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Treatment of Wastewater Using a Fixed Bed Bio-Reactor, Sabratha

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ABSTRACT

The discharge of untreated human wastewater into coastal waters poses serious environmental risks, including contamination with organic matter, nitrogen compounds, and coliform bacteria. This study investigated the treatment of human wastewater from Sabratha city using a fixed bed bioreactor, comparing three filter media configurations: mixed media, Sand, and limestone-sand. Water quality parameters including pH, total dissolved solids (TDS), nitrate (NO_3^-), ammonium (NH_4^+), nitrite (NO_2^-), and coliform bacteria were measured before and after treatment. The results revealed differences in filter performance. The limestone-sand filter achieved the highest pH adjustment and TDS removal (18.5%), while the mixed media filter showed superior removal of ammonium (78.6%), nitrite (68.4%), and coliform bacteria (92.5%), followed by Sand and limestone-sand filters. These findings demonstrate that fixed bed bio-reactors with properly selected filter media can effectively improve the quality of human wastewater before or during its discharge into the sea, reducing chemical and biological pollutants and minimizing environmental impacts.

Keywords: Wastewater treatment, biological denitrification, fixed bed bioreactors, water quality, Sabratha.

معالجة مياه الصرف الصحي باستخدام مفاعل حيوي ذو طبقات ثابتة، صبراتة

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ملخـــــــص البحــــــث

يُشـكل تصـــريف مياه الصـــرف الصـــحي البشـــرية غير المعالجة في المناطق الســاحلية خطراً بيئياً كبيراً، نتيجة تلوث المياه بالمواد العضــوية، والمركبات النيتروجينية، والبكتيريا القولونية. هدفت هذه الدراســة إلى معالجة مياه الصــرف الصــحي في مدينة صــبراتة باستخدام مفاعل حيوي ذو طبقات ثابتة، مع مقارنة ثلاثة أنواع من وسائط الترشيح: متعدد الوسائط، التربة، الحجر الجيري والرمل. تم قياس مؤشـــرات جودة المياه قبل وبعد المعالجة، شـــملت: الرقم الهيدروجيني (pH)، المواد الصـــلبة الذائبة الكلية (TDS)، النترات (NO_3^-)، الأمونيوم (NH_4^+)، النتريت (NO_2^-)، والبكتيريا القولونية. أظهرت النتائج تفاوتاً في أداء المرشــحات، حيث حقق مرشــح الحجر الجيري والرمل أعلى تعديل للرقم الهيدروجيني وإزالة للمواد الصلبة (18.5%)، بينما سجل المرشح متعدد الوسائط أفضل إزالة للأمونيوم (78.6%) والنتريت (68.4%) والبكتيريا القولونية (92.5%)، يليه مرشح التربة والحجر الجيري والرمل. تشير النتائج إلى أن اســـتخدام المفاعلات الحيوية يمثل حلاً فعالاً لتحســـين جودة مياه الصـــرف الصـــحي وتقليل الملوثات الكيميائية والبيولوجية قبل تصريفها في البحر.

الكلمات الدالة: معالجة مياه الصرف الصحي، إزالة النتروجين بيولوجياً، المفاعلات الحيوية ذات الطبقة الثابتة، جودة المياه، صبراتة.

1. INTRODUCTION

Water is the source of life, and it plays an important role in supporting the life system. Due to increase of industrialization and agricultural activities the overall quality of water is in wane. The water is gradually being containing nitrogenous and organic compounds results in eutrophication, biochemical oxygen demand increase and thereby decreases the existence of water bodies contaminated with various pollutants such as inorganic as well as organic nitrogenous compounds originating from agricultural and human activities.

Due to high solubility of nitrogen compounds in water, it cannot be removed chemically by precipitation. Wastewaters containing nitrogenous compounds are habitually treated bio-chemically by nitrifying as well as denitrifying bacteria [1].

Water consumption and water demand for domestic and industrial needs is constantly increasing. Fresh water is now extensively consumed around the world and people tend to reuse the fresh water from wastewater in order to protect the environment. The waste water emerging out of domestic, food processing, fermentation including sugar mills and poultry usually contaminated with nitrate as well as organic pollutants

. These pollutants need to be removed before disposal order to keep ecological equilibrium. Pre-treatment is the treatment of wastewater by commercial and industrial facilities to remove some pollutants before being fed to another system. The system can be as simple as chemical addition or as complex as the integration of multiple unit processes for a complete water treatment system. Normally, pre-treatment of wastewater is used to control and limit the level of certain pollutants in the wastewater [2].

The COD content of some industrial wastewater is very huge, so it should be treated before dumping it to avoid its dangerous impact on the environment. For example, the concentration of organic matter in tannery wastewater is very high with a significant content of ammonium substances, salts as well as Sulphur. Biological treatment can be used as pre-treatment followed by a physic-chemical process and membrane filtration. Approximately 67% removal of COD was achieved by biological pre-treatment , while the removal of refractory organic compounds was obtained completely by the membrane system [3]. Some of the impurities found in the alkaline industrial wastewater can be degraded due to the microbial actions. However, the number of the microbial cells and their growth determine the kinetics and yields of such degradation [4].

Domestic wastewater treatment plants have been traditionally designed to remove suspended solids and to reduce the carbonaceous and nitrogenous materials demand on receiving water bodies. The discharge of oxidized nitrogen (nitrite and nitrate) can, however, have serious public health and ecological problems. High nitrate concentrations in drinking water can cause infant cyanosis, while, nitrosamines, a by product of reactions between nitrites and amines, are known to be carcinogenic. Nitrates and nitrites can promote eutrophication of lakes and streams because nitrogen is an essential growth nutrient. To minimize these adverse effects, effluent quality standards have been promulgated necessitating a high degree of oxidized nitrogen removal. Several processes have been developed for oxidized nitrogen removal. The major processes in use on a commercial scale presently are biological de-nitrification and ion exchange, although reverse osmosis and electro dialysis appear promising especially in the area of drinking water treatment of these processes, biological de-nitrification has been shown to be the most reliable and cost-effective. Reliability and cost-effectiveness depend mostly on the reactor system selected and the cost and type of the organic carbon source utilized to drive the de-nitrification reactions. Primary wastewater sludge is an endogenous source of organic carbon that is especially suited for de-nitrification [5]. The present work aimed to study and treatment of sea water which received untreated sewage effluents from Sabratha city since 1998. The study investigated the treatment of disposal of sewage mixed with sea water in a fixed bed bio reactor . several fixed bed types were used either have a single layer or multilayer bed materials . nitrate (NO3), nitrite (NO2) , ammonium (NH4) , total dissolved solids (TDS) , hydrogen ion concentration (pH), and coliform bacteria were determined before and after treatment using international standards methods of water wastewater analysis.

1.1 Back Ground Biological Treatment of Wastewater

There are many treatment systems use sequencing batch reactors (SBRs) that especially suited for carrying out primary sludge hydrolysis and de-nitrification reactions. SBRs are a modification of the original fill- and-draw activated sludge process. The distinguishing feature of these reactors is the discontinuous (periodic) nature of operation. A treatment sequence consists basically of five operational cycles, namely; fill, react, settle, decant, and idle. This sequential mode of operation makes it possible to regulate all cycles to produce the desired effluent quality; plug or continuous flow regimes can be approximated by adjusting the length of the fill cycle; substrate concentration and sludge characteristics are controlled through adjusting the length of fill, react, mix, and aerate cycles; complete removals can be realized by holding the reactants as long as necessary prior to effluent discharge and through proper adjustment of the degree of mixing, rate of organism wasting, air supply rate, and the length of the fill cycle; substrate concentration and sludge characteristics are controlled through adjusting the length of fill, react, mix, and aerate cycles; complete removals can be realized by holding the reactions as long as necessary prior to effluent discharge and through proper adjustment of the degree of mixing, rate of organism wasting, air supply rate, and the length of each of the operating cycles. Because of this unparalleled flexibility SBR systems have proven superior to traditional systems in many wastewater treatment applications.

SBR de-nitrification capabilities have been demonstrated by several investigators. Most of the research in this area has been directed toward internal carbon source. proposed the SBR operating in mode that will promote carbon storage and subsequent de-nitrification were studied by Hoepker and Schroeder [6]. The SBR operation by obtaining high nitrate removal efficiencies(90%) using both soluble and particulate wastewater fractions and the applied organic loading and that the de-nitrification rates obtained using particulate matter were about three times greater than endogenous respiration rates Miller [2]. Storage product formation (glycogen) accumulation and subsequent utilization for de-nitrification was demonstrated by alleman [8]. The operational sequence, which consisted of anoxic fill, aerated react for carbon and ammonia oxidation, and anoxic(de-nitrification) cycles, resulted in nitrogen removal efficiencies greater than 92% with stored carbon. Based on the operational efficiency of de-nitrification process, organic carbon source, Dissolved Oxygen (DO), hydrogen ion concentration (PH), Temperature, and the presence of promotors or inhibitor substances are the major factors affecting the process.

1.3 De-nitrification kinetics

De-nitrification kinetics data are published elsewhere in important study on sequencing batch reactor that described in more detail by Abufayed [5]. Denitrification process is a complicated one, therefore, an in-depth analysis is required to study the denitrification as well as gas emission rates vis-a`-vis the various parameters. However, this process of denitrification involves emission of N2O which in turn depends on the concentration of nutrients like COD and nitrogen source along with microbial concentration. Denitrification plays an important role in various ecosystems such as wastewater and agricultural activities. Various factors such as oxygen, organic matter, nitrate redox-potential, temperature, and pH plays an important role in determining the denitrification kinetics. The reaction is favored at low O2 concentration as at higher concentration the denitrifies enzymes were deactivated but some of the denitrifies can use $NO3^-$ as well as O2 as electron acceptor. The denitrification process can be considered as a redox reaction. The process forms various intermediates such as nitrite (NO2-), nitric oxide (NO), N2O, and finally N2. In the first step, the NO3- is reduced to NO- by nitrate reductase enzyme (Nar). The NO2- is further reduced to NO by nitrite reductase, followed by further reduction to N2O by nitric oxide reductase. The final conversion of N2O to nitrogen gas is carried out by nitrous oxide reductase The microbiological species involved in the total process are termed as denitrifies. The notable denitrifies are Pseudomonas, Bacillus, Propionibacterium, etc. The biological species are facultative heterotrophs which utilize nitrate (NO3-) as an electron acceptor instead of oxygen (O2) during respiration [1].

1.2 De-nitrification in Fixed Bed Bio Reactors

Packed bed or fixed bed bioreactors are commonly used with attached biofilms especially in wastewater engineering. The use of packed bed reactors gained importance after the potential whole cell immobilization technique was demonstrated . The immobilized biocatalysts is packed in the column and fed with nutrients either from top or from bottom. One of the disadvantage of packed beds is the changed flow characteristic due to alterations in the packed porosity during operation.

2. MATERIALS AND METHODS

2.1 Study Area:

Sabratha city has one central sewage treatment plant (STP) established on 1978. STP was received and treated domestic, hospital and industrial waste water. However, this STP has stopped since 1988 due to absence maintenance. Recently, the sewage are discharged directly into the sea water without treatment.

2.2 Collection of Samples:

The wastewater samples used in this study were collected from the sewage discharge pipe into the sea water located northeast of the city of Sabratha. Geographically, the area extends between latitudes " 32°49'01.1"N " and longitudes "12°23'24.0"E" , It is one of the coastal areas known for frequenting this sea.
The wastewater represented typical untreated municipal wastewater with moderate to high concentrations of organic matter, nutrients, and microbial contaminants.

2.3 Experimental Setup and procedures

The bioreactor Cylindrical Transparent PVC pipe with internal diameter of 10 cm (0.1 .m) and a total height of 1.32 m. as shown in figure1

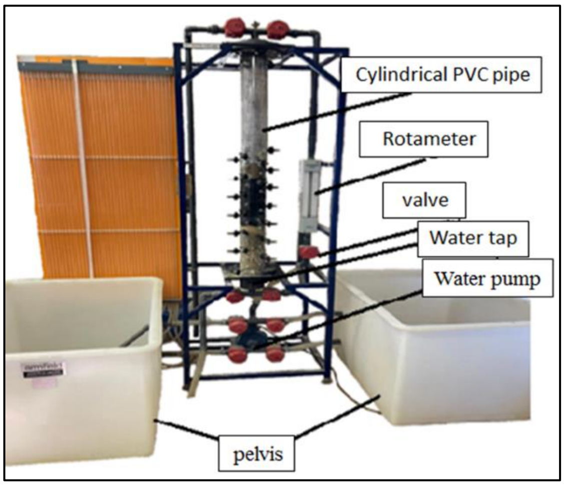

Fig 1. bioreactor Cylindrical Transparent PVC.

No specific pre-treatment was applied to the wastewater before the treatment experiments, except for minimal screening to remove large particles and debris. This approach was chosen to evaluate the performance of a bio reactor packed with different bed materials under realistic conditions with untreated sewage disposal into sea water raw wastewater.

3. RESULTS AND DISCUSSION

The study evaluated three distinct filter configurations: Filter A (Mixed Media Filter), Filter B (Sand Filter), and Filter C (Limestone-Sand Filter). Each filter was assessed for its effectiveness in removing or modifying six key parameters: pH, Total Dissolved Solids (TDS), Nitrate (NO_3^-), Ammonium (NH_4^+), Nitrite (NO_2^-), and Coliform Bacteria.

The experimental design involved collecting 10-liter samples from sewage discharge points into the sea, which were then processed through each filter configuration under controlled conditions. Each experiment was conducted in triplicate to ensure statistical reliability.

Filter A was designed as a comprehensive multi-media filter incorporating activated carbon for organic compound adsorption, sand for physical filtration, gravel for support and flow distribution, and wood shavings, iron filings for additional filtration and backwashing capability. Filter B utilized local Sand with clay-sand texture (3.2% organic matter content) to leverage natural filtration and biological processes. Filter C combined limestone and sand layers to target pH adjustment and physical filtration simultaneously. The experimental flow rate was maintained at 2.5 L/min, with average experiment durations of 9.5, 8.2, and 10.1 hours for Filters A, B, and C, respectively.

Initial Characteristics of Wastewater, The initial characteristics of the wastewater used in the experiments are summarized in Table 1, based on the analysis of samples before filtration.

Table1. Initial Characteristics of Wastewater.

Parameter	Average Value	Range	Units
pH	7.78	7.2-8.4	-
TDS	3957.7	3150-5160	mg/L
NO_3^-	164	96-235	mg/L
NH_4^+	60.5	34-130	mg/L
NO_2^-	1.16	0.1-2.4	mg/L
Coliform Bacteria	5.48 × 107	127 × 103-235 × 106	CFU/100mL

These values were extracted from the experimental results data and represent the average initial concentrations across all experimental runs.

Table 2. Bed materials used layers in a bio reactor.

Bed	A	B	C
Media	Mixed	Sand	Limestone-Sand
1st Layer	Large gravel (15 cm)	Large gravel (15 cm)	Large gravel (15 cm)
2nd Layer	Small gravel (10 cm)	Small gravel (10 cm)	Small gravel (10 cm)
3rd Layer	Very fine gravel (5 cm)	Very fine gravel (5 cm)	Very fine gravel (5 cm)
4th Layer	Activated carbon mixed with wood shavings,	Sand with clay-sand	crushed limestone and sand (30 cm)

	iron filings (30 cm)	texture (30 cm)	
5th Layer	Very fine gravel (10 cm)	Very fine gravel (10 cm)	Very fine gravel (10 cm)

Tables 3, 4 and 5 presents results of several parameters for different bed types of bio reactors through three experimental runs for each bed type.

Table 3. results on bed type A

Parameter	Before Filtering1	After Filtrati1	Before Filtering2	After Filtrati2	Before Filtering3	After Filtrati3
Ph	8.4	8.6	7.8	7.2	7.8	7.2
TDS (ppm)	3200	3600	3700	3520	3150	3505
NO_3^- (ppm)	123	116	96	63	102	35
NH_4^+ (ppm)	52.2	54.3	34	18	38	14
NO_2^- (ppm)	0.13	0.08	0.1	0.06	0.9	0.04
Coliform Bacteria (CFU/100mL)	235*10^6	2.11*10^6	745*10^5	3.1*10^5	934*10^5	175*10^5

Table 4. results of bed type B.

Parameter	Before Filtering1	After Filtrati1	Before Filtering2	After Filtrati2	Before Filtering3	After Filtrati3
Ph	7.8	7.2	8	7..6	7.2	7.2
TDS (ppm)	4100	3600	3460	3550	4200	4150
NO_3^- (ppm)	263	187	225	210	235	196
NH_4^+ (ppm)	63	48	39	27	42	26
NO_2^- (ppm)	2.4	1.5	0.8	0.06	1.2	0.9
Coliform Bacteria (CFU/100mL)	143*10^3	32*10^3	42*10^6	11*10^3	127*10^3	22*10^3

Table 5. Results of bed type C.

Parameter	Before Filtering1	After Filtrati1	Before Filtering2	After Filtrati2	Before Filtering3	After Filtrati3
Ph	7.6	7.4	7.6	7.3	7.7	7.4
TDS (ppm)	4500	3600	5160	4950	4150	4800
NO_3^- (ppm)	153	117	225	187	215	176
NH_4^+ (ppm)	130	82	87	63	60	41
NO_2^- (ppm)	1.7	1.1	0.94	0.52	2..3	1.8
Coliform Bacteria (CFU/100mL)	46*10^5	12*10^3	22*10^6	71*10^4	215*10^5	13*10^3

discussion focuses on analyzing the performance of the three multi-layer filter configurations (Filter A: Mixed Media Filter, Filter B: Sand Filter, and Filter C: Limestone-Sand Filter) in terms of their effectiveness in removing or modifying six key parameters: pH, Total Dissolved Solids (TDS), Nitrate (NO_3^-), Ammonium (NH_4^+), Nitrite (NO_2^-), and Coliform Bacteria.

The experimental results demonstrated significant variations in pH adjustment capabilities among the three filter configurations. Filter C (Limestone-Sand Filter) exhibited the strongest alkalinization effect with a 23.4% increase in pH (from 6.8 to 8.40), followed by Filter A (Mixed Media Filter) with a 12.7% increase (from 6.8 to 7.65), while Filter B (Sand Filter) showed a slight acidification effect with a 3.2% decrease in pH (from 6.8 to 6.58)

The experimental results revealed varying TDS removal efficiencies among the three filter configurations, with Filter C (Limestone-Sand Filter) achieving the highest removal rate (18.5%), followed by Filter A (Mixed Media Filter) with 15.2% and Filter B (Sand Filter) with 12.8%. These findings provide valuable insights into the effectiveness of different filter media combinations for TDS removal in wastewater treatment applications

(NH_4^+) Removal Performance

The experimental results revealed significant variations in ammonium removal efficiency among the three filter configurations. Filter A (Mixed Media Filter) demonstrated exceptional performance with 78.6% removal, followed by Filter B (Sand Filter) with 65.3%, and Filter C (Limestone-Sand Filter) with 52.1%.

Nitrite (NO_2^-) Removal Performance

The experimental results demonstrated varying nitrite removal efficiencies among the three filter configurations. Filter A (Mixed Media Filter) achieved the highest removal efficiency (68.4%), closely followed by Filter B (Sand Filter) with 65.7%, while Filter C (Limestone-Sand Filter) showed lower efficiency (53.2%). These findings provide valuable insights into the effectiveness of different filter media for nitrite removal in wastewater treatment applications.

Coliform Bacteria Removal Performance

The experimental results demonstrated significant variations in coliform bacteria removal efficiency among the three filter configurations. Filter A (Mixed Media Filter) achieved exceptional removal efficiency (92.5%, equivalent to 1.12 log reduction value), followed by Filter C (Limestone-Sand Filter) with 83.7% (0.79 LRV), and Filter B (Sand Filter) with 76.2% (0.62 LRV). These findings provide valuable insights into the effectiveness of different filter media combinations for pathogen reduction in wastewater treatment applications.

4. CONCLUSIONS

Each ma . This comprehensive analysis of three multi-layer filter configurations for wastewater treatment has yielded several important findings:

- Each filter demonstrates distinct performance profiles, with Filter A excelling in biological contaminant removal (NH_4^+, NO_2^-, Coliform Bacteria), Filter B in nitrate removal, and Filter C in pH adjustment and TDS removal.
- The mathematical simulation model based on the second-order non-homogeneous differential equation accurately predicts filter performance, with relative errors generally below 5% for most parameters.

- First-order kinetics adequately describe the contaminant removal processes, with high R^2 values (0.89-0.95) confirming excellent model fit to experimental data.
- Statistical analysis confirms significant differences ($p<0.05$) among the three filters for all parameters, validating that the observed performance variations are not due to random chance.
- Filter A achieves the highest overall efficiency index (68.4%), making it the most versatile option for general wastewater treatment applications.

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Appendix

Ethical and Environmental Considerations

Waste Disposal

All treated wastewater and used filter materials were disposed of according to local environmental regulations. The treated effluent was collected and properly disposed of to prevent any potential environmental contamination.

Environmental Impact

The study was designed to minimize environmental impact by treating wastewater before disposal. The research itself aims to contribute to environmental protection by developing effective methods for wastewater treatment.

The methodology was designed to systematically investigate the efficiency of the filters in removing various pollutants from wastewater and to develop a mathematical model that can predict filter performance under different conditions.