Modification and expansion of a pure oxygen WWTP for biological nutrient removal (BNR)

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Abstract A pure oxygen activated sludge system was converted to a VIP configuration BNR (biological nutrient removal) system wherein three of the five pure oxygen sections were retained, and performance was compared to that of a side-by-side air aeration MUCT (modified UCT) system. Because the pure oxygen BNR system could not obtain good nitrification, its treatment capacity had to be downgraded from 113,550 m^3/d to a flow of only 60,000 m^3/d. At the lesser flow, it was determined that adequate nitrification and improved denitrification could be accomplished in the pure oxygen system by continuously seeding it with 100% of the WAS from the MUCT system. Fortunately, while the capacity of the pure oxygen system had to be downgraded, it was determined that the capacity of the MUCT system was substantially greater than its design flow, and the combined system is capable of treating the entire design flow. However, this requires increasing the operating sludge age of the MUCT system. The pure oxygen BNR system performed better phosphorus removal than the MUCT system, both before and after seeding with the MUCT WAS. Apparently this was because the MUCT system was operated at a substantially higher sludge age than the pure oxygen system. However, both systems have consistently discharged effluent phosphorus concentrations of less than 2.0 mg/L TP, which is the Chesapeake Bay standard. Even with improved nitrification and denitrification in the pure oxygen BNR system, neither it nor the MUCT system have proven to be capable of meeting the Virginia Chesapeake Bay goal of 10 mg/L total nitrogen in the effluent.

Keywords Biological nutrient removal; pure oxygen; aeration; municipal wastewater treatment; performance

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Introduction

The Henrico County, Virginia, Water Reclamation Facility serves the suburbs of Richmond, Virginia, north of the James River. Originally designed as a 113,500 m^3/day UNOX pure oxygen activated sludge process facility, it was determined in 1990 that it needed to be both expanded and upgraded because of increased flows and the more stringent effluent nutrient requirements of the Chesapeake Bay Watershed being implemented as part of the Chesapeake Bay Program. The new standards required average monthly concentrations of 2.0 mg/L or less effluent total phosphorus (TP), and effluent ammonia-N concentrations of 6.4 mg/L during summer and 9.3 mg/L during winter, with a yearly average total nitrogen effluent goal of 10 mg/L or less. After engineering studies, it was decided to expand the facility to a flow capacity of 170,325 m^3/day by adding biological nutrient removal (BNR) units, and to upgrade the existing pure oxygen system by converting it to a BNR configuration. The pure oxygen system did not nitrify as operated because of the depressed pH of the mixed liquor caused by the build-up of carbon dioxide in the sealed UNOX units. It was decided that the new BNR units would be aerated by diffused aeration rather than by pure oxygen technology, while the existing system would continue to be aerated using pure oxygen in most of the aerated sections, and thereby continue to utilize the on-site oxygen generating facility.

Description of the wastewater plant

The VIP (a.k.a. UCT) and Modified UCT (MUCT) configurations were selected for pilot plant evaluation and the two studies were performed in 1991–2 (Black & Veatch, 1992). Based on the pilot plant results, it was decided to modify the existing pure oxygen system to a VIP configuration that included some pure oxygen sections, and to construct two new diffused aeration BNR trains using the MUCT configuration. Construction for both the modifications and the new BNR trains was completed in 1997. Following construction, the total water reclamation facility consists of two separate treatment plants, as shown in Figure 1.

The treatment train of the modified pure oxygen plant was designed to consist of four identical activated sludge basins, which would be operated with an anaerobic section, an anoxic section, two covered pure oxygen sections, and a diffused aeration section for CO_2 stripping, all in series. The pure oxygen train was expected to treat an average daily flow of 113,550 m^3/day by nitrification, denitrification and biological phosphorus removal. However, the configuration had to be modified to the configuration shown in Figure 1 to accomplish adequate nitrification, i.e., with a combination anoxic-anaerobic section, three covered pure oxygen sections, and a CO_2 stripping section. The full pure oxygen plant also consists of four primary clarifiers and four secondary clarifiers.

The MUCT plant consists of two parallel trains with the same configuration shown in Figure 1, and has been operated in that configuration since start-up. It has two primary clarifiers and two secondary clarifiers separate from the pure oxygen plant. However, the two plants share the same effluent filters and the same sludge processing equipment, including two-stage anaerobic digestion (Randall and Ubay Cokgor, 2000).

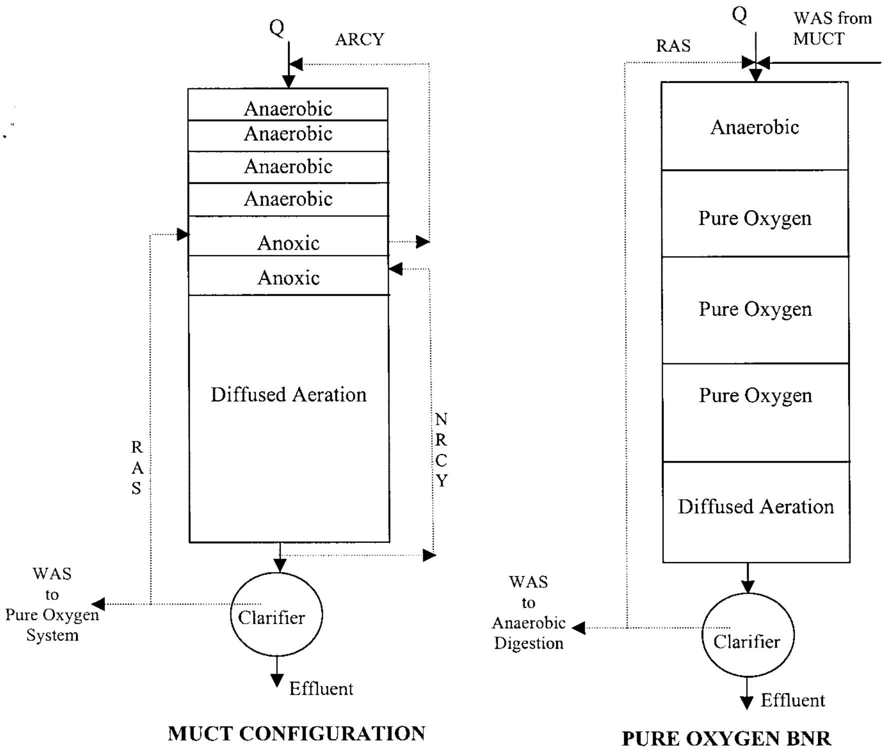

Figure 1 System configurations of Henrico County, Virginia, Water Reclamation Facility

Results and evaluation

Between 1 October 1997 and 31 January 2000, wastewater characterization and performance data was obtained from each of the 2 treatment plants. The wastewater characterization and plant performance data for those systems are tabulated in Table 1. The data are separated into 2 time periods because of changes in the way the modified pure oxygen BNR was being operated during the 25-month period. During the first few months of start-up it was determined that the modified pure oxygen plant was unable to accomplish adequate nitrification. The effluent ammonia-nitrogen concentrations discharged by the two side-by-side plants during this period are illustrated by Figure 2. A fully nitrifying activated sludge was used to seed both configurations for start-up and this resulted in low effluent total ammonia-N concentrations from both during the first two months.

The MUCT plant continued to nitrify very well following start-up, except during February, 1998 when very high influent flows occurred, and during September, 1998, March 1999 and April 1999 when the operators were experimenting with low SRTs. With the exception of those four months, the average ammonia-N effluent concentration from the MUCT plant was around 2 mg/L from October 1998 through May 1999. In contrast, the effluent ammonia-N concentration from the pure oxygen BNR system increased after start-up to an average of 7.3 mg/L during January, 1998, and averaged 8.7 mg/L through May, 1999. The average from May through October was 7.3 mg/L, which exceeded the effluent standard.

Figure 3 illustrates the improvement in nitrification with the introduction of the MUCT WAS to the pure oxygen plant. This graph shows the rapid decrease in effluent ammonia-N that was observed during early June, 1999 when WAS addition was started. Some peaks were observed during July because of SRT experimentation. An SRT of greater than 6 days was needed for optimum nitrification.

Neethling *et al*. (1998) performed a similar experiment wherein they added WAS from a fully nitrifying activated sludge system to a high purity oxygen activated sludge system. This practice reduced the effluent ammonia concentration from more than 5 mg/l to less than 1 mg/l after about a month of operation.

Figure 4 compares the effluent phosphorus concentrations from the two plants during start up and after pure oxygen seeding began. The results show that the performance of the pure oxygen BNR equaled or exceeded the performance of the MUCT system during both the before and after periods. The pure oxygen effluent averaged 1.7 mg/L before seeding, the same as the MUCT system, and 1.2 mg/L after. The MUCT process effluent

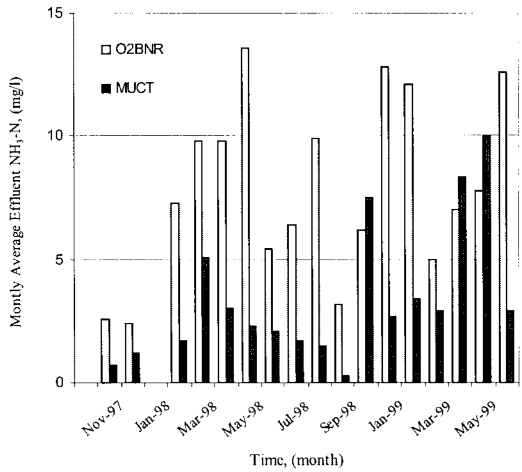

Figure 2 Comparison of effluent ammonia concentrations

Table 1 Wastewater characterization and biological treatment performance of the pure oxygen and MUCT processes

	Primary Effluent							Bioprocess Removal									
	Flow[1] MGD	Flow[2] MGD	BOD[1] mg/l	BOD[2] mg/l	TP[1,2] mg/l	TKN[1,2] mg/l	NH_3-N[1,2] mg/l	BOD[1] %	BOD[2] %	TP[1] %	TP[2] %	NH_3-N[1] %	NH_3-N[2] %	TKN[1] %	TKN[2] %	TN[1] %	TN[2] %
Oct-97	15.24	14.44	100	99	6.2	33.6	21.1	96.6	97.1	69.4	71.0	96.7	87.7	92.86	86.9	58.0	56.3
Nov-97	18.72	18.46	93	92	3.8	23.5	15.2	95.7	96.1	81.6	81.6	92.1	84.2	87.66	82.6	55.3	48.9
Jan-98	20.94	30.18	78	80	4.5	23.6	12.6	92.1	86.3	60.0	66.7	86.5	42.1	83.90	55.9	43.6	41.1
Feb-98	26.07	39.77	57	56	2.8	16.3	10.2	86.5	70.9	73.9	51.2	50.0	3.9	58.28	18.4	39.6	10.9
Mar-98	25.1	33.53	60	67	3.0	18.3	10.7	90.5	91.6	59.5	26.8	72.0	8.4	74.32	27.9	49.9	19.6
Apr-98	22.79	22.86	75	57	3.1	19.7	10.9	92.0	91.8	59.1	33.8	78.9	0	76.14	14.7	51.0	6.9
May-98	21.15	20.24	86	83	3.8	24.5	14.6	94.2	95.1	70.7	54.9	85.6	63.0	83.27	67.8	53.6	47.9
Jun-98	18.76	16.57	116	88	3.8	25.6	15.7	95.4	93.6	75.7	45.1	89.2	59.2	82.42	63.3	48.2	44.1
Jul-98	13.98	18	97	85	4.1	27	17.3	96.3	94.2	54.5	54.0	91.3	42.8	88.15	53.3	51.9	34.9
Aug-98	15.94	13.51	90	80	4.3	28.1	17.5	96.4	94.1	53.7	45.1	98.3	81.7	94.31	73.0	53.2	39.3
Sep-98	18.84	9.72	113	79	4.6	31.4	22	96.2	95.3	52.2	43.5	65.9	71.8	67.52	75.2	43.0	36.0
Oct-98	19	11.21	123	105	4.5	31.6	22.2	97.7	94.5	68.9	46.7	87.8	42.3	87.34	50.3	49.7	24.1
Jan-99	20.22	19.44	101	86	4.1	25.1	17	95.9	95.8	73.2	70.7	80.0	28.8	78.88	40.6	45.8	34.3
Feb-99	16.84	15.08	95	104	4.3	28	19.4	95.1	97.4	27.9	60.5	85.1	74.2	80.36	72.9	51.4	47.1
Mar-99	19.98	19.45	130	85	4.2	26.8	18.1	95.5	96.4	54.8	88.1	54.1	61.3	55.97	63.1	41.8	47.4
Apr-99	18.41	16.26	103	102	4.7	29.2	19.4	95.5	97.3	44.7	57.4	48.5	59.8	48.29	64.4	32.2	49.3
May-99	15.79	15.42	113	126	4.9	31.2	20.3	94.4	97.1	36.7	81.6	85.7	37.9	76.60	47.1	44.9	40.4
Minimum	**14.0**	**9.7**	**57.0**	**56**	**2.8**	**16.3**	**10.2**	**86.5**	**70.9**	**27.9**	**26.8**	**48.5**	**0.0**	**48.3**	**14.7**	**32.2**	**6.9**
Maximum	**26.1**	**39.8**	**130.0**	**126**	**6.2**	**33.6**	**22.2**	**97.7**	**97.4**	**81.6**	**88.1**	**98.3**	**87.7**	**94.3**	**86.9**	**58.0**	**56.3**
Average	**19.3**	**19.7**	**95.9**	**86.7**	**4.2**	**26.1**	**16.7**	**94.5**	**93.2**	**59.8**	**57.6**	**79.3**	**50.0**	**77.4**	**56.3**	**47.8**	**37.0**
Jun-99	15.46	14.52	120	130	4.6	33.9	18.8	96.8	97.9	54.3	63.0	95.2	68.1	90.86	74.3	64.3	59.0
Jul-99	16.28	16.39	107	115	4.5	30.1	19.5	95.7	97.3	51.1	68.9	89.2	88.2	85.05	86.7	56.5	61.5
Aug-99	14.35*	14.35*	118	116	5.1	30.2	19.4	96.5	98.0	41.2	82.4	69.1	63.9	61.26	65.2	45.0	54.0
Sep-99	24.29*	24.29*	86	80	3.9	25.1	14.6	95.2	96.6	71.8	74.4	89.7	83.6	84.46	83.3	59.4	48.2
Oct-99	18.65*	18.65*	104	98	4.6	28.1	16.9	95.0	95.8	63.0	84.8	94.7	55.0	88.97	62.3	56.6	49.8
Nov-99	17.67*	17.67*	133	118	4.8	30.6	18.2	95.0	96.6	43.8	81.3	86.3	80.2	83.33	80.4	60.1	65.7
Dec-99	15.66*	15.66*	143	100	4.9	32.7	20.7	96.2	97.4	67.3	69.4	77.8	87.0	77.68	84.7	59.0	57.5
Jan-00	18.08*	18.08*	120	104	4.2	28.3	17.8	94.0	95.4	59.5	71.4	72.5	69.1	67.49	62.2	48.8	41.3
Minimum	**14.3**	**14.3**	**86**	**80**	**3.9**	**25.1**	**14.6**	**94.0**	**95.4**	**41.2**	**63.0**	**69.1**	**55.0**	**61.3**	**62.2**	**45.0**	**41.3**
Maximum	**24.3**	**24.3**	**143**	**130**	**5.1**	**33.9**	**20.7**	**96.8**	**98.0**	**71.8**	**84.8**	**95.2**	**88.2**	**90.9**	**86.7**	**64.3**	**65.7**
Average	**17.6**	**17.4**	**116**	**107.6**	**4.6**	**29.9**	**18.2**	**95.6**	**96.9**	**56.5**	**74.4**	**84.3**	**74.4**	**79.9**	**74.9**	**56.2**	**54.6**

1 MUCT Process 2 Pure Oxygen Process * 50% Flow Split Assumed

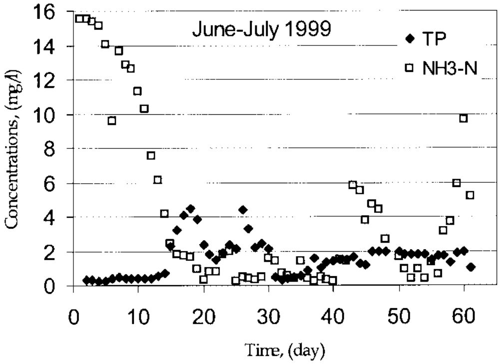

Figure 3 Decrease in ammonia effluent concentrations in the pure oxygen BNR with MUCT WAS addition

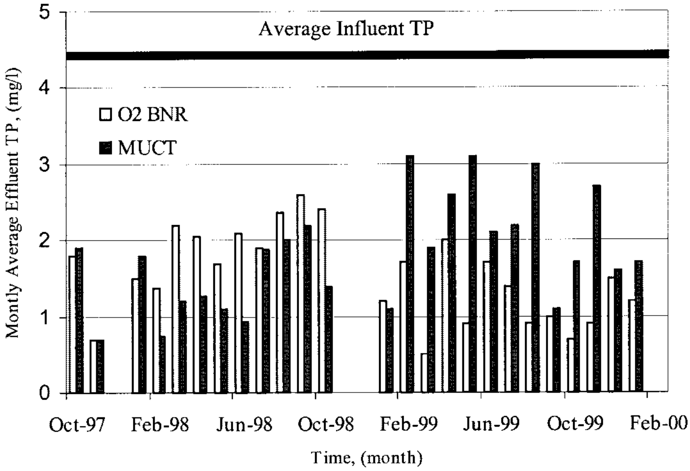

Figure 4 Comparison of effluent TP concentrations

phosphorus, however, increased from 1.7 mg/L to 2.0 mg/L during the second period. However, the MUCT system always had a significantly longer sludge age than the pure oxygen system, and this may have accounted for the difference between the two systems. The pure oxygen sludge age was only 7.1 and 6.2 days during the two periods, respectively, whereas the MUCT sludge age was 11 and 14.4 days during the two periods. Apparently the longer sludge ages had a detrimental effect on the phosphorus removal performance of the MUCT system.

Conclusions

A pure oxygen activated sludge system was converted to a VIP configuration BNR system wherein three of the five pure oxygen sections were retained, and performance was compared to that of a side-by-side air aeration MUCT system. Initially good nitrification could not be obtained with the pure oxygen system following conversion to BNR whereas good nitrification was obtained with the MUCT system except during sludge age experimentation. However, both nitrification and denitrification in the pure oxygen system were improved after WAS from the MUCT system was continuously fed to the pure oxygen system for seeding purposes. But, the capacity of the pure oxygen system had to be downgraded from its monthly average design flow of 113,550 m^3/d to a flow of only 60,000 m^3/d to achieve acceptable performance. Fortunately, the capacity of the MUCT system has proven to be greater than anticipated, and the combined system is capable of treating the entire design flow. However, this required increasing the operating sludge age of the MUCT system.

The pure oxygen BNR system performed better phosphorus removal than the MUCT system, both before and after seeding from the MUCT system. Apparently this was because the MUCT system was operated at a substantially higher sludge age than the pure oxygen system. However, both systems have consistently discharged effluent phosphorus concentrations of less than 2.0 mg/L TP, which is the Chesapeake Bay standard.

Although WAS seeding from the MUCT system has improved nitrification and denitrification by the pure oxygen BNR process, performance is still somewhat erratic with an average effluent ammonia concentration of 4.6 mg/L, and neither plant has been able to consistently achieve the Virginia Chesapeake Bay goal of 10 mg/L total nitrogen in the effluent.

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