

Metabolic Responses of Activated Sludge to Pentachlorophenol in a SBR System

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SBR 처리 장치에서 활성 슬러지의 대사에 미치는 Pentachlorophenol의 독성 효과

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요 약

이 연구의 목적은 Sequencing Batch Reactor (SBR) 처리 장치를 사용하여 pentachlorophenol (PCP)를 함유한 폐수를 처리할 때 활성 슬러지의 대사 작용에 미치는 PCP의 독성 효과를 시험 분석하는 것이다. 이 연구에서 SBR 처리 장치는 두가지 운전 주기 1, 2 (8 시간과 12 시간)와 각각의 운전 주기에 대한 두가지 운전 조건 (I, II)으로 운전되었다. 운전 조건 I은 유입 폐수를 일시에 (5분 안에) 반응조에 부가하고 2시간 동안 폭기없이 교반만 하는 것이고, 운전 조건 II는 운전 조건 I과 똑같은 조건에서 유입 폐수를 2시간 동안 서서히 반응조에 부가하는 것이다. 각 반응조의 슬러지 일령은 15일이었다. 합성 폐수가 유입 폐수로서 사용되었고, 그것의 COD는 대략 380 mg/L이었다. 각 반응조에 대하여 기본 운전이 끝난 후 0.1, 1.0, 5.0 mg/L의 PCP가 들어 있는 유입 폐수를 사용하여 8 시간과 12 시간 운전 주기의 정상 상태 운전이 실시되었다.

사용된 유입 폐수의 PCP 농도에서 COD 제거는 저해를 받지 않았다. 5.0 mg/L의 유입 폐수 PCP 농도와 운전 주기 2의 처리 장치에서, MLVSS 농도는 감소하였고 미생물의 선택성이 증가하므로 생태 반응의 영역이 줄어들었다. 또한 SOUR이 증가하므로 활성 슬러지가 PCP에 의하여 저해를 받았음을 보여주었고, 활성 슬러지의 침전이 좋지 않았다.

운전 주기 2의 처리 장치에서 질산화는 사용된 유입 폐수의 PCP 농도에서 어느 정도까지 일어났으나 운전 주기 1의 처리 장치에서는 질산화가 거의 일어나지 않았다. 그래서 질산화가 일어나는 시기는 PCP의 저해 작용으로 인하여 COD의 제거가 늦어지는 만큼 지체될 것이다. 생물학적인 인 제거는 운전 주기 1, 운전 조건 I 그리고 저농도의 PCP에서 운전되는 처리 장치에서 일어났으나 그 과정은 불안정하였고 쉽게 정지되었다. 그러나 운전 주기 2, 운전 조건 I과 II에서 운전되는 처리 장치에서 생물학적인 인 제거는 유입 폐수의 PCP 농도가 1.0 mg/L로 증가할 때까지 안정하게 일어났다. 유입 폐수의 PCP 농도가 5.0 mg/L로 증가했을 때 생물학적인 인 제거 능력은 정지되었고 쉽게 회복되지 않았다.

1. INTRODUCTION

Pentachlorophenol (PCP) is a priority pollutant which, along with its sodium salt, has been rated as the second heaviest used pesticide in the United States. It has been used as a pre-and post-plant herbicide, as a wood preservative, as a biocide in cellulosic products, starches, adhesives, proteins, leather, oils, paints, rug shampoos and textiles, and for the control of wood-boring insects and termites (Kaufman 1978).

The presence of PCP in the environment is a serious public health problem, because of its carcinogen to man. PCP reveals a significant toxicity to a wide variety of living organisms. For instance, fish are extremely sensitive to PCP poisoning so many species are killed in the presence of 0.6 mg/L PCP or less (Kobayashi 1977).

PCP can uncouple oxidative phosphorylation and thus increase the ratio of respiration to synthesis. The uncoupling of oxidative phosphorylation has important ramifications to an activated sludge process, because oxidative phosphorylation is necessary for cell growth in an aerobic system. The presence of varying concentrations of PCP in wastewaters has a pronounced effect on species predomination in biological treatment processes (Heidman et al. 1967). Conventional activated sludge treatment of wastewaters containing PCP has been shown to be inefficient and unreliable (Jank and Fowlie 1980). There is a need for developing advanced reactor designs and operating strategies for improving treatment of PCP containing wastewaters.

The use of Sequencing Batch Reactor (SBR) system holds considerable promise for the treating of PCP containing wastewaters. The SBR is a fill and draw activated sludge system. Each reactor in the SBR system is filled during a discrete period of time and then operated in a batch treatment mode. Its effectiveness for PCP removal needs to be studied. If found suitable for this purpose, SBR system offers several advantages over continuous flow systems. These advantages include equalization, ideal settling, simple operation, compact layout, and cost savings (both capital and O & M).

It should always be remembered that data obtained from a SBR system should not be used to predict the performance of a continuous flow unit. Although a SBR may be at steady-state from operating cycle to operating cycle, a pronounced transient state exists within each cycle. Selection pressures on the mixed microbial culture are quite high for such systems. At the beginning of each cycle the amount of external substrate available to microorganisms is large. However, this material is used up fairly quickly so that by the end of the cycle the microorganisms will have been in a starvation state for a significant length of time. The pH will normally be somewhat low during the earlier part of the cycle when no aeration is provided. When aeration begins it is not uncommon to observe a 1.5 to 2.0 unit increase in pH. The types of microorganisms which can survive in environments undergoing such oscillations are limited and generally are quite different from those which are observed in continuous flow activated sludge facilities.

The primary objective of this study was to examine the toxic effects of PCP on activated sludge and to analyze its metabolic responses while treating wastewater containing pentachlorophenol (PCP) in a SBR system operating under different control strategies.

2. MATERIALS AND METHODS

2.1. SBR System

A flow schematic of the 12-hour SBR system used in this study is shown in Fig. 1. This study was conducted in two phases. Two 3.0 liter bench-scale sequencing batch reactors were used during each phase of the work. During phase 1 each reactor was operated with three 8-hour cycles each day. The 8-hour cycle included a 2-hour mixed but not aerated period (it was assumed that there were no dissolved oxygen and oxidized nitrogen (NO_x-N) in the reactors), a 4-hour aerated period, and 2 hours for settling, draw and idle. Each reactor was established with a different operating strategy. Strategy I (reactor 1) involved rapid addition (5 minutes to complete) of substrate to the reactor with continuous mixing but no aeration for 2 hours. Strategy II (reactor 2) involved adding the feed continuously during the first 2 hours of the cycle when the system was mixed but not aerated.

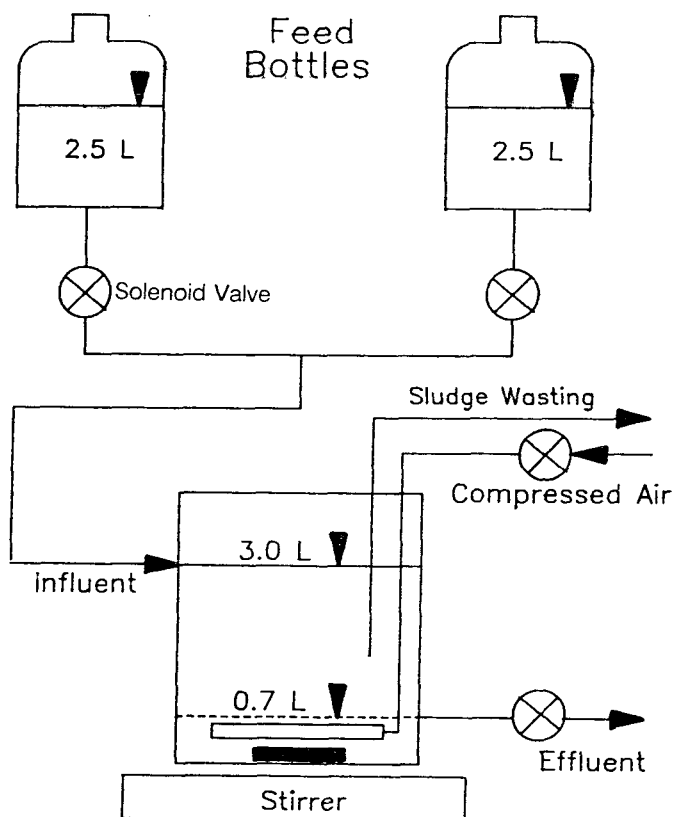


Fig. 1. Schematic representation of bench-scale 12-hour cycle SBR system used in this study.

Phase 2 of the study was much like phase 1 except that during this phase each reactor was operated with two 12-hour cycles each day. The 12-hour cycle included a 2-hour mixed but not aerated period, an 8-hour aerated period and 2 hours for settling, draw and idle.

The reactors were made of plexiglass with dimensions of 15.9×15.9×21.6 cm. The feed tubes (1.3 cm dia.) for the reactors entered through one of the vertical sides and the feed for reactor 1 was passed by gravity through a solenoid valve. The feed for reactor 2 was continuously added for a period of 2 hours by using a variable speed pump set at the rate of 21 mL/min. Laboratory compressed air was used for aeration through a wall-type aquarium diffuser (10.2 cm length) via a filter. Mixing was accomplished by using a magnetic mixer driving a teflon coated stir bar (3.8 cm length) inside the reactor.

Glass feed bottles of 4.5 liters were provided for each reactor to supply feed for each cycle. Each bottle was filled with 2.5 liters of feed. Feed was removed from these bottles during the fill period through a port at the bottom of the bottle. The bottles were covered by plastic beakers to prevent foreign material from entering.

During both phases 1 and 2 each reactor was operated at a sludge age of 15 days by removing 200 mL of mixed liquor suspended solids (MLSS) each day, and wasting was accomplished during each cycle just before the end of the aerated period. During phase 1 sludge wastage was accomplished in increments of about 67 mL per cycle while 100 mL per cycle were wasted during phase 2.

All the operation were controlled through solenoid valves and a ChronTrol Microprocessor based electronic power switching timer/controller. Sufficient flexibility was incorporated into the experimental system to allow any combination of aeration alone, mixing without aeration and either constant or instantaneous addition of feed during the fill period.

2.2. Feed Preparation

The substrate used in this study consisted of nutrient broth, glucose, yeast extract and additional nutrients and minerals, including inorganic phosphorus and nitrogen. The composition of the synthetic wastewater is given in Table 1.

Table 1. Synthetic wastewater composition

Material	Concentration, mg/L
Nutrient broth	300
Glucose	140
Yeast extract	32
MgSO ₄ ·7H ₂ O	20 (2.0 mg/L as Mg ²⁺)
MnSO ₄ ·H ₂ O	13 (4.2 mg/L as Mn ²⁺)
(NH ₄) ₂ SO ₄	118 (25 mg/L as NH-N)
KH ₂ PO ₄	44 (10 mg/L as PO-P)
KOH	23

The contents were mixed thoroughly in distilled water for about 20 to 30 minutes using a mixer. The feed was prepared as a stock solution and then diluted each day to 2.5 liters. BOD bottles were used to store the stock solution. It was refrigerated and kept in the dark for a maximum period of eight days. The feed composition remained unchanged during the entire course of study. The COD of the feed solution was about 380 mg/L.

Technical grade pentachlorophenol was obtained from Aldrich Chemical Company and was specified to be 86% pure. To prepare a stock solution, 1.16 g of PCP was dissolved in 300 mL of 1.0 N sodium hydroxide (reagent grade).

Concentrated sulfuric acid was then added dropwise to this solution until the pH stabilized at 9.0. The acid was added slowly to allow precipitated PCP to completely redissolve. Deionized water was then used to bring the final concentration to 1 liter using a 1000 mL volumetric flask. The strength of this stock solution was 1.00 mg/mL of PCP in the form of NaPCP. The stock solution was stored under refrigeration in the dark. Stock solution was made fresh every three months.

For the purpose of GC analysis a standard PCP solution was prepared from 99+ % pure reagent grade PCP, by the procedure previously outlined. The concentration of the standard solution was 250 µg/L.

2.3. System Operation

At the beginning of phase 1, a sample of soil contaminated with PCP from a wood preserving plant in Alabama was obtained. An inoculum was developed from the contaminated soil and the system was started using this inoculum.

One and a half months after starting the system, the steady state response of each system was established for feed PCP concentrations of 0.1 mg/L, 1.0 mg/L, and 5.0 mg/L for both the 8-hr and 12-hr operating cycles. After a change in the feed PCP concentration, the system was operated for two months to establish biological equilibrium conditions. The system for each phase was operated during 1 year.

Measurements were made for effluent for the following parameters: soluble COD, total suspended solids, ammonia ($\text{NH}_4^+ - \text{N}$), nitrate ($\text{NO}_3^- - \text{N}$), and orthophosphorus ($\text{PO}_4^{3-} - \text{P}$) for five consecutive days. Mixed liquor volatile suspended solids and oxygen uptake rate were measured on the mixed liquor.

The samples for the measurements were obtained from the effluent port during the period draw and were immediately filtered using glass fiber filters (0.45 µm). The analyses, except for PCP, were made according to the techniques described in Standard Methods (1985). For PCP, a gas chromatographic technique (Moos 1980) was used and samples were frozen until analysis was completed.

3. RESULTS AND DISCUSSION

Experimental data obtained during phase 1 and 2 of the work are shown in Figs. 2~8. The values shown are the averages for each parameter for the five-day steady state testing period for each operating strategy and each feed PCP concentration.

3.1. Removal of Soluble COD

The relationships between effluent soluble COD and PCP for each phase of this work are shown in Fig. 2. The COD removal efficiency generally exceeded 93% during phase 2 of this work, with the exception of 5.0 mg/L PCP concentration. Even at 5.0 mg/L PCP concentration, the COD removal efficiencies were 88% and 90% for systems operating with control strategies I and II during phase 2 of this work, respectively. One of them (with control strategy II) showed approximately the same as the best removal (89.7% ; at the 1.0 mg/L PCP dose for the system operating with control strategy II) during phase 1 of this work. The COD removal efficiencies at 5.0 mg/L PCP concentration during phase 1 of this work were 70% and 75% for systems operating with control strategies I and II, respectively. Therefore, it appears that the feed PCP concentrations used in this work had little impact on the soluble COD removal during both phases of this work. For all of the feed PCP concentrations used, the effluent soluble COD concentration is substantially lower for the phase 2 systems than for the phase 1 systems. The system operating with control strategy I could reach the maximum substrate concentration which the system operating with control strategy II could never reach. Thus, the soluble COD removal is always better for the system operating with control strategy II than for the system operating with control strategy I .

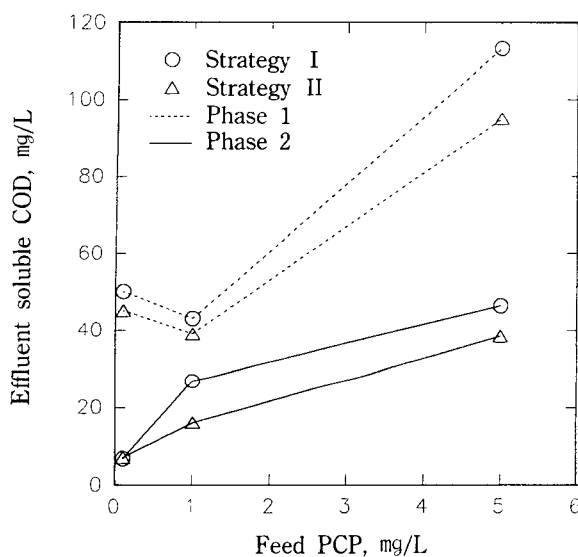


Fig. 2. Relationships between feed PCP concentration and effluent soluble COD concentration.

With increasing in the feed PCP concentration, only metabolically active microorganisms are capable of significant substrate uptake; i. e., shifts in species predominance occur because selection pressures on the mixed microbial culture is increased. In general, when two or more substrates

are present, concurrent growth of microorganisms takes place and the utilization of one substrate is inhibited by another and vice versa. Especially, if one of the substrates is a hazardous substance like PCP, both the COD removal and the reduction of PCP inhibition effects were simultaneously accomplished by providing a longer aerated period.

3.2. Removal of Suspended Solids

The relationships between effluent suspended solids and PCP for each phase of this work are shown in Fig. 3. During both phases 1 and 2 of this work, the concentrations of effluent suspended solids ranged from 9.4 to 37 mg/L until 1.0 mg/L feed PCP concentration, which have been considered as a “good” effluent.

However, when the feed PCP concentration was increased to 5.0 mg/L, the concentrations of effluent suspended solids for the phase 1 systems were slowly increased while those for the phase 2 systems were rapidly increased. This indicates that the characteristics of the activated sludges for the phase 1 systems are quite different from that for the phase 2 systems.

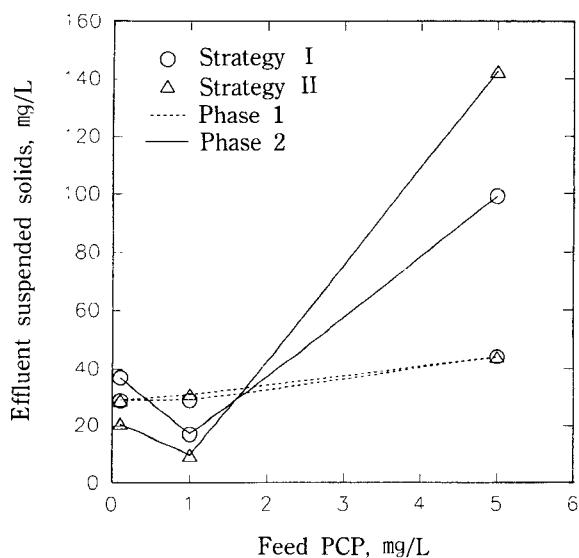


Fig. 3. Relationships between feed PCP concentration and effluent suspended solids concentration.

When examined microscopically, at the feed PCP concentration of 5.0 mg/L during phase 2 of this work the effluent suspended solids were found to consist of a lot of small sludge particles. These particles were not removed through centrifuging at very high speed for several minutes or settling quiescently for several hours. Hence, it is likely that washout of many useful bacteria took place when the effluent was discharged. One possible reason for this may be that the process which

biologically produces polymers is inhibited by PCP. Such polymers in the form of capsules, fiberlike strands, or film meshes can play an important role in the construction of floc particle. Otherwise, the high concentration of PCP presumably inhibited the growth of filamentous organisms in the systems. In general, high concentration of filamentous organisms in a bioreactor causes the development of light, fluffy, and poorly settling floc. However, a small population of filamentous organisms and fungi can play a useful role in the construction of floc particle.

It is interesting that at the feed PCP concentration of 5.0 mg/L (during both phases 1 and 2 of this work) the concentration of effluent suspended solids was oppositely changed to the concentration of effluent soluble COD. At the feed PCP concentration of 5.0 mg/L and during phase 2 of this work, the concentration of effluent suspended solids was greater for the system operating with control strategy II than for the system operating with control strategy I.

3.3. Variation of Mixed Liquor Volatile Suspended Solids

The relationships between mixed liquor volatile suspended solids (MLVSS) and PCP for phase 2 of this work are shown in Fig. 4. When the feed PCP concentration was increased to 5.0 mg/L, the concentrations of MLVSS were decreased to 2150 and 2005 mg/L for systems operating with control strategies I and II, respectively. That is, the specific growth rates were reduced. In this case, the biological solids for systems operating with both control strategies I and II consisted

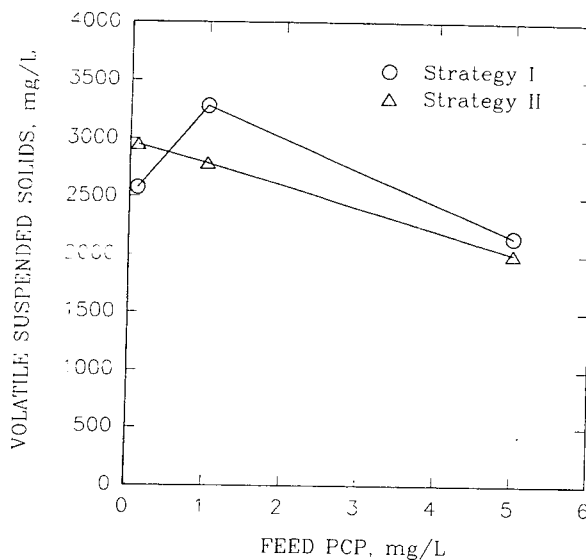


Fig. 4. Relationships between feed PCP concentration and VSS concentration in the 12-hour SBR system.

primarily of small suspended flocculant particles which were totally dispersed and settled very slowly.

Long term exposure to 5.0 mg/L PCP dose caused large changes in predominating species, as evidenced by the difference in the color of the mixed liquor in the reactors at the feed PCP concentrations of 0.1 and 1.0 mg/L (light brown) and at the feed PCP concentration of 5.0 mg/L (light grey). The color was not due to soluble pigment, since membrane filtrates were colorless. In this case, selective pressure on the mixed microbial culture apparently resulted from forcing the biomass to grow in the presence of high concentration of PCP, 5.0 mg/L. It can be expected that the number of species in the biomass will be reduced, thus narrowing the range of possible ecological responses. Based upon these observations, the change in predominating species might become a possible reason for the retardation of settling velocity.

3.4. Variations of Specific Oxygen Uptake Rate

The relationships between specific oxygen uptake rate (SOUR) and PCP for each phase of this work are shown in Fig. 5. When the feed PCP concentration was increased from 1.0 mg/L to 5.0 mg/L, the SOURs were increased from 4.2 mg/g/hr to 5.4 mg/g/hr for systems operating with control strategies I and II during phase 1 of this work and from 4.88 and 4.82 mg/g/hr to 8.26 and 9.06 mg/g/hr for systems operating with control strategies I. and II during phase 2 of this work, respectively. At the beginning of each cycle of an SBR system the amount of external substrate available to microorganisms is large. However, this material is used up fairly quickly so that by

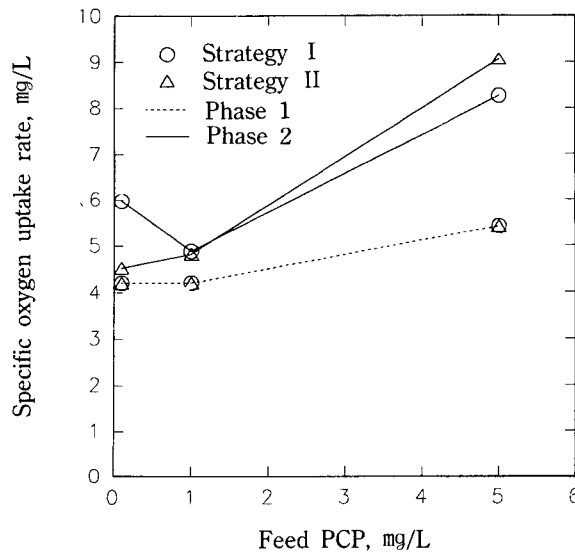


Fig. 5. Relationships between feed PCP concentration and specific oxygen uptake rate.

the end of the cycle the microorganisms will have been in a starvation state for a significant length of time. The oxygen uptake rate was measured near the end of aerated period. Thus, it might represent the endogenous respiration.

Heidman et al. (1967) reported that the ratio of respiration to synthesis was increased with increasing in the feed PCP concentration in a shocked system while the ratio was decreased with increasing in the feed PCP concentration in an acclimated system. The reason for this is as follows. PCP can uncouple oxidative phosphorylation; i. e., oxygen uptake can proceed with less ATP being generated. Thus more substrate is oxidized to obtain the ATP that the organisms need, and the ratio of respiration to synthesis can be increased. In this study, the SOURs for the phase 2 systems were invariably greater than those for the phase 1 systems. This suggests that even if oxidative phosphorylation is partially inhibited by the presence of an uncoupler such as PCP, a greater amount of the substrate might be channeled into respiration to produce the ATP in the phase 2 systems than in the phase 1 systems. It appears that the systems were shocked at the feed PCP concentration of 5.0 mg/L. It is interesting that at the feed PCP concentration of 5.0 mg/L (during both phases 1 and 2 of this work) the SOUR was increased as the concentration of effluent soluble COD was decreased.

3.5. Removal of Ammonia-Nitrogen

The relationships between nitrification and PCP for each phase of this work are shown in Fig. 6 and 7, respectively. Nitrification was made to some extent at all concentrations of feed PCP in the phase 2 systems whereas in the phase 1 systems little nitrification was observed. This indicates that nitrification occurred at least after 4 hours of the aeration period. The extent of nitrification was always greater for the system operating with control strategy II than for the system operating with control strategy I during each phase of this work. The best nitrification occurred at the feed PCP concentration of 0.1 mg/L for the system operating with control strategy II during phase 2 of this work. For a period of two months the reactor exhibited good nitrification at the 0.1 mg/L PCP dose.

There was no $\text{NO}_3^- - \text{N}$ content in the feed. The ammonia content of the feed was 25 mg/L as $\text{NH}_4^+ - \text{N}$ whereas the effluent ammonia content ranged from 34 to 51 mg/L for the phase 1 systems. The increase in the ammonia content was due to hydrolysis of organic nitrogen included in the yeast extract and nutrient broth of the feed solution.

During nitrification, ammonia is oxidized first to nitrite and then to nitrate, most commonly by the autotrophic bacteria *Nitrosomonas* and *Nitrobacter*, respectively (Focht and Verstraete, 1977). Nitrifiers use carbon dioxide, carbonates, or bicarbonates as a carbon source for cell synthesis. The energy available for nitrifiers per unit work is lower than that for aerobic heterotrophic bacteria. Nitrifiers do not successfully compete with aerobic heterotrophic bacteria for available oxygen when large amounts of organic substrate are present. Hence, the growth yield and maximum growth rates for nitrifiers are small relative to those of aerobic heterotrophic bacteria. The slow growth rates of nitrifying bacteria necessitate a longer aeration period for an SBR system.

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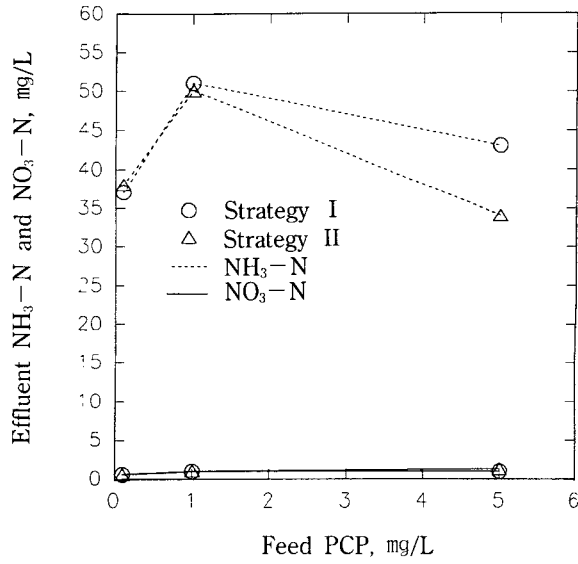


Fig. 6. Relationships between feed PCP concentration and nitrification in the 8-hour SBR system.

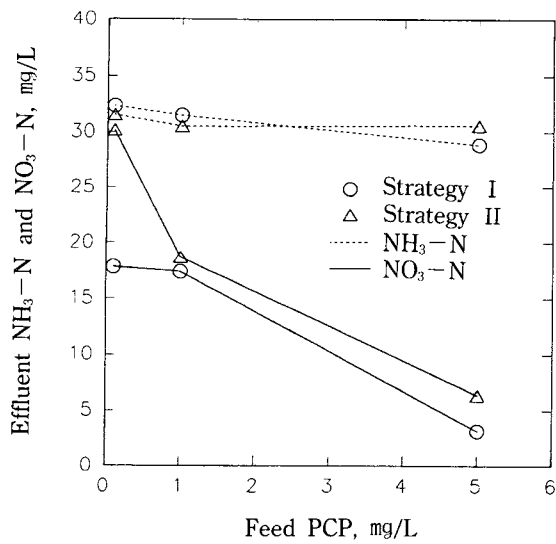


Fig. 7. Relationships between feed PCP concentration and nitrification in the 12-hour SBR system.

In a nontoxic SBR system the organic substance (sucrose) was completely stabilized within 1 hour after aeration was started (Silverstein and Schroeder 1983).

Nitrification would start to occur after that time. In this study the delayed nitrification was caused by the retardation of COD removal due to PCP inhibition effect. The time that nitrification starts will be more delayed with increasing in the feed PCP concentration.

Ammonia is toxic to fish life. Relatively low concentrations of ammonia in the un-ionized form will interfere with oxygen transport at the gills of the fish. A standard being used by the USEPA and the European Inland Fisheries Advisory Commission is 0.02 mg/L un-ionized ammonia-nitrogen in the stream to prevent this problem. A nitrified effluent, hence, is far preferable to one containing an ammonia. Nitrification has been recognized as an important biological means of ammonia removal from soils, wastewaters, and rivers and lakes. However, high nitrate levels can occur eutrophication in a receiving water body and accelerate algal blooms. To control algal growth, it is necessary to remove nitrate. For this purpose, biological nitrification/denitrification using an SBR system is the most reliable and cost-effective process.

3.6. Removal of Phosphorus

The relationships between effluent phosphorus and PCP for each phase of this work are shown in Fig. 8. Control strategies IV and VI employed by Manning and Irvine (1985) were the same as control strategies I and II employed in this study. However, the successful phosphorus removal reported by these investigators was not observed during phase 1 of this work. During phase 1, enhanced phosphorus removal was observed only once during the 12-month period as shown in Fig. 8. This occurred for operating strategy I during the period when 1.0 mg/L of PCP was being fed to the reactor. For a period of two months the reactor exhibited almost total phosphorus removal at the 1.0 mg/L PCP dose, even though enhanced removal was not observed for strategy I in the control or at a PCP dose of 0.1 mg/L. However, right after the feed PCP concentration was changed to 5.0 mg/L, the ability to remove high levels of phosphorus was lost and was never regained during phase 1.

Steady state testing for the 0.1 mg/L feed PCP concentration during phase 2 of this work was begun four months after system operation was changed to the 12-hr cycle and the feed PCP concentration was decreased from 5.0 mg/L to 0.1 mg/L. The results are shown in Fig. 8, which shows that when steady state testing was initiated, enhanced biological phosphorus removal was occurring under both control strategies. At the feed PCP concentration of 1.0 mg/L enhanced biological phosphorus removal was still occurring under control strategy I. This suggests that the indicated long-term change in the feed PCP concentration had little effect on the effluent phosphorus level of the system operated with control strategy I. However, the steady-state effluent phosphorus level of the system operated with control strategy II increased by almost three units.

Enhanced biological phosphorus removal was always better for the system operated with control strategy I than for the system operated with control strategy II during phase 2 of this work. This statement is supported by the following explanation. The system (reactor 1) operating with control strategy I was instantaneously fed but the system (reactor 2) operating with control strategy II

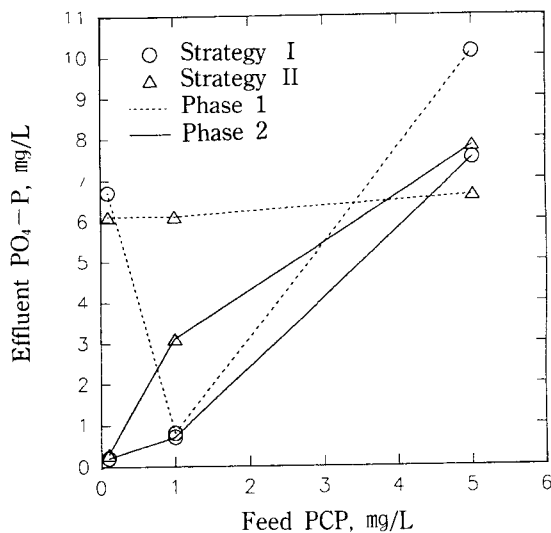


Fig. 8. Relationships between feed PCP concentration and effluent $\text{PO}_4^{3-}\text{-P}$ concentration.

was continuously fed. Reactor 2 could never reach the maximum substrate concentration which Reactor 1 could reach. Under anaerobic conditions, the maximum substrate concentration may stimulate poly-p forming bacteria to produce the energy (proton motive force) by the hydrolysis of polyphosphate which may be directly utilized for the active transport of the substrate across the cell membrane and to form an organic storage polymer such as PHB. Under aerobic conditions, phosphorus uptake may rapidly occur by poly-p forming bacteria and ATP is formed by oxidative phosphorylation utilizing the energy (proton motive force) produced by the aerobic decomposition of PHB. The excess ATP is converted to polyphosphate by polyphosphate kinase for regulating ATP/ADP ratio in the cell.

As shown in Fig. 8, 50 mg/L PCP dose was prohibitive to enhanced biological phosphorus removal. Immediately after increasing the feed PCP concentration to 5.0 mg/L, enhanced phosphorus removal ceased and never returned, even though during the last four weeks of the study the feed PCP concentration was reduced to 0.1 mg/L. At the feed PCP concentration of 5.0 mg/L, PCP probably acted on poly-p forming bacteria as an uncoupler in oxidative phosphorylation. Thus ATP formation was inhibited and subsequent polyphosphate formation was also inactive. As a result, enhanced phosphorus removal was lost. When the feed PCP concentration, otherwise, was changed from 1.0 mg/L to 5.0 mg/L, shifts in species predominance occurred because of the high selective pressure for microorganisms. This caused a loss of poly-p forming bacteria from the system. This may be another possible reason for the failure of phosphorus removal. Phosphorus removal was very sensitive to environment conditions.

4. CONCLUSIONS

The toxic effects of PCP on activated sludge in SBR systems operating under different control strategies and different PCP doses were examined. Specific conclusions were:

1. The feed PCP concentrations used in this work had little impact on soluble COD removal during both phases 1 and 2 of this work. Soluble COD removal is always better in the phase 2 systems than in the phase 1 systems. Also, soluble COD removal is always better for the system operating with control strategy II than for the system operating with control strategy I during each phase of this work.
2. Effluent suspended solids were removed very well until 1.0 mg/L PCP dose for each phase of this work. However, at 5.0 mg/L PCP dose settleability was poor for the phase 2 systems and washout of many useful bacteria might take place when the effluent was discharged.
3. At 5.0 mg/L feed PCP concentration, the concentrations of MLVSS were decreased, that is, the specific growth rates were reduced. Prolonged exposure to 5.0 mg/L PCP dose would tend to select for more resistant organisms; selective pressure on the mixed microbial culture might be increased, thus narrowing the range of possible ecological responses.
4. The SOURs were increased at 5.0 mg/L feed PCP concentration, showing that the systems were shocked.
5. Nitrification was made to some extent at all concentrations of feed PCP for the phase 2 systems whereas for the phase 1 systems little nitrification was observed. Thus, nitrification occurred at least after 4 hours of the aeration period. The extent of nitrification was always greater for the system operating with control strategy II than for the system operating with control strategy I during each phase of this work. The best nitrification occurred at the feed PCP concentration of 0.1 mg/L for the system operating with control strategy II during phase 2 of this work. The delayed nitrification was caused by the retardation of COD removal due to PCP inhibition effects. More aeration period will be need for occurring nitrification with increasing in the feed PCP concentration.
6. During the course of this study it was observed that enhanced biological phosphorus removal may occur in an SBR system operating on phase 1 (an 8-hour cycle) with control strategy I and in the presence of low concentrations of PCP. However, the process was unreliable and might cease at anytime. Enhanced biological phosphorus removal was also observed in SBR systems operating on phase 2 (a 12-hour cycle) with either control strategy I or control strategy II. Such processes appear to be reliable at feed PCP concentrations up to 1.0 mg/L. If, however, they were exposed to feed PCP concentration of 5.0 mg/L or greater, process failure would occur.

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ABSTRACT

The primary objective of this study was to examine the toxic effects of PCP on activated sludge and to analyze its metabolic responses while treating wastewater containing pentachlorophenol (PCP) in a sequencing batch reactor (SBR) system operating under different control strategies. This study was conducted in two phases 1 and 2 (8-hr and 12-hr cycles). Each phase was operated with two control strategies I and II. Strategy I (reactor 1) involved rapid addition (5 minutes to complete) of substrate to the reactor with continuous mixing but no aeration for 2 hours. Strategy II (reactor 2) involved adding the feed continuously during the first 2 hours of the cycle when the system was mixed but not aerated. During both phases each reactor was operated at a sludge age of 15 days. The synthetic wastewater was used as a feed. The COD of the feed solution was about 380 mg/L. After the reference response for both reactors was established, the steady state response of each system was established for PCP feed concentrations of 0.1 mg/L, 1.0 mg/L, and 5.0 mg/L in SBR systems operating on both 8-hr and 12-hr cycles.

Soluble COD removal was not inhibited at any feed PCP concentrations used. At 5.0 mg/L feed PCP concentration and in SBR systems operating on phase 2, the concentrations of MLVSS were decreased; selective pressure on the mixed biomass might be increased, narrowing the range of possible ecological responses; the settleability of activated sludge was poor; the SOURs were increased, showing that the systems were shocked.

Nitrification was made to some extent at all concentrations of feed PCP in SBR systems operating on phase 2 whereas in SBR systems operating on phase 1 little nitrification was observed. Then, nitrification will be delayed as much as soluble COD removal is retarded due to PCP inhibition effects. Enhanced biological phosphorus removal occurring in the system operating with control strategy I during phase 1 of this work and in the presence of low concentrations of PCP was unreliable and might cease at anytime, whereas enhanced biological phosphorus removal occurring in the system operating with either control strategy I or II during phase 2 of this work and in the presence of feed PCP concentrations up to 1.0 mg/L was reliable. When, however, such processes were exposed to 5.0 mg/L PCP dose, enhanced phosphorus removal ceased and never returned.

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