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INTENSIFICATION OF NITRIFICATION PROCESS IN AERATION TANKS

تعزيز عملية النترتة فى أحواض التهوية

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الملخص العربى

تعتبر زيادة تركيز الأمونيا فى مياه الصرف الصحى المعالجة أحد العوامل الهامة التى تعوق إعادة استخدامها فى أى مجال من مجالات التنمية. ونظراً لأن المعالجة البيولوجية الحالية بمصر لمياه الصرف الصحى تتميز بمقدرتها المحدودة على إزالة هذا النوع من التلوث. لذلك كان الهدف الأساسى من البحث هو رفع كفاءة المعالجة البيولوجية التقليدية بدراسة تأثير وضع وسط مسامى ذو كثافة خفيفة فى أحواض التهوية بحيث تكون لهذا الوسط المقدرة على استيعاب والاحتفاظ بأعداد مضاعفة من مستعمرات البكتريا وخاصة تلك التى يمكن ان تؤكسد الأمونيا. تم إجراء تجارب عملية باستخدام نموذج معملى لمحطة المعالجة تم وضعة بمحطة معالجة ه الصرف الصحى بمدينة المنصورة. أثناء إجراء التجارب تم وضع قطع من الإسفنج الصناعى داخل حوض التهوية فى حالة خلط تام مع مكونات الحوض.

وقد تناولت الدراسة العديد من المتغيرات، بعضها كان يتغير طبقا للظروف المياه الخام الواردة للمحطة وذلك مثل تركيز الملوثات، وبعضها كان يتم التحكم فيه وذلك مثل نسبة إشغال الإسفنج فى حوض التهوية وزمن المكث به، والبعض الآخر تم تثبيته خلال مدة الدراسة وذلك مثل تركيز البكتريا والأكسجين الذائب فى حوض التهوية. بمناقشة تأثير هذه المتغيرات أظهرت هذه التجارب تحسن ورفع كفاءة إزالة الأمونيا داخل المعالجة البيولوجية إلى حوالى ٩٦% بالإضافة الى تحسن ظروف التشغيل ورفع كفاءة لأكسدة المواد العضوية الكربونية الى حوالى ٩٩,٥ % .

ABSTRACT

Ammonia nitrogen is one of the important treated wastewater-quality parameters. Effluent of a wastewater treatment plant that has high concentration of ammonia nitrogen consumes a great quantity of the used disinfectants. When discharged to the aquatic environment it can lead to decrease of dissolved oxygen in water, develop an undesirable aquatic life, and cause pollution of ground water.

Nowadays several treatment methods are employed for removing ammonia nitrogen from wastewater, these include physical, chemical, and biological treatment.

In this study, a new method for adopting biological nitrification mixed culture system is employed for the removal of ammonia from wastewater. The study had been carried out by using an experimental activated sludge pilot plant system. The wastewater from El-Mansoura wastewater treatment plant was used as the source for the pilot study.

In this study, several variables were monitored. Some varied naturally such as concentration of the pollutants in raw wastewater, other variables

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were monitored by the researchers such as the volume of the sponge and the retention time in the aeration tank. Some other variables were held constant through the study such as the concentration of the MLVSS and DO in the aeration tank. The results of the study showed that a 95% of ammonia-nitrogen, and 99.5 % of BOD removal can be achieved.

Kev words Aeration Tanks, Biological Treatment, Mixed Culture Nitrification, Tertiary Treatment, Wastewater Reuse.

INTRODUCTION

The nitrogen present in fresh wastewater is primarily combined in pertinacious matter and urea. Decomposition by bacteria readily changes the form to ammonia. The age of wastewater is indicated by the relative amount of ammonia that is present. In an aerobic environment, bacteria can oxidize the ammonia nitrogen to nitrites and nitrates. The oxygen demand associated with the oxidation of ammonia to nitrate is called the nitrogenous biochemical oxygen demand- NBOD. The predominance of nitrate nitrogen in wastewater indicates that the waste has been stabilized with respect to oxygen demand [3,6,7].

Ammonia nitrogen is one of the important treated wastewater- quality parameters. Effluent of a wastewater treatment plant that has high concentration of ammonia nitrogen consumes a lot of the disinfectants. When discharged to the aquatic environment it can lead to the decrease of dissolved oxygen in water, develop an undesirable aquatic life, and cause pollution of ground water.

So, the law 4 of 1994 [21] for protecting the environment states that the concentration of ammonia nitrogen in the effluent of a wastewater treatment plant discharged to clean water should not exceed 3.0 mg/l [20,21]. The discharge of nitrified wastewater will generally satisfy receiving water requirements where reduction of nitrogen oxygen demand is required or when reduction of ammonia toxicity is necessary [6,7,16,17].

Wastewater Ammonia can be removed or converted to nitrate by using physical, chemical, or biological processes. The most efficient physical and chemical processes are air stripping, reverse osmosis, ion exchange, and break point chlorination. These methods have limited practical application because of their special requirements of influent wastewater quality and costs [6,7,8,13,14,16,17]. The biological nitrification processes in which ammonia nitrogen in wastewater is substantially converted to nitrate achieve a great importance and prestige because of their flexibility. reliability and economic value [3,4,5,8,18].

Carbonaceous organic oxidation and nitrification processes may occur in a single reactor, termed " single stage ", or in a separate stage. Any way, the volume of the biological reactor is typically bigger than that of the conventional treatment [11,15].

The objective of this study was to evaluate the effect of the mixed culture on the nitrification process. This study was conducted to examine a new approach. The idea of the new approach can be explained as follows. By keeping in the conventional biological reactors special light porous medium, that can host and incubate a huge population of microorganism as an attached culture, the average concentration of mixed cultures (suspended & attached) volatile suspended solids will be increased, resulting in longer sludge residence time (SRT). By this means the average sludge age of the system may be increased more than the original SRT consequently the ratio of the nitrified bacteria should be increased very much. Specifically, the study was designed to determine: -

1- The ability of the holding medium to host and incubate the bacterial culture.

2- The performance of the mixed culture system.

3- The relation between the removal efficiency of different contaminants against the medium volume and the retention time.

LITERATURE REVIEW

Biological nitrification is a chimoautotrophic process in which energy for bacterial growth is derived from the oxidation of reduced inorganic compound, primarily ammonia. In contrast to heterotrophs, nitrifies use carbon dioxide (inorganic carbon) rather than organic carbon for synthesis of new cells [3,4,8,15]. Nitrifies, as the autotrophic organisms must therefore spend more of this energy for synthesis than do heterotrophs, resulting in generally lower growth rates among the autotrophs. So, nitrifier cell yield per unit of substrate metabolized is much lower than the cell yield for heterotrophs.

Nitrification of ammonia is a two-step process involving two genera of nitrifies microorganisms, *Nitrosomonas* and *Nitrobacter*. In the first step ammonium is converted to nitrite; in the second step, nitrite is converted to nitrate. The conversion process is described as follows:

First step,

$$NH_4^+ + \frac{3}{2} O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O \qquad (1)$$

Second step,

$$NO_2^- + \frac{1}{2}O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \qquad (2)$$

Equations 1 and 2 are energy yielding reactions. Along with obtaining energy, some of the ammonium ion is assimilated into cell tissue. The biomass synthesis reaction can be represented as follows:

$$4CO_2 + HCO_3^- + NH_4^+ + H_2O \longrightarrow C_5H_7O_2N + 5O_2 \qquad (3)$$

The chemical formula $C_5H_7O_2N$ is used to represent the synthesized bacterial cells. The overall oxidation and synthesis reaction can be represented as follows: [3,8,15]

$$NH_4^+ + 1.83\,O_2 + 1.98\,HCO_3 \longrightarrow 0.021C_5H_7O_2N + 0.98NO_3^- + 1.041H_2O + 1.88H_2CO_3 \qquad (4)$$

Nitrifying organisms are present in almost all aerobic biological treatment processes, but usually their numbers are limited. The ability of various activated-sludge processes to nitrify has been correlated to the BOD_5/TKN (total Kjeldahl Nitrogen) ratio [7,15]. The fraction of nitrifying organisms increases as the BOD_5/TKN ratio decreases. In most conventional activated-sludge processes, where BOD_5/TKN ratio is equal or greater than 3, the fraction of nitrifying organisms would be considerably less than the 0.083 value.

From experience and laboratory studies [7,16] it has been found that the following factors have a significant effect on the nitrification process: ammonia and nitrate concentrations, BOD_5 / TKN ratio , sludge residence time (SRT), dissolved oxygen concentration (DO), temperatures , and the pH.

For the nitrification process, it is recommended that the dissolved oxygen (DO) level should not be less than 2.0 mg\l to avoid the depressing effect. It is also recommendable to maintain a pH in the range of 7.2 to 9.0 .

The sludge residence time (SRT) is defined as the average time that microorganisms spend in the treatment process. In most biological treatment processes, cell wastage is accomplished by drawing off from the sludge recycle line.

The impact of SRT on effluent organic matter was further detailed by Saunders and Dick [10]. They proved that effluent organic, comprising slime and dissolved fractions, decreased with increasing SRT. Alam and Angelbec [1] indicated that at high values of (SRT), reactor stability was good for both major and minor influent disturbances. Chiang [2] indicated that systems operated at high values of SRT were less susceptible to shock loading when considering effluent substrate concentration. As influent organic concentration was increased, the value of SRT had to be increased if the predetermined effluent substrate concentration was to be met continuously.

The work published on nitrification, by Downin [4] showed that for all the systems tested nitrification could be completed with minimum SRT of 3 day. However, Jenkins and Garrison [9] found a higher degree of nitrification at 10 day SRT than 5 day SRT. With SRT of less than 3 days no nitrification occurs.

In practice, there are two approaches for the intensification of the nitrification process in the biological suspended culture reactors. These approaches are:

a) increasing the SRT thorough single carbonaceous organic oxidation and nitrification process, or

b) reducing BOD_5 / TKN ratio to be in the range of 1-3 in order to increase the fraction of nitrifying organisms through separate stage , where carbonaceous organic oxidation and nitrification processes occur in different suspended culture reactors .

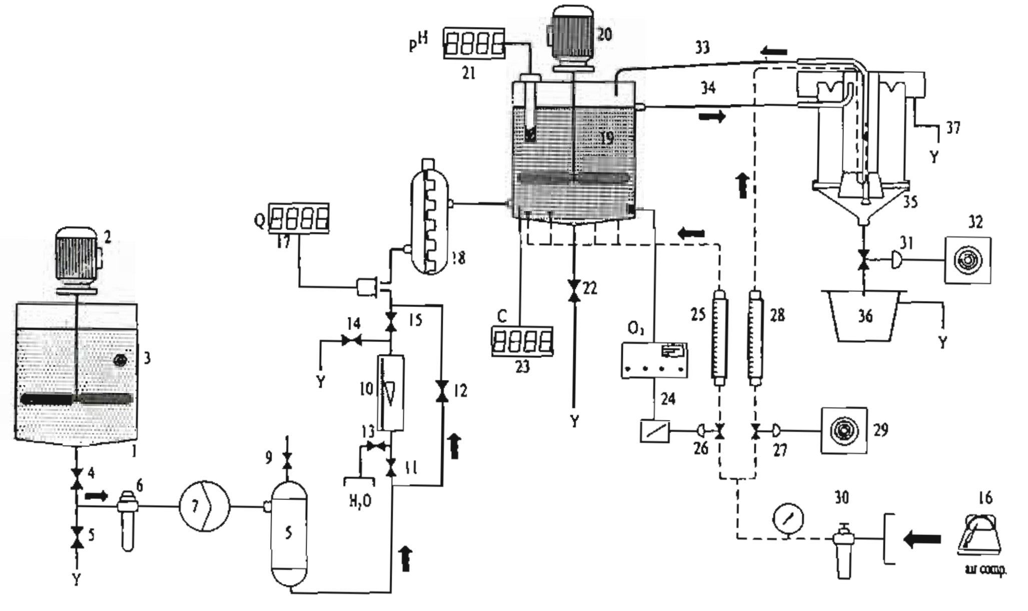
The above two approaches lead to increasing the volume of the biological reactors and sedimentation tanks.

MATERIAL AND METHOD

The field study was carried out in Mansoura wastewater treatment plant using an activated sludge sewage treatment experimental pilot plant. The raw wastewater was supplied from the effluent of aerated grit removal chamber. The raw water of the pilot plant was treated by screening, grit removal, and oil and grease removal.

The pilot plant illustrated in figure (1) consists of the following major components: -

- 150 liter feed tank with mechanical stirrer,
- basket filter,
- feed pump with flow rate from zero up to 50 l/h ,
- damper to reduce the effect of wastewater pulses,
- flow-meters,
- heater,
- aeration tank with probes for temperature, pH, and dissolved oxygen monitoring,
- sedimentation tank,
- air compressor for supplying the air diffusers in the aeration tank and air lift recirculation system.



Pilot plant components

1-Feed tank with capacity 150 l
2-Fixed speed stirrer-100 RPM,90W
3-Low level indicator
4-Feed cut-off valve
5-Feed discharge valve
6-Basket feed filter
7-Feed metering pump-capacity 0-50 l/h
8-1.5L damper
9-Breather valve
10-Feed flowmeter 60 l/h
11-On-Off Flowmeter valve
12-By-pass valve
13-Flowmeter washing discharge valve
14-Flowmeter washing drainage
15-On-Off Flowmeter valve
16-Air compressor
17-Digital totalizer
18-2000W feed heater
19-Oxidation reaction tank
capacity approx. 35 L
20-200W variable speed stirrer
21-Digital pH measuring device
22-Reactor discharge valve
23-Digital temperature
indicator-regulator
24-Digital dissolved oxygen
indicator-regulator
25-Aeration air flowmeter 500 l/h
26-Air valve
27-Air-lift valve
28-Air-lift flowmeter 500 l/h
29-Air-lift digital timer
30-Coming air pressure reducer
31-Deactivated sludge discharge valve
32-Digital timer for deactivated
sludge discharge
33-Sludge recovery with air-lift
34-Reactor discharge
35-Settling tank
36-Deactivated sludge collection tank
37-Clarified water discharge

Fig. (1) Flow Diagram of the Experimental Pilot Plant

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In this pilot plant the flow rate, the feeding temperature of wastewater, the concentration of dissolved oxygen, and the flow rate of returned activated sludge can be controlled automatically or manually.

A very porous medium from artificial sponge was used to host the microorganisms in the aeration tank. The sponge was cut to cubes of 1.0 cm side length. The density of sponge was 0.35 gm/ cm^3. The change in the volume of sponge cubes was monitored through the experimental time.

In this study, several variables were monitored. Some varied naturally such as concentration of the contaminants in raw wastewater, other variables were controlled by the researchers such as volume of the sponge and the retention time in the aeration tank. Some other variables were held constant through the study such as concentration of the biological solids and DO in the aeration tank.

Suspended solids (SS) and volatile suspended solid (VSS) were monitored in order to effectively assess the operational condition of the pilot plant. The VSS concentration in the aeration basin mixed liquor (i.e., MLVSS) is particularly important since MLVSS is used for approximation of biological solids concentration in the aeration tank. Suspended solids levels (SS) are measured in the final settling tank effluent.

Chemical and physical examinations of the raw wastewater, final effluent, mixed liquor, and wasted sludge were done according to the standard methods for the examination of water and wastewater (12).

The schedule of experimental work was designed to contain a start -up phase and five groups of runs. Each group was carried out at a certain percentage of sponge in aeration tank (8%, 6%, 4%, 2%, 0.0%). Each run of any group was carried out with a certain retention time of wastewater in aeration tank (3.3, 4.5, 6.7, 8 hr).

Records of each steady state for each run were registered. The steady state means that a condition of constant MLVSS had been achieved. During the experimental work the concentration of DO in aeration tank and the temperature of raw wastewater were automatically adjusted to a values of 2.5 mg/l, and 20°C.

RESULTS

The experimental investigation was divided into a growth phase and five different operational phases. In the growth phase the concentration of the mixed liquor volatile suspended solids (MLVSS) had reached its designed value- 3000 mg/l. Each phase of the others operates at a certain volume ratio of synthetic sponge, and at different six steady state conditions with regards to retention time in the aeration tank.

Microorganisms Growth Phase

The largest volume percent of sponge that can be accommodated in the aeration tank was 8%. Where larger volume was employed, part of the sponge was not mixed properly with liquid. The sponge had been inoculated with the microorganisms and reached to a constant weight of its dry mass after a period of 86 days. The removal efficiency of ammonia-nitrogen reached to a constant value of about 96% at an aeration time of about 6.0 hours. During this phase, the influent, effluent concentration of NH_3-N and the removal efficiency have been registered, figures (2&3).

First Phase

The reactor was operated at six steady states with regard to aeration tank retention time (3.3, 4, 5, 6, 7, and 8 hours). During this phase, the sponge volume was 2640 cm^3 which represents 8% of aeration tank volume. The average variations in influent, effluent, and removal efficiency of NH_3-N, BOD_5, COD, and SS at the steady state of the different aeration tank retention times are shown in figure 4. The daily wasted sludge that to keep the concentration of MLVSS constant at the value of 3000 mg/l was 1.2 liters in average.

At the end of this phase and after a working period of 100 days a 20% average reduction in the volume of sponge due to abrasion and biological actions was noted.

Second Phase

Taking a 20% volume reduction factor into consideration, the volume of sponge was reduced to 6% of aeration tank volume. The reactor was operated at different six steady states with regard to retention time (3.3, 4, 5, 6, 7, and 8 hours). The daily wasted sludge required to keep the concentration of MLVSS constant at the value of 3000 mg/l was 1.3 liters in average.

Third Phase

More sponge volume reduction was applied in this phase. The volume ratio used was 0.04. Typical operation conditions were as in the previous two phases. The average removal efficiency of NH_3-N, BOD, COD, and SS are shown in figure 5. The daily wasted sludge required to keep the concentration of MLVSS constant at the value of 3000 mg/l was 1.5 liters in average.

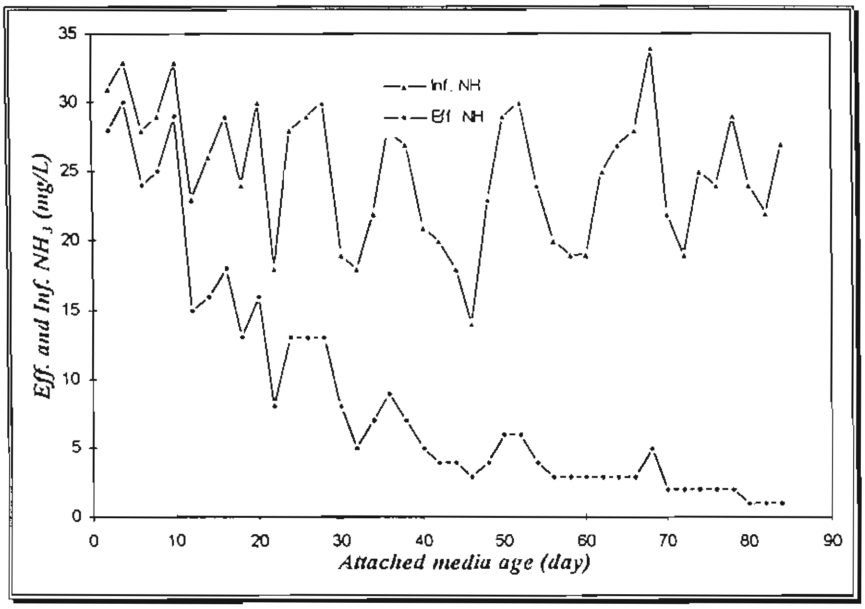

Fig. (2) Inf. and eff. concentration of NH_3-N during the microorganisms growth phase

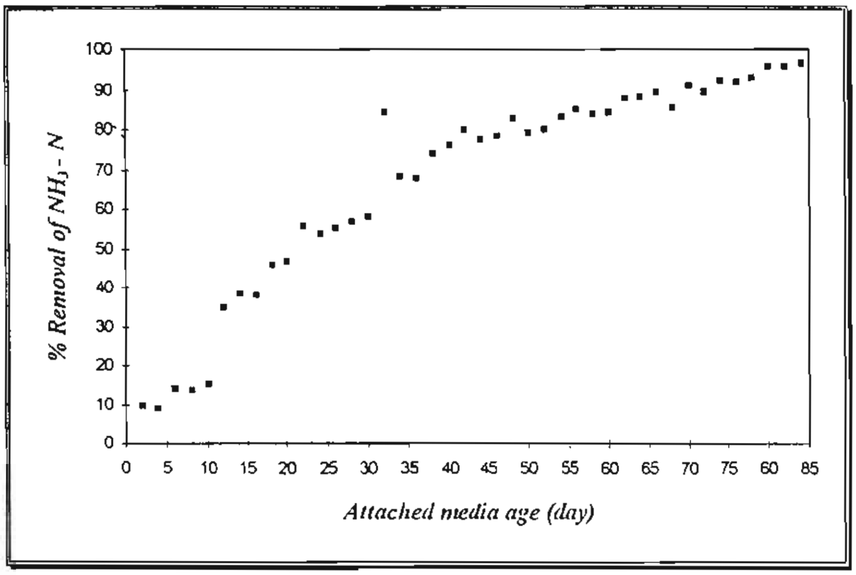

Fig. (3) Removal efficiency of NH_3-N during the microorganisms growth phase

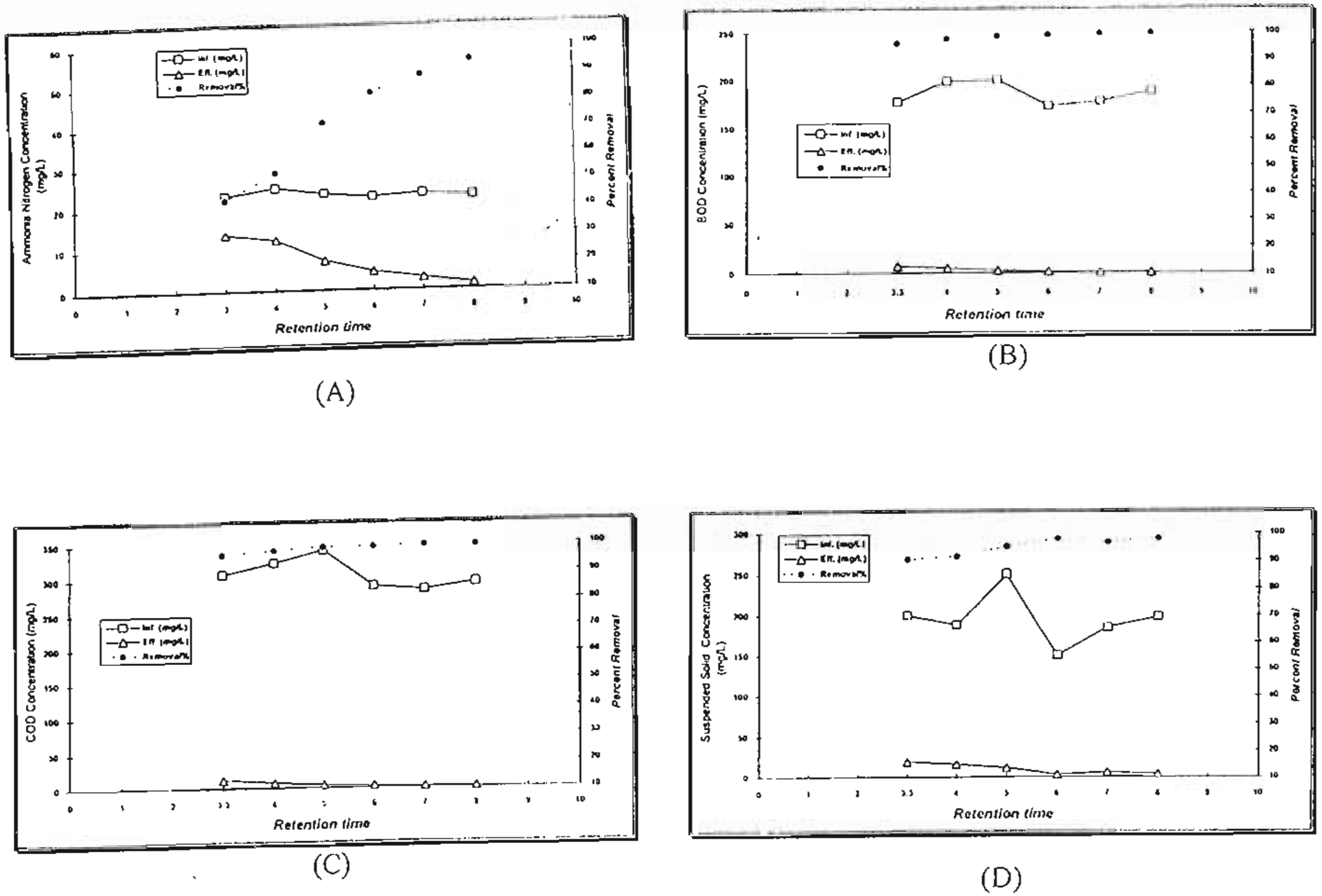

Fig. (4) FIRST PHASE : Influent, Effluent and % Removal Efficiency of
(A) NH_3-N, (B) BOD_5,
(C) COD, (D) SS

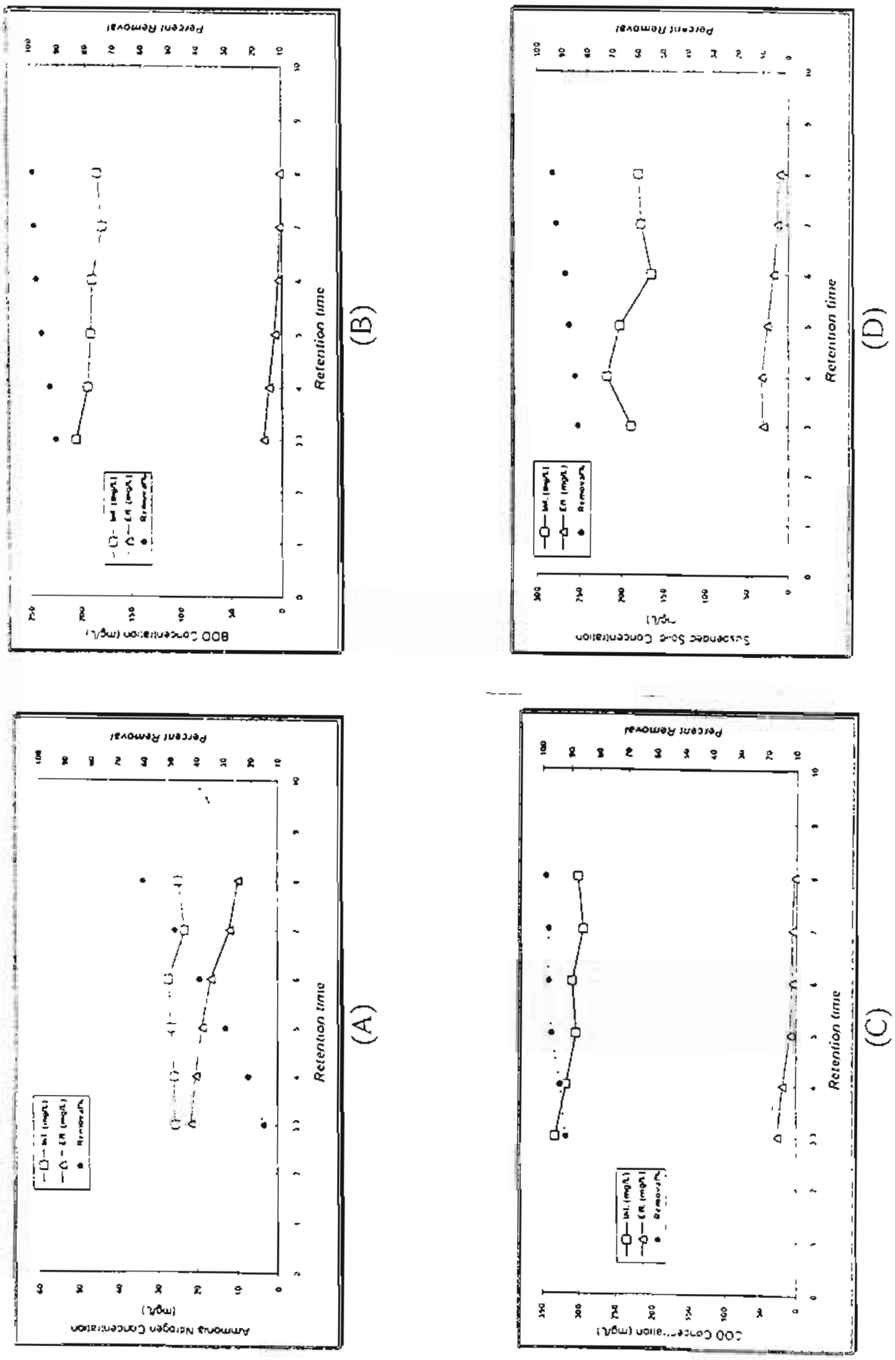

Fig (5) THIRD PHASE: Influent, Effluent and % Removal Efficiency of
(A) NH_3-N, (B) BOD_5,
(C) COD, (D) SS

Fourth Phase

The system was operated with a ratio of 2 % of the sponge. The daily wasted sludge required to keep the concentration of MLVSS constant at the value of 3000 mg/l was 1.7 liters in average.

Fifth Phase

The system was operated without using the sponge. Hence the performance of the biological treatment system with and without the sponge can be compared. The daily wasted sludge required to keep the concentration of MLVSS constant at the value of 3000 mg/l was 2.25 liters in average. The average removal efficiency of NH_3-N, BOD_5, COD, and SS are shown in figure 6.

In order to estimate the sludge age and the nitrifying fraction of bacteria in the sponge and the aeration tank a microbiological examination had been carried out when the ratio of the sponge was 2 %. The VSS on the sponge was 41.0 mg/cm^3; and the nitrifics fraction was 0.064 for BOD_5/TKN = 5.0 (BOD_5 = 200 mg/l TKN = 40 mg/l).

DISCUSSION

From the literature, the SRT is the most important factor of all the factors required for successful nitrification process. So, the average SRT of each phase has been calculated by dividing the total mass of volatile suspended solids (VSS) in the aeration tank by the mass of sludge wasted from the system each day, table (1). The average concentration of solids in the wasted sludge was 6500 mg/l.

Table (1): The effect of the synthetic medium on the SRT

Ratio Of medium	*Volume of medium, cm^3*	*Weight of VSS in medium, gm*	*Weight of VSS in mixed liquid, gm*	*Total weight of VSS in system, gm*	*Volume of wastage sludge, Lit*	*SRT, day*
0.00	-	0.00	99.00	99	2.25	6 77
0.02	660	27.06	97.02	124 08	1.7	11.23
0.04	1320	54 12	95.04	149.16	1.5	17.87
0 06	1980	81.18	93 06	174.24	1.3	20.62
0 08	2640	108.24	91.08	199.32	1.2	25.55

From figures 4 to 6 it's clear that the removal efficiency of NH_3-N depends strongly on the time while that of BOD_5, COD, and SS slightly depend on the retention time in the aeration tank.

The removal efficiency of NH_3-N in case of no sponge increased from 10.7% at retention time of 3.30 hr. to 32.2% at the retention time of 8 0 hr

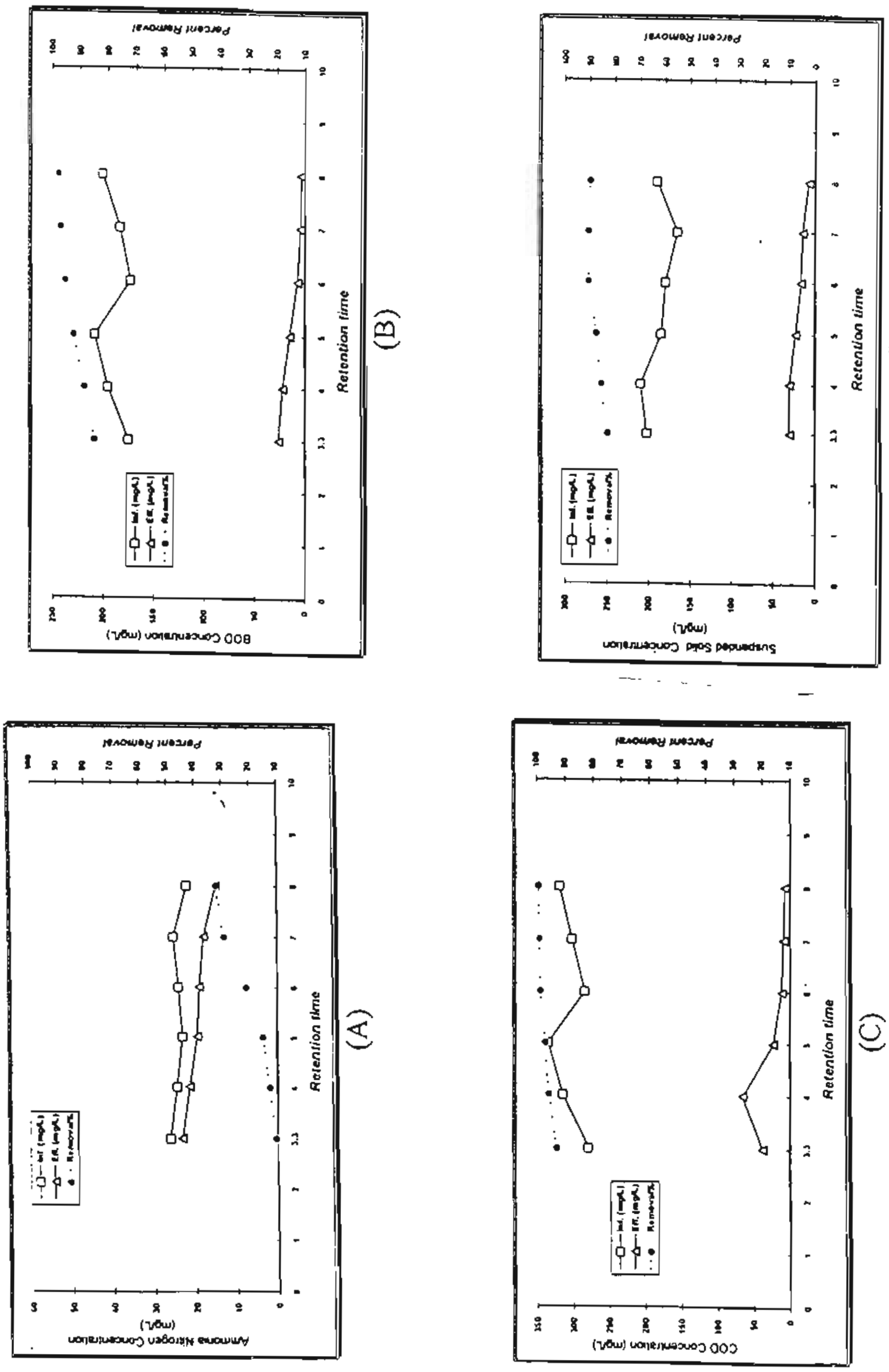

Fig. (6) FIFTH PHASE . Influent, Effluent and % Removal Efficiency of
(A) NH_3-N, (B) BOD_5,
(C) COD, (D) SS.

while in case of 8% the removal efficiency increased from 43.1% to 94.0%. At the same retention times the removal efficiency of BOD_5 and COD increased from 85% to 98% at zero sponge, and from 96% to 99.5% when the sponge was used with a percent of 8%. This means that the present of sponge as attached bacterial culture in the aeration tank helped the system to be stable against the change in the flow rate values.

The high removal efficiency of NH3-N when using sponge, can be explained by the fact that through the growth phase the of sponge had been submerged by a very huge bacterial mass of different kinds. This high mass of microorganisms in the sponge led to the increase of average MLVSS in the aeration tank from 3000 mg/l at zero sponge to 6040 mg/l at a percent of sponge 8%, table (1). That also led to increase the SRT from 6.77 days to 25.55 days.

The sponge cubes incubated in the aeration tank the microorganisms preventing them from the withdrawal from the aeration to sedimentation tank. Thus resulting in the following advantages:

a) an increase in the MLVSS in the aeration tank which improves the oxidation of the carbonaceous BOD_5,

b) a decrease in the solid loading on the final sedimentation tanks,

c) a decrease in the discharge of recirculated sludge,

d) an improvement of the nitrification process at lower retention time in the aeration tank,

e) a decrease in the F/M ratio producing a lower sludge volume with good settling characteristics, and

f) an increase in the stability of the system against the shock loads.

The increase of average MLVSS leads to the decrease of food to microorganism (F/M) ratio resulting in bacterial growth to occur in endogenous phase. On the other hand, the high value of SRT allows different kinds of organisms that are able to assimilate different types of organic matter, to exist. Consequently, in the new system the removal efficiency of not only NH_3-N but also the BOD_5, COD, and SS had been enhanced.

Finally the increase in SRT and the decrease in F/M ratios resulted in lower production of daily wasted sludge.

CONCLUSION

The biological nitrification processes, in which ammonia nitrogen in wastewater is substantially converted to nitrate, achieve great importance and prestige because of their flexibility, reliability and economic value. The SRT is one of the key factors of the nitrification process.

In this study, a system of mixed-attached and suspended cultures composed of synthetic sponge cubes with a volume of 1.0 cm^3 for attached culture suspended in aerated mixed liquor suspended culture, has been examined. The main results of this study can be summarized in the following points:

1- The maximum volume percent of sponge that can be accommodated in the aeration tank was 8 %.
2- The maximum mass percent of attached culture that can be achieved in this study was 54% of the total mass of MLVSS.
3- The removal efficiency of the different contaminants has increased with the increase of the attached culture in the system.
4- Using the mixed culture has improved the removal efficiency of NH_3-N, BOD_5, COD, and SS by 83.8 %, 14.5 %, 13.24% & 15 % respectively.
5- In mixed culture systems there was no need to increase the volume of the aeration or sedimentation tank to achieve high values of SRT.
6- In practice, to achieve high performance, the volume of sponge in the aeration tank has to be monitored and periodical supplement of new sponge pieces has to be added to keep the sponge volume percent at its original required value.
7- Using the mixed culture systems leads to achieving the following advantages:

    a) an increase in the MLVSS in the aeration tank which improves the oxidation of the carbonaceous BOD_5 & COD,

    b) a decrease in the solid loading on the final sedimentation tanks,

    c) a decrease in the discharge of recirculated sludge ,

    d) an improvement in the nitrification process at lower retention time in the aeration tank,

    e) a decrease in the F/M ratio producing a lower sludge volume with good settling characteristics, and

    f) an increase in the stability of the system against the shock loads.

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٢٠. اللائحة التنفيذية للقانون رقم ٤٨ لسنة ١٩٨٩ فى شأن حماية المجارى المائية.

٢١. اللائحة التنفيذية للقانون رقم ٤ لسنة ١٩٩٤ فى شأن حماية المجارى المائية.