



## Treatment of Synthetic Wastewater Containing Phenol, Thiocyanate and Nitrate-N in Anoxic Fixed Film Reactor

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### ABSTRACT

Phenol and thiocyanate are present in many industrial effluents like chemical industries, oil refineries, coal gasification, coke and steel plant, synthetic fuel processing operations, coal carbonization, etc. The objective of the present research is to investigate the removal of phenol, thiocyanate and nitrate-N in anoxic fixed-film reactors. Cultures were acclimatized in three continuous reactors (named R1, R2 and R3) under anoxic environment with sponge cubes as media for biomass immobilization. Acclimatization time was around 41 days. Study was conducted with synthetic feed containing varying concentrations of phenol, thiocyanate ( $\text{SCN}^-$ ) and nitrate-N. HRT of anoxic reactors was maintained at two days. In reactor (R1),  $\text{NO}_3^-$ -N concentration was varied from 50-200 mg/L at a constant phenol and COD concentrations of 200 and 480 mg/L respectively. COD to  $\text{NO}_3^-$ -N removal ratio varied from 1.58 to 10.12 in R1. In reactor R2, feed  $\text{SCN}^-$  concentration was varied from 42 to 350 mg/L. It was observed that due to change in feed  $\text{SCN}^-$  concentration, phenol removal remained unaffected and complete phenol removal was achieved from influent concentration of 200 mg/L. In R2 higher concentration of  $\text{SCN}^-$  in feed had inhibitory effects on both denitrification and thiocyanate removal efficiencies. In reactor R3, feed phenol concentration was varied from 200-600 mg/L. COD removal increased due to increase in influent phenol concentration. However,  $\text{SCN}^-$  and  $\text{NO}_3^-$ -N removals decreased. Sulphate was generated in anoxic reactor from thiocyanate. It was observed that performance of bioreactors remained unaffected due to sudden increase of influent phenol and  $\text{SCN}^-$  concentrations of 1.3 times and 1.7 times respectively.

### INTRODUCTION

Phenol and phenolic compounds and thiocyanate are common constituents of aqueous effluents from industrial processes, including oil refineries, steel plants, coal conversion process, petrochemical plants, coal gasification, coal conversion, etc. Both, phenol and thiocyanate are discharged into various surface and underground aquifers and make them polluted. Also, contamination of groundwater aquifers by high amount of nitrate-N is an alarming problem throughout the world. Excessive use of fertilizers for crop production is responsible for high amount of nitrate in groundwater aquifers. In many places in the world groundwater already affected by phenol pollution has an unnaturally high concentration of nitrate, raising the possibility of beneficial pollutant-pollutant interactions. Some workers have reported phenol removal in presence of nitrate (Hussain et al. 2008). However, removal of thiocyanate and phenol in anoxic environment has not been addressed so far (Banerjee 1996). The major objective of the present study is to investigate the nitrate, thiocyanate and phenol removal in anoxic environment. Attached growth system is selected for the present work due to higher efficiency of this system above suspended growth reactors. Present study was conducted in three anoxic

attached growth reactors operated in continuous mode. Seed sludge was collected from an anaerobic digester and acclimatized with synthetic wastewater containing phenol, thiocyanate and nitrate-N. Influent phenol, thiocyanate and nitrate-N concentrations were varied at a constant reactor HRT of two days. Finally, reactor efficiency was monitored after introducing shock load of phenol and thiocyanate on anoxic microorganisms.

## MATERIALS AND METHODS

**Chemicals and reagents:** The concentrated acid was made to 1 N/0.1 N by dilution and used for all experimental work. Dextrose anhydrous purified, phenol, potassium nitrate, ammonium chloride purified (99%),  $K_2HPO_4$ ,  $KH_2PO_4$  (98%),  $ZnCl_2$  (95%),  $NiCl_2 \cdot 6H_2O$  (97%),  $MgSO_4 \cdot 7H_2O$ ,  $CaCl_2 \cdot 2H_2O$ ,  $FeCl_3 \cdot 6H_2O$ ,  $CuCl_2$ ,  $ZnCl_2$ ,  $NiCl_2 \cdot 6H_2O$  and  $CoCl_2$  used for synthetic feed for biological reactors were manufactured by E. Merck (India) Ltd., Mumbai. Yeast extract was procured from Nice Chemicals Pvt. Ltd, Cochin. Single distilled water prepared in the laboratory was used for preparation of all the reagents and all experimental work, except feed of biological reactor, for which tap water was used.

Experimental methods: The present work was conducted in following two phases:

1. Phase-I: Heterogeneous cultures were developed in three continuous reactors maintained under anoxic environments.
2. Phase-II: Three-stage anoxic reactor system was fabricated along with the iron frame and PVC columns for continuous study. Continuous study was conducted in the three-stage attached growth system.

### Phase-I Studies

**Seed sludge:** Sludge collected from an anaerobic biogas plant at IIT Guwahati was used as seed for start-up of anaerobic and anoxic reactors. The biogas plant is fed with animal droppings and kitchen waste and is under operation for approximately three years. The characteristics of the seed sludge collected from biogas plant are given in Table 1.

**Characteristics of media:** Present reactors were operated as attached growth system. Sponge sheets were procured from local market. Cubes (dimensions: 1cm  $\times$  1cm  $\times$  1cm) were made manually from sponge sheet. These sponge cubes were used as inert media for the present work.

**Reactor assembly:** Three PVC (polyvinyl chloride) columns purchased from local market were used as anoxic reactor in the present work and they were named as R1, R2 and R3. Diameter of each column was 15 cm and height 118 cm. All the three columns were closed at the bottom with a plastic cap. An iron frame was fabricated to support PVC columns, which were connected to an iron frame using clamps. The scheme of anoxic reactor R1 used for present work is shown in Fig. 1. Reactors R2 and R3 were identical to R1; only synthetic feed given to each reactor was variable parameter in this study.

An inlet and outlet were constructed in all three columns. In each PVC column, 50 g of sponge cubes and 10 L of seed sludge were added. Total volume (liquid, biomass and sponge) of each reactor was 15 L. All the three reactors were operated in upflow mode. One plastic settling tank (each volume 500 mL) was connected to each reactor for liquid-solid separation. Supernatants from settling tanks were allowed to flow

Table 1: Characteristics of seed sludge.

Parameters	Value
Total Solids (TS) (g/L)	53.16
Volatile Solids (VS)(g/L)	18.21
VS/TS ratio	0.3425
Color	Dark Grey

Table 2: Feed pattern in anoxic reactor during acclimatization.

Time (day)	Feed			
	Phenol	NO <sub>3</sub> -N	SCN <sup>-</sup> *	
			R2	R3
1	5	100	0	2
3	10	100	0	5
5	20	100	0	10
7	30	100	0	20
11	40	100	0	30
13	50	100	0	40
15	60	100	0	50
17	70	100	0	60
19	80	100	0	70
21	100	100	0	80
23	120	100	0	90
25	150	100	0	100
27	180	100	0	110
29	200	100	0	110
31	200	100	10	110
33	200	100	20	110
35	200	100	30	110
37	200	100	42	110

\*SCN<sup>-</sup> was added only in feed of reactors R2 and R3.

KH<sub>2</sub>PO<sub>4</sub>) as phosphorus source and to maintain reactor pH; trace metals solution (1mL/L) and yeast extract (10 mg/L) as nutrients. Composition of trace metal solution was: MgSO<sub>4</sub>·7H<sub>2</sub>O: 10,000 mg/L, CaCl<sub>2</sub>·2H<sub>2</sub>O: 10,000 mg/L, FeCl<sub>3</sub>·6H<sub>2</sub>O: 5000 mg/L, CuCl<sub>2</sub>: 1000 mg/L, ZnCl<sub>2</sub>: 1000 mg/L, NiCl<sub>2</sub>·6H<sub>2</sub>O: 500 mg/L and CoCl<sub>2</sub>: 500 mg/L (Chakraborty & Veeramani 2005). Concentration of phosphate buffer, yeast extract and trace metal solution remained unchanged throughout the study. Synthetic feed was prepared daily and added to reactors.

**Culture development:** Sludge acclimatization was conducted in continuous mode in the three anoxic reactors. Reactors R1, R2 and R3 were operated with synthetic feed containing phenol, thiocyanate (SCN<sup>-</sup>) and potassium nitrate along with other nutrients. Thiocyanate was added only in the feed of R3 during acclimatization phase. Since phenol and thiocyanate are toxic to microorganisms, their concentration was increased gradually in the anoxic reactors. Nitrate-N was not considered as toxic substance and its concentration was increased suddenly, when required. The pattern of feed addition during acclimatization is given in Table 2.

Feed flow rate (Q) to each reactor in acclimatization phase was 5 mL/min (7.2 L/day). Hydraulic retention time of each reactor was calculated using equation (1). HRT of each reactor during acclimatization phase was 2 days.

$$\text{Reactor HRT (day)} = \frac{\text{Liquid volume of reactor (L)}}{Q \text{ (L/day)}} \quad \dots(1)$$

On day-1, in reactor R1, 5 mg/L of phenol was added in the feed and reactor was operated in this feed for almost two days (one HRT). Then on day-3, feed phenol concentration was increased to 10 mg/L and finally phenol concentration reached to 200 mg/L in feed. Feed NO<sub>3</sub>-N concentration was

to a plastic bucket by gravity. One peristaltic pump having three channels was used for supply of feed to three reactors. No external unit was used for mixing of liquid and biomass in the reactors. All three reactors were maintained as open reactors. However, due to narrow mouth and higher depth of the reactor (height: diameter ratio of 7.86), very little oxygen penetration inside anoxic reactor was expected.

All three reactors were maintained in the same temperature range of 30-32°C using a hot air blower throughout the study. Effluents collected from the supernatant of plastic bucket attached to respective reactor and settling tank, were centrifuged at 1000 rpm for one minute and then used for chemical analysis. In all the three reactors pH was maintained within 7.0-7.5 by adding 0.1 N HCl/NaHCO<sub>3</sub>.

**Synthetic feed characteristics:** Study was conducted with synthetic feed consisting of phenol, nitrate-N (as KNO<sub>3</sub>) and thiocyanate (as KSCN). The synthetic feed also included ammonium chloride (50 mg NH<sub>4</sub>Cl/L) as nitrogen source; phosphate buffer of pH 6.8 (104.5 g/L K<sub>2</sub>HPO<sub>4</sub> and 72.3 g/L

maintained at 100 mg/L (by adding 721 mg/L of  $\text{KNO}_3$ ) throughout the acclimatization period. This constant nitrate addition made phenol: $\text{NO}_3\text{-N}$  ratio very low (1:20 at feed phenol concentration of 5 mg/L) and finally increased to (2:1 at feed phenol concentration of 200 mg/L). From the beginning nitrate concentration was maintained relatively higher in order to ensure anoxic environment in the reactors.

In anoxic reactors R2 and R3, on day 1, along with feed phenol concentration of 5 mg/L and  $\text{NO}_3\text{-N}$  of 100 mg/L, 2 mg/L of  $\text{SCN}^-$  was added. When feed phenol was increased to 10 mg/L, feed  $\text{SCN}^-$  concentration was increased to 5 mg/L. In reactor R2, feed  $\text{SCN}^-$  concentration was increased up to 42 mg/L and in R3 it was increased up to 110 mg/L.

### Phase-II Studies

**Continuous studies:** Acclimatized sludge was used for continuous study in the three anoxic reactors, R1, R2 and R3. Synthetic feed used for continuous study consisted of phenol and thiocyanate as pollutants. Other feed constituents like phosphate buffer, yeast extract and trace metals solutions concentrations were maintained same like acclimatization phase. In the present work feed phenol, nitrate-N and thiocyanate concentrations were varied. HRT of each reactor was maintained same as acclimatization phase (i.e. HRT of each reactor 2 days).

In reactor R1 five experimental runs were conducted with varying feed and pattern of feed addition as shown in Fig. 2. In reactor R1, run 1 experiment was conducted at feed phenol concentration of 200 mg/L and  $\text{NO}_3\text{-N}$  of 50 mg/L from 1-25 days. Steady state data were collected from 15-25 days. Thereafter, in run 2, feed  $\text{NO}_3\text{-N}$  was increased to 100 mg/L on day 26 without changing feed phenol concentration. Reactor R1 was operated from 26-55 days in run 2 experiment and steady state data were collected from 45-55 days. Run 3 experiment was conducted from day 56 to 84 at feed phenol and  $\text{NO}_3\text{-N}$  concentrations of 200 mg/L each.

After run 3 experiment,  $\text{SCN}^-$  was gradually added in the feed of R1 at the rate of 10 mg  $\text{SCN}^-/\text{L}$  in every alternate day from day 85-92. Once feed  $\text{SCN}^-$  concentration reached at 42 mg/L, R1 was operated with feed phenol of 200 mg/L,  $\text{NO}_3\text{-N}$  of 200 and  $\text{SCN}^-$  of 42 mg/L from 91 to 114 days and

Table 3: Acclimatization results in three anoxic reactors.

Day	Feed				Effluent								
	Phenol	$\text{NO}_3\text{-N}$	$\text{SCN}^-^a$		Phenol			$\text{NO}_3\text{-N}$			$\text{SCN}^-^a$		
			R2	R3	R1	R2	R3	R1	R2	R3	R2	R3	
19	80	100	0	70	-	-	-	-	-	-	-	-	-
21	100	100	0	80	2.0	2.0	2.0	17.5	14	15	-	1.0	
23	120	100	0	90	0	0	0	36.5	33	25	-	1.0	
25	150	100	0	100	2	0	0	26	49	9	-	1.5	
27	180	100	0	110	0	5	0	33	57	3.5	-	3.0	
29	200	100	0	110	3.5	1.5	11.0	37	46	33	-	2.5	
31	200	100	10	110	2.6	1.5	0	36.5	46	22.5	-	1.5	
33	200	100	20	110	0	3.0	0	49.5	55	8.0	5.5	3.0	
35	200	100	30	110	3.6	0	1.0	31.0	20	13.0	3.5	7.0	
37	200	100	42	110	3.6	1.6	1.0	37.5	31	9.0	7.5	6.0	
40	200	100	42	110	7.6	3.6	7.0	45.0	39	15.0	16.5	10.0	
41	200	100	42	110	4.6	3.6	7.5	59.5	27	18.0	9.0	7.0	

<sup>a</sup> $\text{SCN}^-$  was added only in the feed of R2 and R3 reactors.

Table 4: Phenol and COD removal efficiency in anoxic reactor (R1).

Run	Influent NO <sub>3</sub> -N	Influent SCN <sup>-</sup>	Phenol effluent <sup>a</sup>	Removal (%) <sup>a</sup>	Effluent COD <sup>a</sup>	COD removal (%) <sup>a</sup>
1	50	0	0.20 ± 0.26 <sup>a</sup>	99.90	46.08 ± 12.79 <sup>a</sup>	90.4
2	100	0	2.30 ± 1.18	98.85	69.12 ± 19.59	85.6
3	200	0	0.10 ± 0.19	99.95	142.08 ± 26.43	70.4
4	200	42	0.40 ± 0.52	99.80	140.16 ± 17.78	70.80
5	300	42	0.40 ± 0.78	99.80	140.16 ± 17.78	70.80

<sup>a</sup>Influent phenol 200 mg/L and influent COD 480 mg/L; <sup>a</sup>Data are shown as average ± 95% Confidence interval.

Table 5: Thiocyanate and nitrate-N removal efficiency in anoxic reactor.

Run	Influent NO <sub>3</sub> -N	NO <sub>3</sub> -N effluent (mg/L)*	NO <sub>3</sub> -N Removal (%)	SCN <sup>-</sup> effluent (mg/L)*	SCN <sup>-</sup> removal (%)	NO <sub>3</sub> -N removed (mg/L)	COD removed (mg/L) <sup>a</sup>	COD/N <sub>rem</sub>
1	50	7.15 ± 0.73	85.70	NA	NA	42.85	433.92	10.12
2	100	7.56 ± 0.71	92.44	NA	NA	92.44	410.88	4.44
3	200	85.20 ± 2.69	57.40	NA	NA	114.80	337.92	2.94
4	200	79.85 ± 6.26	60.07	8.60 ± 0.74	79.52	120.15	339.84	2.83
5	300	85.2 ± 2.69	71.60	10.0 ± 1.43	76.00	214.80	339.84	1.58

<sup>a</sup>Influent COD of 480 mg/L in all five runs and SCN<sup>-</sup> of 42 mg/L in run 4 and 5 only; <sup>a</sup>Data are shown as average ± 95% Confidence interval.

steady state data of run 4 experiment was collected from days 104-114. In run 5 experiment feed NO<sub>3</sub>-N was increased on day 115 from 200 to 300 mg/L and reactor was operated from day 115 to day 134 at feed phenol 200 mg/L, SCN<sup>-</sup> 42 mg/L and NO<sub>3</sub>-N of 300 mg/L.

In anoxic reactor R2, pattern of feed addition is shown in Fig. 3. Four experiments were conducted at a constant feed phenol and NO<sub>3</sub>-N concentrations of 200 and 100 mg/L respectively. Feed SCN<sup>-</sup> concentration was varied at 42, 125, 200 and 350 mg/L in four experimental runs respectively. Run 1 was continued from day 1-25 and steady state data were collected from day 15 to 25. From day 26<sup>th</sup> onward feed SCN<sup>-</sup> was increased at the rate of 20 mg/L in every alternate day. Once feed SCN<sup>-</sup> reached at 125 mg/L, reactor was operated from day 34 to day 55 at feed phenol 200 mg/L, NO<sub>3</sub>-N 100 mg/L and SCN<sup>-</sup> 125 mg/L and steady state data were collected from day 45 to day 55 in run 2. In a likely manner, in run 3 experiment, feed SCN<sup>-</sup> was increased gradually from 125 to 200 mg/L (with increment of 25 mg SCN<sup>-</sup>/L in every alternate day) and run 3 experiment was conducted from day 56-84 with steady state condition of 74-84 days.

Run 4 experiments were conducted from day 85-114, with steady state data of day 104-113 at feed phenol 200 mg/L, NO<sub>3</sub>-N 100 mg/L and SCN<sup>-</sup> 350 mg/L. Feed SCN<sup>-</sup> was increased from 200 to 350 mg/L gradually with increment of 25 mg SCN<sup>-</sup>/L in every alternate day.

In run 5, effect of shock load of SCN<sup>-</sup> on reactor performance was studied. Feed SCN<sup>-</sup> concentration was increased by 71% (from 350 to 600 mg/L) on day 115. Feed SCN<sup>-</sup> was maintained constant at 600 mg/L for next twenty days and steady state reactor performance was monitored from day 125-134.

Anoxic reactor R3 was operated with varying feed phenol concentrations. Pattern of feed addition in R3 during continuous studies is presented in Fig. 4. Experimental run 1 was conducted from

day 1 to day 25 at feed phenol concentration of 200 mg/L,  $\text{NO}_3\text{-N}$  of 100 mg/L and  $\text{SCN}^-$  of 110 mg/L. Steady state data of reactor R3 were collected from day 15 to day 25. Then on day 26<sup>th</sup> onward feed phenol concentration was increased with increment of 25 mg phenol/L in every alternate day without changing concentrations of feed  $\text{SCN}^-$  and  $\text{NO}_3\text{-N}$ . On day 32, feed phenol concentration was 300 mg/L and reactor was operated for another twenty-three days (day 55) and steady state data for run 2 were collected from day 45 to 55 days.

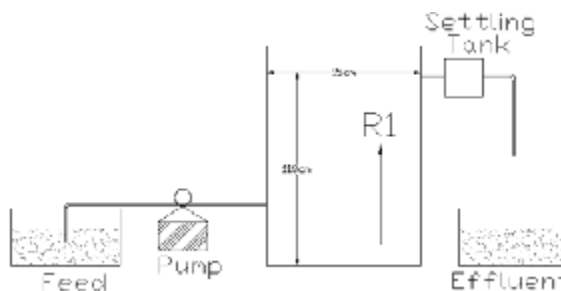


Fig. 1: Anoxic reactor R1 other two reactors R2 and R3 were identical to R1.

In experimental run 3, feed phenol concentration was increased from 300 to 400 mg/L from day 56 to day 84 with increment of 25 mg phenol/L in every alternate day and steady state data were collected from day 74 to day 83. On day 85, feed phenol concentration was increased from 400 to 600 mg/L with increment of 40 mg phenol/L in every alternate day. Steady state data of run 4 was collected from 105 to 114 days. In run 5, effect of shock load of phenol on reactor performance was studied. Feed phenol concentration was suddenly increased by 33% (from 600 to 800 mg/L) on day 115. Other feed constituents were maintained same as run 4 and R3 was operated at feed phenol of 800 mg/L for next 20 days and steady state reactor performance was monitored from day 125 to day 134.

**Analytical protocol:** All analyses were carried out according to standard methods (APHA 1998). High speed centrifuge was used for separation of biomass from liquid samples. Solution pH was measured by a digital pH meter. Phenol was estimated by direct photometric method using 4-aminoantipyrine and measuring the absorbance at 500 nm using a UV-Spectrophotometer. Nitrate-N concentration was determined by measuring absorbance of samples and standards at 210 nm and then at 275 nm to identify the interference of organic matter present in effluents. The absorbance values at 275 nm were doubled and subtracted from absorbance values at 210 nm and used for nitrate-N estimation. Thiocyanate concentration was estimated using  $\text{FeNO}_3$  colorimetric method and measuring absorbance at 460 nm. Sulphate concentration was estimated using barium chloride solution and measuring absorbance at 420 nm. Concentration of total solids and volatile solids in seed was estimated by weighing method using a drying oven and a muffle furnace.

## RESULTS AND DISCUSSION

In the present work, removal of thiocyanate, phenol and nitrate-N were studied in anoxic fixed-film reactors. Study was conducted in two phases: (a) Phase-I: Heterogeneous cultures were acclimatized using synthetic feed containing phenol, nitrate and thiocyanate in three anoxic reactors under continuous mode. (b) Phase-II: Continuous studies were conducted with varying concentrations of phenol, nitrate-N and thiocyanate in three anoxic reactors.

**Phase-I studies:** In phase-I heterogeneous cultures were acclimatized with synthetic feed in three continuous reactors. For the first twenty days only pH was measured in reactor effluent and reactor pH was maintained at 7.0 by adding  $\text{HCl}/\text{NaHCO}_3$ . During this period calibration curves for phenol, thiocyanate and nitrate were prepared. The results on day-21 onwards are shown in Table 3.

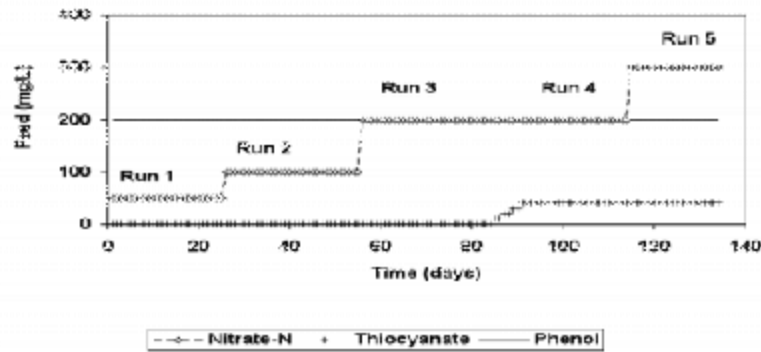


Fig. 2: Pattern of feed addition in anoxic reactor R1 during continuous studies.

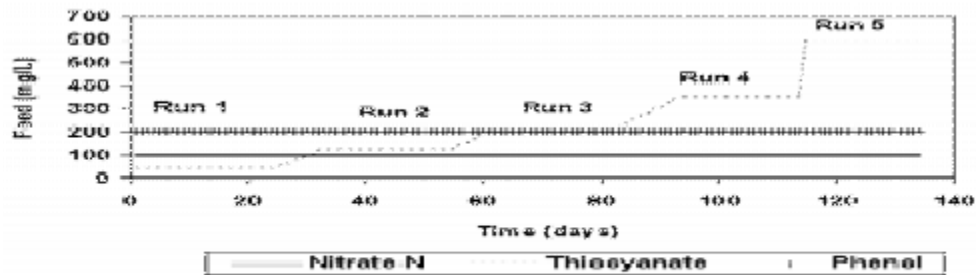


Fig. 3: Pattern of feed addition in anoxic reactor R2 during continuous studies.

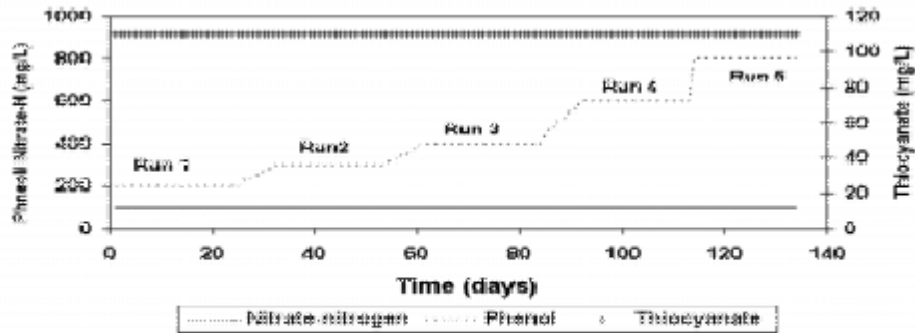


Fig. 4: Pattern of feed addition in anoxic reactor R3 during continuous studies.

**Phase-II studies:** The three anoxic reactors were started using acclimatized cultures. The concentration of phenol, thiocyanate and nitrate-N in feed were varied in three reactors and performance of the reactors was monitored. Five sets of experiments were conducted in each reactor under continuous mode. Each experimental run was continued for a total period 20-25 days, including a transient period of 8-10 days until steady state conditions were established. The system was operated for four-five times of reactor HRT in each run before collecting steady state data. Subsequently the performances were monitored for 8-10 days to generate data for pH and concentrations of phenol, thiocyanate, COD,  $\text{SO}_4^{2-}$  and  $\text{NO}_3\text{-N}$ . A set of 8-10 observations was made in each run to establish the performance trend of the reactor.

Average values of the effluent parameters and 95% confidence intervals for all pollutants were calculated. Performance of the reactors was evaluated by following parameters:

$$\text{Loading (g/m}^2\cdot\text{day)} = \frac{S_0}{\theta \times 1000}$$

$$\text{Removal efficiency (\%)} = \frac{(S_0 - S_e) \times 100}{S_0}$$

Where  $S_0$  = Influent concentration of pollutant (mg/L),  $S_e$  = Effluent concentration of pollutant (mg/L),  $q$  = Reactor HRT (day).

**Performance of anoxic reactor (R1):** Five experimental runs were conducted in reactor R1. Studies were conducted at varying feed  $\text{NO}_3^-$ -N concentrations of 50 (run 1), 100 (run 2) and 200 mg/L (run 3) at constant feed phenol concentration of 200 mg/L. In run 4, feed  $\text{SCN}^-$ , of 42 mg/L was added in the feed at phenol and  $\text{NO}_3^-$ -N concentrations of 200 mg/L each. Run 5 was conducted with same feed as run 4 except  $\text{NO}_3^-$ -N concentration was 300 mg/L. Volumetric loading of phenol in R1 in all five run was 0.1 kg phenol / $\text{m}^3\cdot\text{day}$ . Phenol removal in R1 was almost complete in all five runs. Table 4 shows that phenol removal efficiency in anoxic reactor R1 was unaffected by presence of feed  $\text{SCN}^-$  concentration of 42 mg/L. Thiocyanate and nitrate removal efficiencies are given in Table 5.

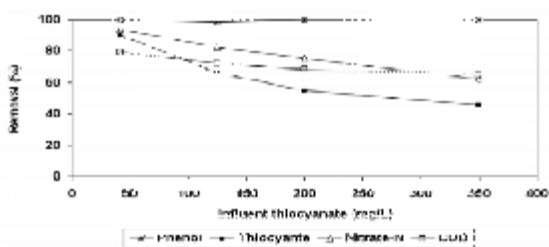


Fig. 5: Effect of influent thiocyanate on pollutants removal in reactor R2 (in the graph, phenol removal was nearly 100%).

**Performance of anoxic reactor (R2):** In anoxic reactor R2, studies were conducted with varying feed  $\text{SCN}^-$  concentrations. Feed phenol and  $\text{NO}_3^-$ -N concentrations were maintained constant at 200 mg/L and 100 mg/L respectively. Feed  $\text{SCN}^-$  was varied gradually from 42 to 350 mg/L in initial four experimental runs. In run 5, effect of shock load of  $\text{SCN}^-$  was studied in reactor R2. Effluent phenol and COD concentration profiles are shown in Fig. 5. Effluent phenol concentration was within  $0.2 \pm 0.39$  to  $5.0 \pm 0.72$  (with 95% confidence interval). Influent COD in R2 was 480 mg/L throughout the study. Effluent COD values were  $96.6 \pm 13.70$  to  $170.88 \pm 36.71$  (with 95% confidence interval). However, COD removal declined from 80% to 64% (declined by 20%) with increase in feed  $\text{SCN}^-$  concentration from 42 to 350 mg/L.

**Performance of anoxic reactor (R3):** In reactor R3, influent phenol concentration was varied from 200-600 mg/L at constant  $\text{SCN}^-$  of 110 and  $\text{NO}_3^-$ -N of 100 mg/L. It shows that effluent phenol concentrations were:  $3.35 \pm 1.42$  (run 1),  $0.40 \pm 0.52$  (run 2),  $0.20 \pm 0.39$  (run 3),  $10.00 \pm 1.43$  (run 4). Removal efficiencies were varying from 98-99%. It seems that at reactor HRT of 2 days anoxic reactor R3 was able to degrade phenol from influent concentration of 600 mg/L efficiently.

In run 5, the effect of phenol shock load was studied. Feed phenol concentration was increased from 600 to 800 mg/L and maintained at that concentration. It shows that phenol removal in R3 remained unaffected due to sudden increase in phenol concentration (effluent phenol concentration



6.00±3.36). Volumetric phenol loadings were 0.1, 0.15, 0.2, 0.3 and 0.4 kg/m<sup>3</sup>.day in experimental runs 1, 2, 3, 4 and 5 respectively.

## CONCLUSIONS

Process effluents generated from chemical industries, oil refineries, coal gasification, coke and steel plant, coal carbonization, etc. contain phenolic compounds, thiocyanate and nitrate-N along with other toxic substances. Present lab-scale investigation was conducted in continuous mode to study the feasibility of using three-stage attached growth anoxic system for removal of high concentrations of phenol and nitrate from synthetic wastewater. Study was conducted in two phases: (a) phase I: acclimatization studies (b) phase II: study in continuous mode. Experimental observations can be summarized as follows:

1. Heterogeneous cultures from anaerobic digester and sewage were collected as seed source. Acclimatization was done in continuous mode under anoxic environments. Acclimatization required almost 41 days.
2. Continuous three-stage anoxic system was fabricated and acclimatized cultures were used for continuous work. Feed phenol, thiocyanate and nitrate-N concentrations were varied from 0-800, 0-600 and 0-300 mg/L respectively for this work. Steady state data were used for assessing performance of reactors and the three-stage system.
3. In reactor (R1), NO<sub>3</sub>-N concentration was varied from 50-200 mg/L at a constant phenol and COD concentrations of 200 and 480 mg/L respectively. COD to NO<sub>3</sub>-N removal ratio varied from 1.58 to 10.12 in R1.
4. In reactor R2, feed SCN<sup>-</sup> concentration was varied from 42 to 350 mg/L and phenol removal remained unaffected and complete phenol removal was achieved from influent concentration of 200 mg/L. It was observed that increase in SCN<sup>-</sup> concentration had inhibitory effect on denitrification and thiocyanate removal efficiencies.
5. In reactor R3, feed phenol concentration was varied from 200-600 mg/L. COD removal increased due to increase in influent phenol concentration. However, SCN<sup>-</sup> and NO<sub>3</sub>-N removal decreased. It was observed that performance of bioreactors remained unaffected due to sudden increase of influent phenol and SCN<sup>-</sup> concentrations of 1.3 times and 1.7 times respectively.

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## ENVIRONMENTAL NEWS

### **Fire-Resistant Polymer**

Researchers in Melbourne, Australia, have developed a new class of fire-resistant polymer coatings that they claim are not only cheap and versatile but are also able to survive much higher heat. A team at CSIRO in Australia has developed the fire-resistant coating materials, called HIPS (hybrid inorganic polymer system), which can withstand temperatures of up to 1000°C and could be applied to building materials.

HIPS coatings contain an inorganic geopolymer resin and a small component of polymer additives, can form thin fireproof coatings on timbers, such as weather boards and on metals like galvanised steel. It can also protect brickwork, either a thin coating or as a render. HIPS can be applied by spray equipment, roller or brush, and cures from ambient temperature to below 90°C.

It is claimed that coatings are not only fire, blast and acid-resistant, they are also strong, castable, spray-able and extricable, making their potential uses almost limitless. As water-based products, HIPS coatings are free of volatile organic compounds, do not burn or produce heat, and do not release smoke or toxic chemicals at temperatures up to 1200°C.

Geopolymers are cost-competitive, since they are made from readily available raw materials. They can also be derived from industrial byproducts, such as flyash and blast furnace slag. They can be cheaper than organic resins and coloured with pigments or dyes. CSIRO also sees potential for the manufacture of fireproof wood composites and fire seals from HIPS technology.

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### **UK's Tidal Farms**

Marine Current Turbines (MCT) a British Tidal Company, announced that it has raised £3.5m in a new funding round that will allow it to move forward with plans to deploy the UK's first commercial tidal energy farm over the next two years. A trial of the commercial scale device in Northern Ireland's Strangford Lough has already proved successful, with the system delivering over 350MW hours of power to the Irish grid in the six months it has been running.

As MCT moves forward with its Angelsey project, it is also eyeing up similar projects in Canada after recently inking memoranda of understanding with Minas Basin Pulp and Power and BC Tidal Energy Corporation that could see the companies co-operate on potential projects in Nova Scotia and Vancouver, respectively.

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