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Ambient temperature treatment of low strength wastewater using anaerobic sequencing batch reactor

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Low strength wastewater having chemical oxygen demands (COD) concentrations of 1000, 800, 600 and 400 mg/l were treated at 35, 25, 20 and 15°C using four anaerobic sequencing batch reactors (ASBRs). Reactor 1 was operated at hydraulic retention time (HRT) of 48 h, reactor 2 at 24 h HRT, reactor 3 at 16 h HRT and reactor 4 at 12 h HRT. 80 to 99% soluble COD was removed at the various operational conditions, except during 15°C treatment of 1000 and 800 mg/l COD wastewater at 12 h HRT and 1000 mg/l COD wastewater at 16 h HRT, where excessive loss of biological solids occurred. The ASBR process can be an effective process for the treatment of low concentrated wastewaters which are usually treated aerobically with large amount of sludge production and higher energy expenditures.

Introduction

Anaerobic treatment has been considered unsuitable for the treatment of low concentrated wastewaters (wastewaters with COD < 1000 mg/l), however anaerobic plants utilizing modern high-rate anaerobic reactors, such as the upflow anaerobic sludge blanket (UASB) are now used to treat such wastewaters. Such plants are located in Brazil (Viera and Garcia, 1992), Columbia (Schellinkhout and Collazos, 1992), and India (Draaijer, *et al.*, 1992). There is a need to investigate anaerobic treatment of low strength wastewaters at non-tropical temperatures.

The ASBR is a high-rate anaerobic treatment process developed by Dague, *et al.* (1992, 1970, 1966). The ASBR is a batch process which can be operated at various number of sequences per day. Each sequence of operation of the ASBR process include feed, react, settle and decant steps. The feed step involves the addition of substrate to the reactor during which time the reactor is continuously mixed. Substrate concentration and metabolic rates increase to their maximum values during the feeding step. The volume of substrate fed depends on a number of factors, including the desired hydraulic retention time (HRT), organic loading, and expected settling characteristics. The conversion of biodegradable organic matter to biogas is achieved during the react step. Continuous or intermittent mixing could be used during the react step. The time required for the react step depends on the required effluent quality as well as biomass concentration, temperature, substrate characteristics, and type of biomass (flocculent or granulated). The settling step requires that mixing be shut off allowing biomass settling to occur within the reactor. The required time for the settling step depends on biomass concentration, temperature, and type of biomass (flocculent and granulated). Decantation takes place at the end of settling. The volume decanted is normally equal to the volume fed during feeding so that the volume is maintained. Since partial volume is withdrawn during decantation, the ASBR operation results in a variable substrate concentration in the reactor, alternating from high concentration during and immediately after feeding to low substrate concentration at the end of the reaction, just before biomass (M) settling and the beginning of effluent decanting. The variable substrate concentration (food: F) results in a variable food-to-microorganism (F/M) ratio in the reactor. The high F/M ratio occurring immediately after feeding results in high rate of substrate utilization, in accordance with Monod kinetics. The low F/M ratio occurring at the end of the react step through the end of the decant step is known to foster bioflocculation, granulation, efficient biomass settling and a long biological solids (biomass) retention time (SRT). Numerous laboratory and pilot plant studies have been conducted using the ASBR for the treatment of high strength industrial and agricultural wastes but not for treating low strength industrial and municipal wastewaters. Research was conducted to investigate the application of the ASBR process for the

Table 1 ASBR sequencing characteristics used for the treatment of synthetic milk substrate

Parameter	Hydraulic retention time (HRT), h			
	48	24	16	12
Sequencing Characteristics				
Number of sequences per day	6	6	6	6
Length of sequence, (hours)	4	4	4	4
Volume of feed per sequence, (liters)	0.5	1.0	1.5	2.0
Volume of feed per day, (liters)	3	6	9	12
Volume of decanted per sequence, (liters)	0.5	1.0	1.5	2.0
Volume decanted per day, (liters)	3	6	9	12
Feeding time; (min)	5	10.5	16.87	11.22
React time; (min)	189.5	179.5	171.11	180.8
Settling time; (min)	40	40	40	40
Decanting time; (min)	5.5	10	12	8
Substrate COD, (mg/L)	COD Loadings (g/L.day)			
1000	0.5	1.0	1.5	2.0
800	0.4	0.8	1.2	1.6
600	0.3	0.6	0.9	1.2
400	0.2	0.4	0.6	0.8

treatment of low strength wastewaters at various operational conditions, especially at low (non-tropical) temperatures.

Materials and methods

Synthetic milk (non-fat dry milk; NFDM) at 1000, 800, 600, 400 mg/L with corresponding BOD_5 values of 490, 394, 293 and 196 mg/L was used as substrate. Four identical, 6-liter laboratory scale ASBRs were used, but operated under different conditions as given in Table 1. Reactor one was operated at 48 hour hydraulic retention time (48 h HRT), reactor two at 24 h HRT, reactor three at 16 h HRT and reactor four at 12 h HRT. All reactors were operated at 35, 25, 20 and 15°C. The four substrate concentrations were treated in each reactor at all the temperatures. Properties of the NFDM are shown in Table 2. The substrate was supplemented with trace minerals solution containing the following mineral salts: $FeCl_2.4H_2O$ at 35.60 g/L, $ZnCl_2$ at 2.08 g/L, $NiCl_2.6H_2O$ at 4.05 g/L, $CoCl_2.6H_2O$ at 4.04 g/L, $MnCl_2.4H_2O$ at 3.61 g/L. $NaHCO_3$ was added to maintain the pH between 6.8 to 7.2. The four ASBRs were seeded with primary anaerobic digester sludge obtained from the Water Pollution Control Plant at Ames, Iowa.

Table 2 Properties of the non-fat dry milk (NFDM)

Parameter	Value
Chemical Oxygen Demand, (g COD/L per g NFDM)	1.04
Five-day Biochemical Oxygen Demand, (g BOD/L per g NFDM)	0.49
Total Kjeldahl Nitrogen, (% w/v)	5.4
Total phosphate, as PO_4 (% w/v)	2.2
Lactose, (% w/v)(1)	51.0
Protein, (% w/v)(1)	>36.0
Fat, (% w/v)(1)	<1.0
Ash, (% w/v)(1)	8.2
Trace Minerals(1)	
Iron, (mg/l)	4.6
Nickel, (mg/l)	1.0
Cobalt, (mg/l)	0.8
Molybdenum, (mg/l)	3.0
Zinc, (mg/l)	15.0

(1) Source of data is Swiss Valley Farms, Inc., Davenport, Iowa.

Results and discussion

The results of the study are presented in Tables 3 to 6 for the study at 35, 25, 20 and 15°C, respectively. As presented in Table 3, soluble COD removal at 35°C ranged from 92 to 99% at all substrate concentrations and HRTs. However, the operation of anaerobic reactors at 35°C requires external heating of the system. For high strength wastes, the external heating may be supplied by the utilization of methane gas produced. However, minimum amount of methane is produced during anaerobic treatment of low strength wastes. Therefore, it is essential that an anaerobic system be capable of operating under ambient temperature for economical anaerobic treatment of low strength wastes. The results of this study show 88 to 98% and 85 to 98% soluble COD removal at 25 and 20°C respectively, at the various substrate concentrations and HRTs, as presented in Tables 4 and 5. At 15°C, the ASBR

Table 3 COD and BOD_5 removal efficiencies for various substrate concentrations and HRTs at 35°C

Hydraulic Retention Time(h)	Effluent COD, (mg/L)		COD Removal, (%)		Effluent BOD_5, (mg/L)		BOD Removal, (%)	
	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)
				Feed COD = 1000 mg/L (BOD_5 = 490 mg/L)				
48	74	14	93	99	29	4	93	99
24	90	35	91	97	36	13	92	97
16	94	50	91	95	38	19	91	96
12	135	80	87	92	56	31	87	93
				Feed COD = 800 mg/L (BOD_5 = 392 mg/L)				
48	90	33	89	96	36	12	90	97
24	94	30	86	96	38	11	89	97
16	95	36	91	96	30	13	92	96
12	100	67	88	92	40	23	89	94
				Feed COD = 600 mg/L (BOD_5 = 294 mg/L)				
48	83	28	87	95	33	10	88	97
24	88	28	86	96	36	9	87	97
16	51	23	92	96	19	7	99	97
12	66	43	89	93	26	16	90	94
				Feed COD = 400 mg/L (BOD_5 = 196 mg/L)				
48	58	16	86	97	23	4	87	97
24	53	19	86	95	20	6	86	97
16	44	21	89	95	17	6	90	96
12	37	23	91	94	13	7	92	96

Table 4 COD and BOD_5 removal efficiencies for various substrate concentrations and HRTs at 25°C

Hydraulic Retention Time (h)	Effluent COD, (mg/l)		COD Removal, (%)		Effluent BOD_5, (mg/L)		BOD Removal, (%)	
	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)
				Feed COD = 1000 mg/L (BOD_5 = 490 mg/L)				
48	47	19	95	98	18	6	96	99
24	68	35	94	97	27	12	94	97
16	236	119	77	88	102	51	77	89
12	431	25	77	88	102	51	77	89
				Feed COD = 800 mg/L (BOD_5 = 392 mg/L)				
48	55	24	93	97	21	8	94	98
24	64	26	92	97	25	9	93	98
16	153	85	81	90	64	34	82	90
12	161	87	80	89	67	35	81	90
				Feed COD = 600 mg/L (BOD_5 = 294 mg/L)				
48	54	23	92	96	21	7	92	97
24	47	20	92	97	18	6	93	98
16	103	52	85	92	43	20	84	92
12	101	46	84	93	41	17	85	94
				Feed COD = 400 mg/L (BOD_5 = 196 mg/L)				
48	37	18	91	96	13	5	93	97
24	35	17	92	96	13	5	93	97
16	58	35	86	92	23	12	87	93
12	59	32	86	92	23	12	87	94

Table 5 COD and BOD_5 removal efficiencies for various substrate concentrations and HRTs at 20°C

Hydraulic Retention Time (h)	Effluent COD, (mg/l)		COD Removal, (%)		Effluent BOD_5, (mg/L)		BOD Removal, (%)	
	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)
			Feed COD = 1000 mg/L (BOD_5 = 490 mg/L)					
48	57	17	94	98	36	5	95	99
24	81	37	92	96	32	13	93	97
16	298	184	71	82	126	77	71	83
12	212	151	69	85	134	62	70	86
			Feed COD = 800 mg/L (BOD_5 = 392 mg/L)					
48	61	29	93	97	24	10	93	97
24	68	31	91	96	30	118	92	97
16	141	100	83	88	58	40	84	89
12	212	118	74	86	89	48	75	86
			Feed COD = 600 mg/L (BOD_5 = 294 mg/L)					
48	54	26	91	96	21	9	92	97
24	46	26	91	96	17	9	94	97
16	95	69	85	89	39	27	85	90
12	117	86	81	86	48	34	82	87
			Feed COD = 400 mg/L (BOD_5 = 196 mg/L)					
48	54	24	87	94	21	8	88	96
24	50	22	88	95	19	7	89	96
16	57	40	86	90	22	15	87	92
12	64	45	84	89	25	17	86	90

Table 6 COD and BOD_5 removal efficiencies for various substrate concentrations and HRTs at 15°C

Hydraulic Retention Time (h)	Effluent COD, (mg/l)		COD Removal, (%)		Effluent BOD_5, (mg/L)		BOD Removal, (%)	
	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)	Total (unfiltered)	Soluble (filtered)
			Feed COD = 1000 mg/L (BOD_5 = 490 mg/L)					
48	86	47	92	95	24	5	98	99
24	131	73	87	93	35	13	92	97
16	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
			Feed COD = 800 mg/L (BOD_5 = 392 mg/L)					
48	86	48	89	94	34	18	90	95
24	98	58	88	93	40	22	89	94
16	149	114	82	86	62	46	82	87
12	–	–	–	–	–	–	–	–
			Feed COD = 600 mg/L (BOD_5 = 294 mg/L)					
48	86	50	86	92	34	19	87	93
24	62	39	90	94	24	14	91	95
16	116	85	81	86	48	34	82	87
12	121	88	81	86	49	34	81	87
			Feed COD = 400 mg/L (BOD_5 = 196 mg/L)					
48	64	41	84	90	25	15	86	91
24	54	36	87	91	21	13	88	93
16	75	50	82	88	30	19	83	89
12	81	54	80	87	32	20	82	88

systems were able to achieve over 85% soluble COD removal for the lower substrate concentrations of 600 and 400 mg/l at all HRTs (Table 6). Treatment at substrate concentrations of 1000 and 800 mg/l COD at 15°C resulted at 82 to 98% COD removal at longer HRTs of 48 and 24 h. At the 15°C, treatment was not possible at the lower HRTs (16 and 12 h) as a result of excessive loss of biological solids in the effluent. These findings show that the ASBR process could be used to treat various low strength wastewaters which are usually treated aerobically with high energy expenditures and high sludge production, especially at ambient temperatures.

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