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INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Denitrification by Fluidized Bed Biofilm Reactor Using Stone Dust as Biofilm Carrier Media

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Abstract

In many areas of the world, nitrate concentration has reached serious level, which is responsible for environmental problems. Hence it is necessary to remove nitrate from water resources. Among the various options, denitrification is the versatile option for the removal of nitrate. This paper represents the results of experimental work of biological denitrification by Fluidized Bed Biofilm Reactor using stone dust as biofilm carrier media.In this study, the maximum average nitrogen removal efficiency of 96.93% at HRT of 30 minutes and optimum efficiency of 90.57% at HRT of 10 minutes is observed. For nitrogen loading rates varying from 0.48 to 28.80 kg N m^{-3} d^{-1}, denitrification rates observed are 0.46 kg N m^{-3} d^{-1} to 17.91 kg N m^{-3} d^{-1}. Optimum nitrogen loading rate and denitrification rate observed are 4.32 kg N m^{-3} d^{-1} and 3.98 kg N m^{-3} d^{-1} respectively. The results of the study depict the usefulness of FBBR for denitrification.

Keywords*:* Denitrification; Fluidized Bed Biofilm Reactor (FBBR); Methanol; Nitrate.

Introduction

Nitrogen is a major constituent of the earth's atmosphere and occurs in many different gaseous forms such as elemental nitrogen, nitrate and ammonia. While nitrate is a common nitrogenous compound due to natural process of nitrogen cycle, anthropogenic sources have greatly increased the nitrate concentration, particularly in groundwater [7]. The excessive applications of fertilizers, intensive exploitation of farms and the significant contribution from industry have increased the nitrogen load discharged to receiving waterways [29, 40, 5]. Nitrate contamination of water resources is becoming a serious environmental problem worldwide [43, 21, 28, 6, 31]. A physico-chemical analysis study of groundwater in Sambhar lake city, Rajasthan, India was carried out and researchers have found Nitrae concentration levels upto 1100 mg l^{-1} [19]. After assessing the water quality of Upper Lake, Bhopal (India), which supplies drinking water to 16 lakh population, found Nitrate concentration as 150 – 720 mg l^{-1}[30]. In a case study carried out for water quality of water sources of Yavatmal district, Maharashtra (India), found nitrate concentration in the range of 100 mg l^{-1} to 500 mg l^{-1}. Nitrate concentration is above the permissible level of 45 mg l^{-1} in 11 states, covering 95 districts and 2 blocks of Delhi [20]. Similar high concentratios of nitrate found in an investigation of nitrate content in ground and surface waters in urban and rural areas [13]. Nitrate contamination of groundwater resources is becoming a problem in Europe as well as in the United States and Canada. In many areas the nitrate concentration in groundwater has reached serious levels exceeding the nominal limits of 10.0 mg l^{-1} as NO_3^--N (nitrate nitrogen) set by the U.S. Environmental Protection Agency or 50 mg l^{-1} as NO_3^-(nitrate) set by the World Health Organization, the European Economic Community, and some former East European countries, e.g. Czechoslovakia. Concern over increase in nitrate concentrations is very legitimate due to potential ill effects on health. The toxicity of nitrates for humans is not clearly established. However, their consumption can cause infant methemoglobinemia (blue baby syndrome). Reduction of nitrates into nitrites in saliva may contribute to the formation of nitrosoamines, which are known carcinogens [33, 39, 14, 62, 64, 56]. Accumulation of various forms of nitrogen in surface and ground waters can lead to adverse effects including depletion of dissolved oxygen (DO) in receiving waters, Eutrophication, ammonia toxicity to aquatic life, and public health problems related to the presence of nitrate in drinking water supplies [61, 17, 11, 46, 45]. Nitrate can also cause anaemia, oral cancer, cancer of colon, vascular dementia and multiple sclerosis [40].

Till today, presence of nitrate in potable water had not been given serious attention in India. However with the new dimensions of nitrate concentrations such as stomach cancer and other health problems, there is a vital need to identify the areas of high nitrate waters and develop appropriate treatment. A survey of literature yielded an abundance of information on the technical treatment to remove nitrate from water including ion exchange, biological denitrification, chemical denitrification, catalytic denitrification, reverse osmosis and electrodialysis [49]. Three methods show some potential for full-scale application: ion exchange, reverse osmosis, and biological denitrification [33].

Nitrate from the contaminated water can be removed by ion exchange. Ion exchange is basically a physical/chemical process which requires periodic regeneration to restore its exchange capacity and process efficiency. It is known that periodic regeneration of exhausted resins with sodium chloride (NaCl) or sodium bicarbonate ($NaHCO_3$) results in a spent regenerant or brine waste containing high concentrations of nitrate-N, NaCl and $NaHCO_3$ [65]. Ion exchange is limited by two problems. The first is that a resin of high selectivity for nitrates over ions that are commonly present in groundwater does not exist. The second problem involves providing an adequate resin regenerant such that regenerant disposal does not become a problem itself [33].

The problem of reverse osmosis is that the membranes used generally do not exhibit high selectivity for nitrates. The degree of salt rejection is directly related to the valency of the ions. That is why the reverse osmosis process results in better removal of multivalent ions. Reverse osmosis results in the removal of many ionic species and in a significant reduction in the mineral content of the water.

The most promising and versatile approach being studied is biological denitrification. This process has been used for years in wastewater treatment. Biological denitrification is highly selective for nitrate removal. The efficiency of the process is very high and can reach nearly 100%, which is not matched by any other methods available for nitrate reduction. The potential bacterial contamination of treated water is the main disadvantage. This risk is very legitimate and subsequent treatment and disinfection are required to meet current drinking water standards [33]. Biological Denitrification can be carried out in either fixed film or suspended growth systems with the use of methanol or some equivalent carbon source. The Fluidized Bed Biofilm Reactor (FBBR) is one of the methods, which comes under the category of fixed film type of system. FBBR is the recent method and can be used for biological denitrification with great advantages.

The work presented in this paper is related to an experimental work carried out in the laboratory. A setup of FBBR was established in the laboratory to study biological denitrification. The biofilm carrier media used was stone dust. The FBBR was run for several days to observe denitrification of synthetic wastewater for various concentrations of NO_3^--N, which varies from 10 mg l^{-1} to 100 mg l^{-1}. The results showed, the FBBR has great potential for denitrification.

Biological Denitrification

Biological nitrification and denitrification is one of the most economical processes of nitrogen removal from municipal wastewaters [27, 22, 47, 53]. Nitrate removal from wastewaters is commonly achieved by employing the bacterial process of denitrification, in which nitrate is reduced to innocuous nitrogen gas (N_2). The process requires an electron donor to supply electrons (energy) to the bacteria [25, 59, 36, 23, 9, 60]. The condition suitable for denitrification – absence of oxygen but presence of nitrate, is commonly referred as anoxic. The biological denitrification process (dissimilation) involves the conversion of nitrate ions into nitrogen gas by facultative heterotrophic bacteria. Anoxic conditions and an energy source are required for this.

Heterotrophic denitrifying bacteria require an organic carbon source for respiration and growth. Carbon source plays an important role in biological nitrogen and phosphorus removal during the wastewater treatment [63]. A wide variety of organic compounds has been used, such as methanol, ethanol, glucose, acetate, aspartate, or formic acid as well as different industrial wastes including molasses, whey, distillery spillage, and sulfite waste liquor. However, most of the published research regarding denitrification involves the use of methanol, ethanol, and acetic acid [33]. The usefulness of methanol in the denitrification process is determined first of all by economic considerations [15, 48]. Methanol is a very convenient carbon source for denitrification due to its high solubility in water, high biodegradability and known stoichiometry [2, 12]. Methanol is the most appropriate choice because of its availability, low cost, favorable sludge production, low volatile organic compound (VOC) emissions potential and lack of nitrogen and phosphorus.

If methanol is used as a carbon source, the stoichiometric relationships describing bacterial energy reactions in two steps are written as Equations (1) and (2) which give the overall (dissimilation) Equation (3): [33, 65, 34]

$$6NO_3^- + 2CH_3OH \rightarrow 6NO_2^- + 2CO_2 + 4H_2O \qquad (1)$$

$$6NO_2^- + 3CH_3OH \rightarrow 3N_2 + 3CO_2 + 3H_2O + 6OH^- \qquad (2)$$

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^- \quad (3)$$

Nitrate assimilation is generally expressed by Equation (4):

$$3NO_3^- + 14CH_3OH + CO_2 + 4H \rightarrow 3C_5H_7NO_2 + 19H_2O \quad (4)$$

The cell formula $C_5H_7NO_2$ suggested by Hoover and Porgess was used. The "overall" (dissimilation + assimilation) process in nitrate-limiting conditions is described by McCarty's Equation (5) :

$$NO_3^- + 1.08CH_3OH + H^+ \rightarrow 0.065C_5H_7NO_2 + 0.467N_2 + 0.76CO_2 + 2.44H_2O \quad (5)$$

Extension of Equation 5 to take also nitrite and oxygen, which often keep company with nitrate in the feed, into account, gives to the empirical relation Equation (6) weight basis [58].

$$M = 2.47(g\,NO_3^- - N) + 1.53(g\,NO_2^- - N) + 0.87(g\;O_2) \quad (6)$$

The data found in the literature significantly differ from those in the above. In spite of 2.47, the value of the coefficient in Equation (6) was often found to be 2.65. and the suggested working value is 3.0 (g methanol) /(g NO_3^- –N) removed); in spite of the coefficient 0.87 in Equation (6), values as large as 1.1-1.2 have been found as well [3].

This process of biological denitrification depends on environmental conditions such as oxygen content, temperature and pH [16]. Alkalinity is produced in denitrification reactions and the pH is generally elevated, instead of being depressed as in nitrification reactions. In contrast to nitrifying organisms, there has been less concern about pH influences on denitrification rates. No significant effect of the denitrification rate has been reported for pH between 7.0 and 8.0 [34].

Biological Denitrification System

Denitrification of a well nitrified effluent can be achieved by providing a zone in which the effluent is brought into contact with a large biomass containing heterotrophic micro-organisms, in an anoxic environment; and in the presence of a suitable exogenous carbon source. Complete denitrification appears feasible with the use of methanol or some equivalent carbon source, in either attached growth (fixed film) or suspended growth system.

Fluidized Bed Biofilm Reactor

The Fluidized Bed Biofilm Reactor (FBBR), the attached growth type of reactor (system), is a recent process innovation in wastewater treatment, which utilizes small, fluidized media for cell immobilization and retention. [37, 54]. Main application of the fluidized bed biofilm reactor is in the field of biological treatment of wastewater. Aerobic as well as anaerobic fluidized bed biofilm reactors (FBBRs) have received increasing attention for being an effective technology to treat water and wastewater [55, 51, 50, 35, 25, 38, 18, 4, 52, 42, 8]. Its most important features are - the fixation of microorganisms on the surface of small-sized particles, leading to high content of active microorganisms and large surface area available for reaction with the liquid; the high flow rate (low residence time) which can be achieved, leading to high degree of mixing (decreased external mass transfer resistances) and to large reduction in size of the plant; and the removal of risk of clogging [58].

The basic concept of the process consists of passing wastewater up through a packed bed of particles at a velocity sufficient to impart motion to or fluidize the particles. As the flow of the wastewater passes upward through the biological bed, very dense concentrations of organisms growing on the surface of the bed particles consume the biodegradable waste contaminants in the liquid. Figure 1 is a schematic of the basic unit of the process, showing the entire fluidized bed biofilm reactor with the wastewater flowing upwards through the bed, fluidizing the particles in the liquid. Above the bed is a clear water zone wherein the particles separate from the liquid.

From a biological point of view, the attached microorganisms on the suspended particles may include any of the aerobic, facultative, or anaerobic organisms typically found in trickling filters and suspended growth type of treatment systems. The predominating species would depend entirely on the waste contaminant being consumed and whether an aerobic or anaerobic environment is maintained, as well as other factors that affect biological growth.

Fluidized beds combine the best features of activated sludge and trickling filtration into one process. Offering a fixed film and a large surface area, fluidized bed systems offer the stability and ease of operation of the trickling filter as well as the greater operating efficiency of the activated sludge process. More importantly, treatment is accomplished in significantly less space and time, which can be translated into less cost than conventional treatment. The primary reason for this savings in space, cost, and treatment time is that the measured concentration of active biomass in the fluidized bed system reported is in the order of 8,000 mg l^{-1} – 40,000 mg l^{-1}, which is usually greater than conventional treatment systems such as the complete-mix activated sludge process in which the MLSS ranges between 3,000 mg l^{-1} – 6,000 mg l^{-1} or the pure oxygen systems where the MLSS ranges from 6,000 mg l^{-1} – 8,000 mg l^{-1} [57, 42]. The reason for this is that the available surface area per unit of volume of reactor for biological growth in the fluidized bed system is much greater than either trickling filters or rotating biological contactors. This area is estimated to be about 3,290 m^2 m^{-3}, which is far greater than that of trickling filter (82.25 m^2 m^{-3}) or of the rotating disc (164.5 m^2 m^{-3}). Fluidized beds with attached microbial growth on carrier particles have been found to be extremely efficient for biodegradation of liquid waste. Both aerobic as well as anaerobic degradation can effectively be obtained. In capital cost including land, tanks, pumps, clarifiers and solid separators, works out at $1/4^{th}$ the cost of that for the conventional suspended growth process. The operating cost is slightly lower for the same capacity [32]. In anaerobic fluidized bed biofilm reactor, biomass concentrations exceeding 30,000 mg l^{-1} have been reported and organic removal efficiencies of 80 percent were achieved at loadings of 4 kg COD m^{-3} d^{-1} on dilute wastewaters. [10].

The advantages of FBBR can be summarized as follows. First, higher biomass concentration can be maintained in the process; hence the system has more metabolic activities, compared to that of suspended growth system. Second, the presence of longer food chains in biofilm with abundant microbial species and can provide stability, long retention time of microbes and much less surplus sludge. Third, the coexistence of aerobic and anoxic zones within the biomass film could provide an opportunity for simultaneous nitrification and denitrification to occur. Fourth, the biofilm processes are less sensitive to the toxic condition and other adverse operational conditions, thus making them easy to operate and maintain. Finally, problems caused by poor settling of sludge and sludge bulking would not be encountered during operation [41].

Materials and Methods

Fluidized Bed Biofilm Reactor (Denitrifying Unit)

The experimental setup used for this study is shown in Figure 1. Its main part was the 1.22 l reactor made of Plexiglas tube (0.036 m diameter, 1.20 m long), which was fixed to a steel stand. It was loaded with uniform stone dust as a biofilm carrier to a settled depth of 0.30 m. At the bottom, a small closed influent tank of 6 l capacity was provided to which pump was fitted which supply the influent to the reactor. At the top of the reactor an outlet pipe (tube) was joined which collects the effluent from the reactor and discharge again into influent tank. At the inlet of the reactor, a regulator cock was provided to regulate the flow as well as fluidization of media in the reactor. A fine screen was provided at both the ends (bottom and top end) of the reactor to avoid escape of stone dust media from the reactor and also to distribute the flow uniformly in the reactor. pH, temperature, alkalinity, COD and NO_3^- N concentrations were systematically recorded at the end of each run.

Biofilm Carrier Media

Various materials have been tried by researchers as biofilm carrier media. e.g. sand, glass beads, activated carbon, cement ball [18], plastic, etc. In this study stone dust was used as biofilm carrier media. The stone dust is prepared by crushing and sieving basalt rock (coarse aggregate used for concreting in building construction). The characteristics found after performing particle size distribution of stone dust were – Effective size (D_{10}) 0.126 mm, Coefficient of Uniformity Cu (D_{60}/D_{10}) 3.128, Coefficient of curvature or gradation Cc ($(D_{30})^2/(D_{60}*D_{10})$) 0.017, and Specific gravity 2.57.

Feed

A synthetic medium (synthetic wastewater) was prepared using deionized water in addition to the other chemicals. Potassium Nitrate (KNO_3) was added as the Nitrogen source at different varying concentrations of $NO3^-$-N in mg l^{-1}. PO_4^{3-} (as $Na_2HPO_4.12H_2O$ and KH_2PO_4) both as P source and medium buffering agent. Trace mineral constituents essential to the bacterial growth added per liter were : 0.85 mg $FeSO_4.7H_2O$, 0.25 mg $Na_2MoO_4.2H_2O$, 0.157 mg $MnSO_4.7H_2O$ and 33 mg $NaHCO_3$. Sodium Sulfite and Cobalt Chloride were added at concentrations of 20 and 0.55 mg l^{-1} respectively, to reduce the oxygen concentration to below 0.5 mg l^{-1} to ensure anoxic conditions in the reactors [42]. The Methanol was used as carbon source. The concentration of NO_3^- - N and methanol in the medium was varied at different stages of the study to maintain (Methanol/NO_3^--N) ratio.

Operation of a Fluidized Bed Biofilm Reactor

Figure 1 shows schematic diagram of the Fluidized Bed Biofilm Reactor which was operated daily for denitrification, nearly for a year. The reactor was inoculated with domestic wastewater and run by feeding synthetic medium for 15 days. After getting proper results, the reactor was run for 75 days to find out optimum Methanol/NO_3^-- N ratio. For this, reactor was run for 15 days each for each Methanol/NO_3^-- N ratio. Methanol/NO_3^-- N ratios taken were 2.25, 2.50, 2.75, 3.00 and 3.25. Average NO_3^-- N removal efficiency obtained was 67.95%, 78.96%, 84.55%, 89.88% and 86.63% for Methanol/NO_3^-- N ratios 2.25, 2.50, 2.75, 3.00 and 3.25 respectively. Hence, Methanol/NO_3^-- N ratio of 3.00 was finalized for the present study.

ISSN: 2277-9655
Impact Factor: 1.852

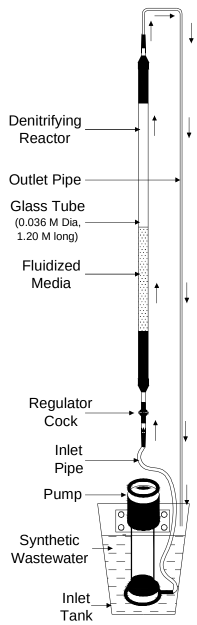

Figure 1. Experimental Setup of Fluidized Bed Biofilm Reactor.

For Experimental work, by maintaining constant Methanol/NO_3^-- N ratio as 3.00, the synthetic wastewater samples were prepared for varying concentration of NO_3^- - N. The NO_3^-- N concentrations taken were 10.00 mg l^{-1}, 20.00 mg l^{-1}, 30.00 mg l^{-1}, 40.00 mg l^{-1}, 50.00 mg l^{-1}, 60.00 mg l^{-1}, 70.00 mg l^{-1}, 80.00 mg l^{-1}, 90.00 mg l^{-1}, 100.00 mg l^{-1}. For these each concentration of NO_3^--N, **t**he reactor was run for 10 days and various characteristics of influent and effluent were measured at the end of each run (i.e. hydraulic retention time (HRT) of 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes). The characteristics measured were Temperature, pH, Alkalinity, COD and NO_3^--N.

Analytical Methods

Samples were collected from the FBBR at regular intervals. These samples were tested for pH, Alkalinity, COD, NO_3^--N. pH was measured by digital pH Meter. Alkalinity was determined by titration method according to APHA [1]. COD was measured by reflux method according to APHA [1]. NO_3^--N was measured by UV-Spectrophotometer (Schimadzu make, Model – UV 1650).

Results and Discussion

The experimental denitrification reactor was operated for 10 different concentrations and readings were recorded at HRT of 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes. The NO_3^--N removal was determined on the basis of the results of analysis of medium entering and leaving the reactor for Methanol/ NO_3^--N ratio of 3.00. Average NO_3^--N removal Efficiency was found to be 66.21%, 90.57%, 95.34%, 95.52%, 95.66% and 95.87% for HRT of 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes respectively. The results are shown graphically in Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7.

In this study, it was found that, NO_3^--N removal efficiency was in the increasing order for the increasing concentration of NO_3^--N up to 60 mg l^{-1}, after this trend was declining. Average NO_3^--N removal efficiency for hydraulic retention time of 30 minutes for NO_3^--N concentration of 10 mg l^{-1}, 20 mg l^{-1}, 30 mg l^{-1}, 40 mg l^{-1}, 50 mg l^{-1}, 60 mg l^{-1} was 95.11%, 95.93%, 94.94%, 95.44%, 95.80%, 96.93%. respectively while for concentrations of 70 mg l^{-1} , 80 mg l^{-1}, 90 mg l^{-1}, 100 mg l^{-1} ^{it} was 96.17%, 96.74%, 95.99%, 95.66% respectively. Figure 8 shows graphical representation of NO_3^--N removal % for different HRTs. From the Figure, it was observed that, as the concentration of NO_3^--N increases in the wastewater sample (i.e. from 10.00 mg l^{-1} to 60.00 mg l^{-1}) there was a gradual increase in NO_3^--N removal. But after this there was a slight decrease in NO_3^--N removal rate. This might be due to less concentration of available NO_3^--N present in the wastewater.

Figure 9 shows the graphical representation of NO_3^--N removal % for wastewater containing varying concentration of NO_3^--N at different HRTs.

From the readings and figures, it was observed that most of the NO_3^--N was removed at HRT of 10 minutes. There is a very little difference between NO_3^--N removal % at HRT of 10 and 30 minutes. Thus HRT of 10 minutes can be considered as optimum condition. The nitrogen loading rate varies from 0.48 kg N m^{-3} d^{-1} to 28.80 kg N m^{-3} d^{-1}. For these nitrogen loading rates, denitrification rates observed varies from 0.46 kg N m^{-3} d^{-1} to 17.91 kg N m^{-3} d^{-1}. But optimum (at optimum NO_3^--N removal efficiency), nitrogen loading rate and denitrification rate observed were 4.32kg N m^{-3} d^{-1} and 3.98 kg N m^{-3} d^{-1} respectively. In a study to investigate technical feasibility of biological nitrate removal in a packed bed reactor using microbial cellulose as biopolymer carrier, the researcher got denitrification rate of 4.70 kg NO_3^--N $m^{-3}d^{-1}$ for loading rate of 5.64 kg NO_3^--N $m^{-3}d^{-1}$ [44]. The biofilm reactors give high nitrate removal rate from 3.10 - 4.40 kg NO_3^--N $m^{-3}d^{-3}$ to 10.00 – 12.00 kg NO_3^--N $m^{-3}d^{-3}$ [26]. The author presented the results of his study in comparison with the other studies in which fluidized bed reactors were reportedly used with methanol as the carbon source (Table 1) [42]. Results found by Chen and Rabah were found to be in agreement with the results obtained in this research[42]. In this study, locally available and low cost material is used as biofilm carrier media. By considering this, and other advantages of FBBR, this will prove to be best option for biological denitrification.

Heterotrophic denitrification causes a release of hydroxyl ions and raises alkalinity. Each mg of nitrate-N reduced to N_2 causes an alkalinity increase of 3.57 mg $CaCO_3$ [45]. In this study, average g of Alkali produced per g of NO_3^--N removed was found to be 3.60 which is in agreement with the value found in literature. As alkalinity is produced, there is a rise in pH. pH of the influent was in the range of 6.16 – 8.01 and that of effluent observed was in the range of 6.56 – 8.01.

The denitrification intensity depends on carbon availability. The carbon to nitrogen ratio in the biological reactor influent should be high enough to denitrify all nitrates arisen in the nitrification process. The author [24], mentioned in his paper, many researchers' work revealed the g ΔCOD/g ΔN ratio as 3.5 – 4.5. In the present study, based on all the results, average g of COD consumed per g of NO_3^--N removed is found to be 3.96. This is in confirmation with the results obtained by many researchers.

Conclusion

The result of this study demonstrated conclusively that Fluidized Bed Biofilm Reactor with stone dust as a biofilm carrier media can be used with great advantages for denitrification.

This study provides the justification for the recommendation of FBBR for denitrification by many researchers.

The results of the investigation, demonstrated that the trend of the removal of NO_3^--N is quite high up to hydraulic retention time of 10 minutes. An average removal rate athis HRT observed was 92.15%. Also on the initial NO_3^--N concentration basis, it was observed that for initial concentrations upto 60 mg l^{-1}, the NO_3^--N removal rate was in increasing order but for higher concentrations, the trend was slightly declining. The efficiency can be improved by using special culture of denitrifying microorganisms in the FBBR.

The result of this study demonstrated conclusively that FBBR with stonedust as a biofilm carrier media can be used with great advantages for denitrification.

This study provides the justification for the recommendation of FBBR for denitrification by many researchers.

Acknowledgement

We are grateful to Principal, Government College of Engineering, Amravati and Incharges of Environmental Engineering Laboratory at Government College of Engineering, Amravati Prof. Mokadam A. M., Prof. Gulhane M. L. and Prof. Rai R. K. for giving permission to carry out laboratory work in their Institute and their guidance and timely help. We are also thankful to Prof. D. N. Shingade, Principal, Government Polytechnic, Amravati, for giving permission to carry out the present study.

Table 1: Comparison of some studies on denitrification using fluidized bed reactors

Form of Nitrogen	**Temperature** (^0C)	**Concentration of Nitrogen** (mg l^{-1})	**Denitrification Rate** (kg N m^{-3} d^{-1})	**References**
NO_3^-N	18-23	5 – 100	5.4 – 20.70	Jeris and Owens (1975).
NO_3^-N	-	6.6 – 30	0.69 – 3.28	Hermanwicz and Cheng (1990).
NO_3^-N	30	15 – 300	3.23 – 18.70	Hirata and Meutia (1996).
NO_3^-N	20	20	3.5	MacDonald (1990).
NO_3^-N	-	676 – 1500	11.8 – 17.7	Chen et al (1996).
NO_3^-N	23	1000	12	Rabah Fahid K. J., et al, (2004).
NO_3^-N	24.5 – 40.5	10 – 100	0.457 – 17.911 (Optimum 3.98)	This Study

Courtesy:[42]

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ISSN: 2277-9655
Impact Factor: 1.852

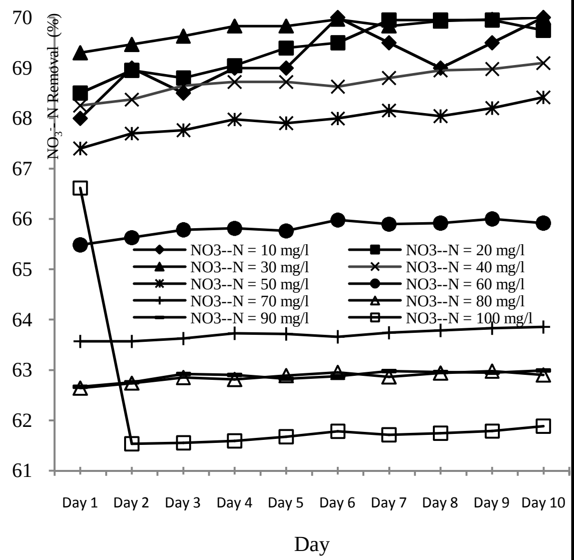

Fig. 2 : NO_3^--N Removal after 05 Minutes (HRT) for Different Concentrations of NO_3^--N

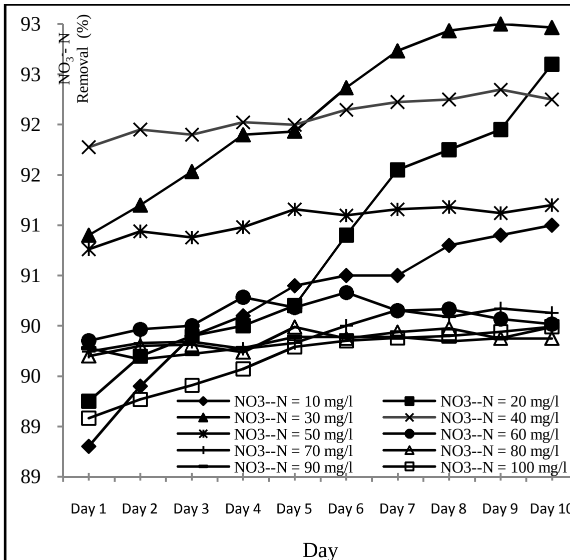

Fig. 3 : NO_3^--N Removal after 10 Minutes (HRT) for Different Concentrations of NO_3^--N

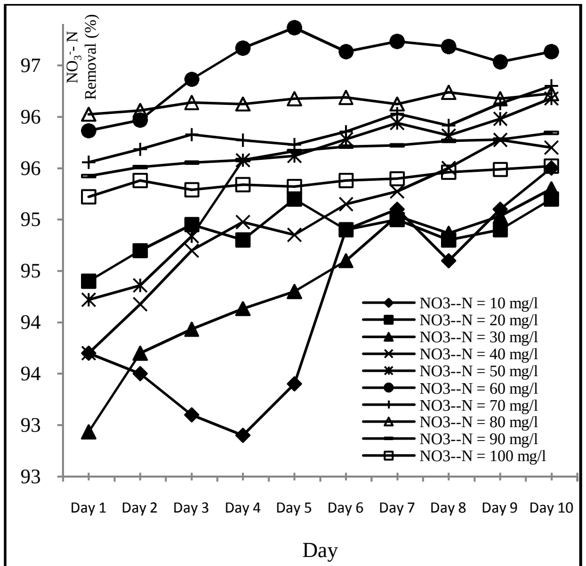

Fig. 4 : NO_3^--N Removal after 15 Minutes (HRT) for Different Concentrations of NO_3^--N

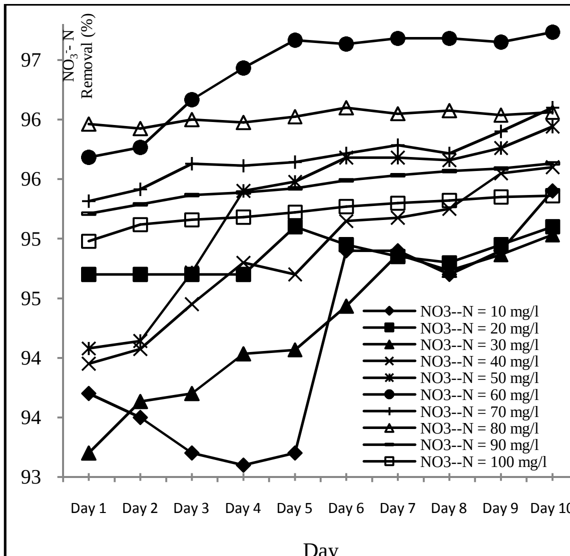

Fig. 5 : NO_3^--N Removal after 20 Minutes (HRT) for Different Concentrations of NO_3^--N

ISSN: 2277-9655
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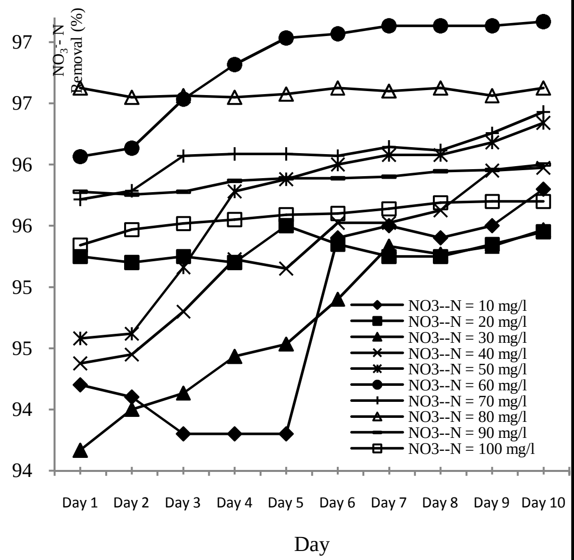

Fig. 6 : NO_3^--N Removal after 25 Minutes (HRT) for Different Concentrations of NO_3^--N

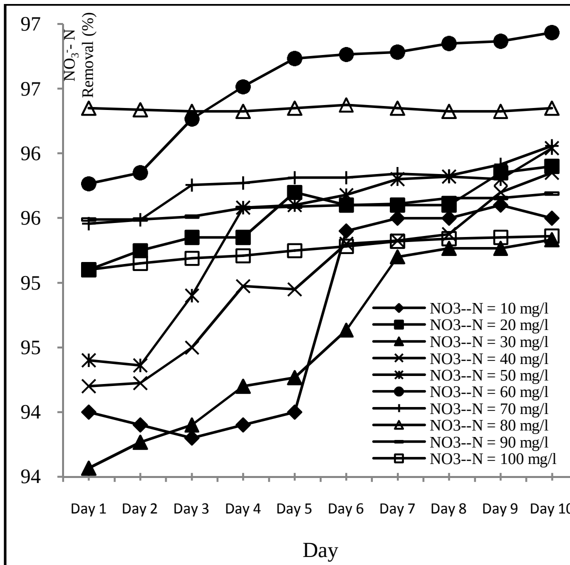

Fig. 7 : NO_3^--N Removal after 30 Minutes (HRT) for Different Concentrations of NO_3^--N

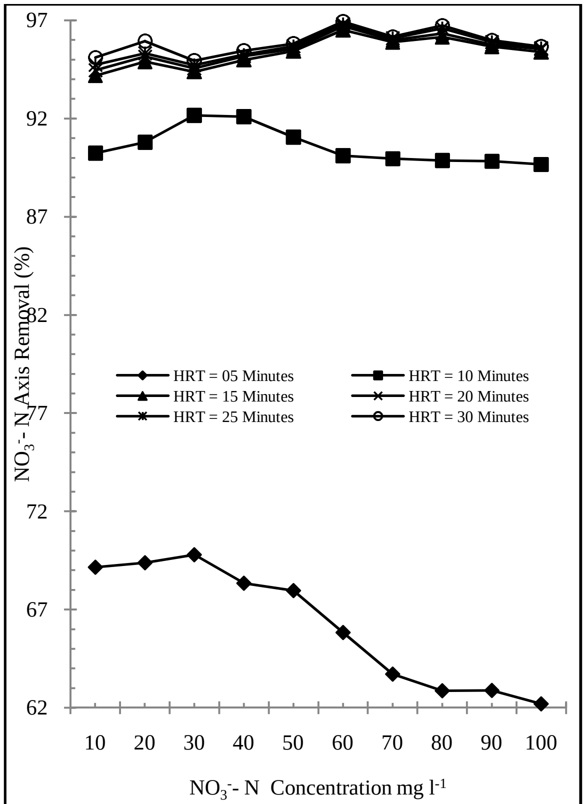

Fig. 8 : NO_3^-- N Removal (%) for Different HRTs for Different Concentrations of NO_3^-- N

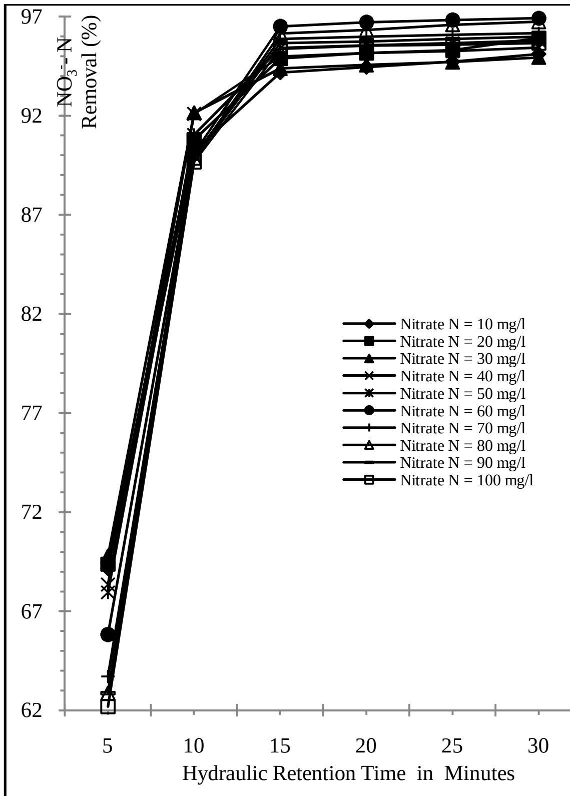

Fig. 9 : NO_3^--N Removal for Different Concentrations of NO_3^--N at Different HRTs

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