in both of the hospitals.

Recommendations

Based on the findings of this study, the hospital management body is recommended to maintain, replace or redesign the existing anaerobic digester and/or ABR apparatus with the state-of the-art mechanism of wastewater treatment. It is also recommended to separate the solid wastes from the liquid effluents right at the point of discharge or the hospital in order to ensure better treatment efficiencies and ecologically sound water treatment may be realized by combining EM with supplementary treatment methods. Mass production, application and utilization of effective micro-organisms must be encouraged through reward and recognition mechanisms. Investments in the areas of wastewater treatment can also be considered as a policy direction. Raising awareness followed by government subsidy in the area of research could be of a great help to the overall control in the pollution problems caused by hospital wastewater. Strict monitoring of these healthcare facilities by regulatory agency should be implemented as well as environmental agencies visit to the particular treatment plants can be made more mandatory. As a body to safeguard the public's health, hospitals need to take an active role in recognizing the impact and hazards posed by their wastewater discharged towards the aquatic and terrestrial ecosystems and, most importantly, carry out proper and effective measures. In order to achieve effective wastewater control from hospitals, collaboration among healthcare professionals, management personnel and the environmental protection agencies are necessary.

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