NITROGEN AND PHOSPHOROUS REMOVAL FROM HIGH STRENGTH WASTEWATERS

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ABSTRACT

The present paper reports on an extended aeration wastewater treatment plant in Jordan in which BOD, nitrogen, and phosphorous are removed in a single reactor. The plant treats high strength wastewater with an average COD, phosphorous, and nitrogen concentration of 2000, 35, and 120 mg/L, respectively. The aeration reactor configuration consists of an anoxic contact zone followed by an anaerobic zone, and then an aerobic/anoxic zone through time sequencing (AZENIT P® configuration). Aeration of the aerobic/anoxic zone is achieved by circular surface aerators. The time sequencing is supposed to be controlled by oxidation reduction potential (ORP) measurements. The plant achieves high levels of BOD (98%) and nitrogen removals (90%) with almost continuous aeration in the aerobic/anoxic zone. Nitrogen removal is mainly due to simultaneous nitrification and denitrification (SND). SND occurred at ORP values of about zero (about -20 mV to +20 mV). It is believed that SND will be responsible for nitrogen removal if surface aerators are used in the treatment of high strength wastewater. Phosphorous removal percentages were low resulting in effluent concentrations (about 10 mg/L) higher than that required by Jordanian standards. This is mainly due to the high phosphorous concentration and to the low amount of sludge wasted as a result of high sludge age and low F/M.

Keywords: SND, Nitrification, Denitrification, Extended aeration plants, Redox Potential.

1. Introduction

The operation of a single reactor to achieve nitrogen removal usually involves the repeating sequence (either in time or in space) of an aerated period (air-on period) followed by a period with no aeration (air-off period). However, a number of studies have indicated that nitrification could be achieved at lower oxygen concentration than previously thought. Oxygen concentration as low as 0.3 mg/l achieved nitrification (Pochana and Keller, 1999), while denitrification was observed at dissolved oxygen concentration as high as 1.5 mg/l (O'Neill and Horan, 1995; Di Bella and Torregrossa, 2013). This simultaneous nitrification/ denitrification (SND) process has been reported to occur at full scale extended aeration treatment plants and in lab scale studies.

The successful operation of the timed sequence plants depends on the optimization of the air-on/air-off periods. As the discharge and the strength of wastewater are variable from hour to hour, the air-on/air-off periods have to be tailored and altered constantly throughout the day to match the varying wastewater discharge and strength. One way to control these periods is to have a fixed air-on period followed by another fixed air-off period. These fixed values are subject to change according to the effluent quality. This method requires frequent changes in the air-on/air-off periods that consistent high removal efficiencies may not be possible. Other online control methods have been suggested and used to control the air-on/air-off periods. Oxidation reduction potential (ORP) can be used to start and to shut down aeration in one of two ways. The first one is to specify a maximum value for aeration to stops and a minimum value, at which aeration starts (Yu *et al*.

2000). The advantage of this method is that it is easy to implement. The disadvantage is that the maximum and minimum ORP set points vary from wastewater to wastewater and with changing wastewater characteristics. The second method is based on monitoring the slope of the ORP with time. When nitrates disappear from wastewater, the slope suddenly drops creating what resembles a knee (Vanrolleghem and Lee 2003). Aeration should start as this knee is detected. The disadvantage of this method is that it is not always possible by the computer to detect the occurrence of this knee.

2. Treatment plant operation

The aeration tank of the treatment plant reported here starts by an initial anoxic zone (zone 1 in Table 1) followed by an anaerobic zone (zone 2 in Table 1). The purpose of the initial anoxic zone is the removal of nitrate recycled from the aeration tank effluent (denitrification). This zone also insures that the following anaerobic zone is truly anaerobic. The treatment process at the remaining part of the aeration tank (zone 3) is supposed to operate in an aerated/non-aerated sequence, by implementing an air-on period, followed by an air-off period (AZENIT P® configuration). During the time of this study zone 3 was aerated most of the time with short random air-off periods. The plant operators experimented with various air-on and air-off periods in an attempt to optimize the process operation, but with limited success. During the almost continuous aeration period of zone 3, the effluent quality continued to be excellent (average 10 and 31 mg/L BOD and TSS, respectively). During the study period, the duration of the air-on (aerobic, nitrification) cycle was more than 20 hours a day most of the times. In some days it was 23 hours. The ORP signal from the aeration tank was monitored remotely throughout the project. As nitrate concentration was measured at the most daily there is no way of comparing the nitrate concentration to the ORP reading. Therefore the observation of the "knee" is not possible.

3. Results and discussion

Table 1 shows the average operating parameters of the treatment plant. The long hydraulic retention time (HRT) and low food to microorganism (F/M) ratio are apparent. Table 2 shows the average (and range) influent and effluent concentrations of a number of parameters. Table 2 shows that the plant achieves high rate of BOD, COD, and TSS removals that averaged about 98%, 97% and 96%, respectively. The high retention time is responsible for the high removal efficiencies. Sludge bulking is not a problem despite the low F/M ratio. This may be due to the presence of the anoxic contact zone at the start of the aeration tank.

Nitrogen is measured here in terms of ammonia plus nitrate. The average effluent ammonia and nitrate (as N) concentrations are about 1.0 mg/L, and 4 mg/L, respectively. The average removal efficiency is 94%. During the course of this study, the aerobic/anoxic zone of the aeration tank was almost always continuously aerated. Aeration time at high speed reached in some days 23 hours, while the off aeration time was only 1 hour. In many days, aeration reached 22 hours per day at high speed, while the off time was 2 hours. Aeration time ranged between 18-22 hours, with an average aeration time of 19 hours. In addition, the off aeration time was not systematically applied. In most cases, the off aeration periods were at least 1or 2 continuous hours. No systematic alteration between aeration and off periods was practiced. The air-on period to air-off period reached values like 180 minutes to 11 minutes, respectively. Both ORP and timer operation were used to control the process of aeration. The occurrence of the high nitrogen removal percentages during aerated periods is a clear indication of the occurrence of SND. SDN occurred at DO concentrations that are typical in the design of surface aerators for high strength wastewaters. It has been suggested that surface aerators in deep tank creates a vortexing action that produce areas of aerobic and anoxic conditions (Naidoo *et al*., 2002). Regardless of the explanation, SND is the mechanism of nitrogen removal in plants aerated by surface aerators treating high strength wastewaters. SND was also observed in three other plants in Jordan, where surface aerators are

used in treating high strength wastewaters. Ammary and Radaideh (2005) reported on one of these plants.
During the aeration periods, the dissolved oxygen (DO) concentrations were between 0.4 – 2.3 mg/L and the ORP ranged between -10 to + 80 mV with an average value of about +25 mV. When aeration was turned off, the DO dropped to almost zero, while the ORP dropped to become negative. SND occurred at ORP values of around zero (-20 mV to about +20 mV) (see Figure 1). It is believed that SND is responsible for nitrogen removal during the aeration phase if surface aerators are used in the treatment of high strength wastewater. When long air-off period was provided, the ORP value was almost always below zero, even though SND was occurring during the air-on period. Figure 2 is an example of such operation.

Phosphorous removal percentages were low resulting in effluent concentrations (about 10 mg/L) higher than that required by Jordanian standards. This is mainly due to the high phosphorous concentration and to the low amount of sludge wasted as a result of high sludge age and low F/M ratio.

4. Conclusion

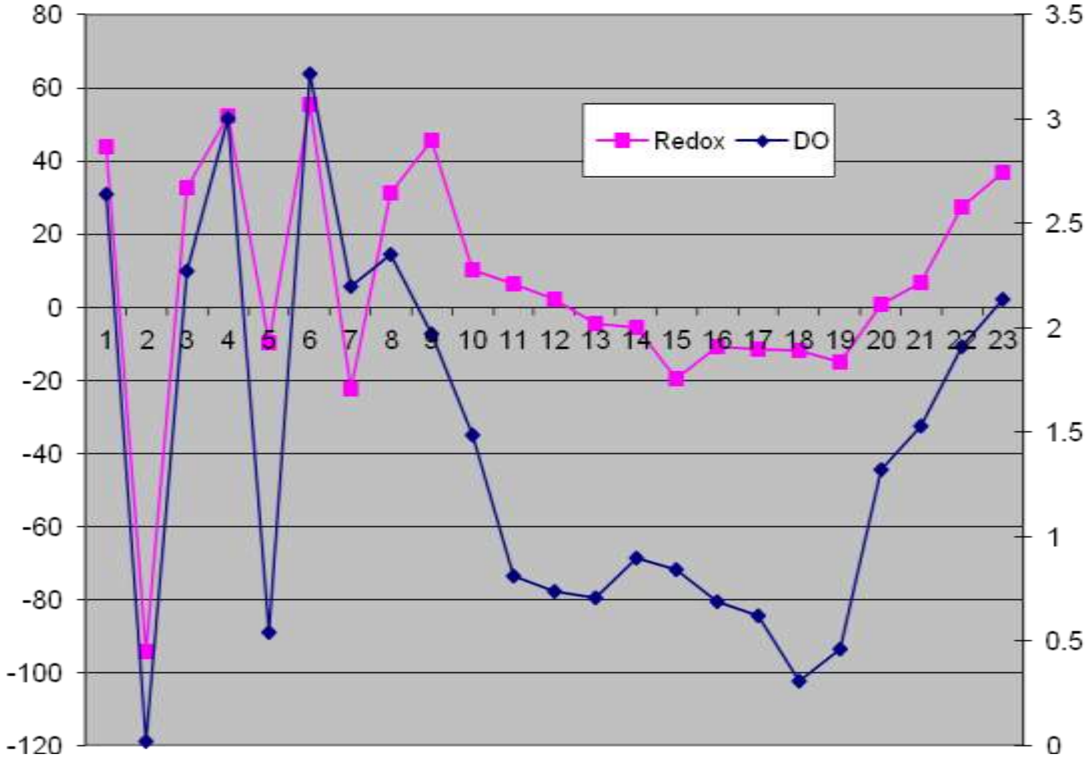
SND occurred in an extended aeration treatment plant treating high strength wastewater in which surface aerators were used. SND occurred at ORP near zero (-20 mV to +20 mV). Phosphorous removal in such plant was not high due to low sludge production in such plants.

Table 1: Wastewater treatment plant average operating conditions during the study period.

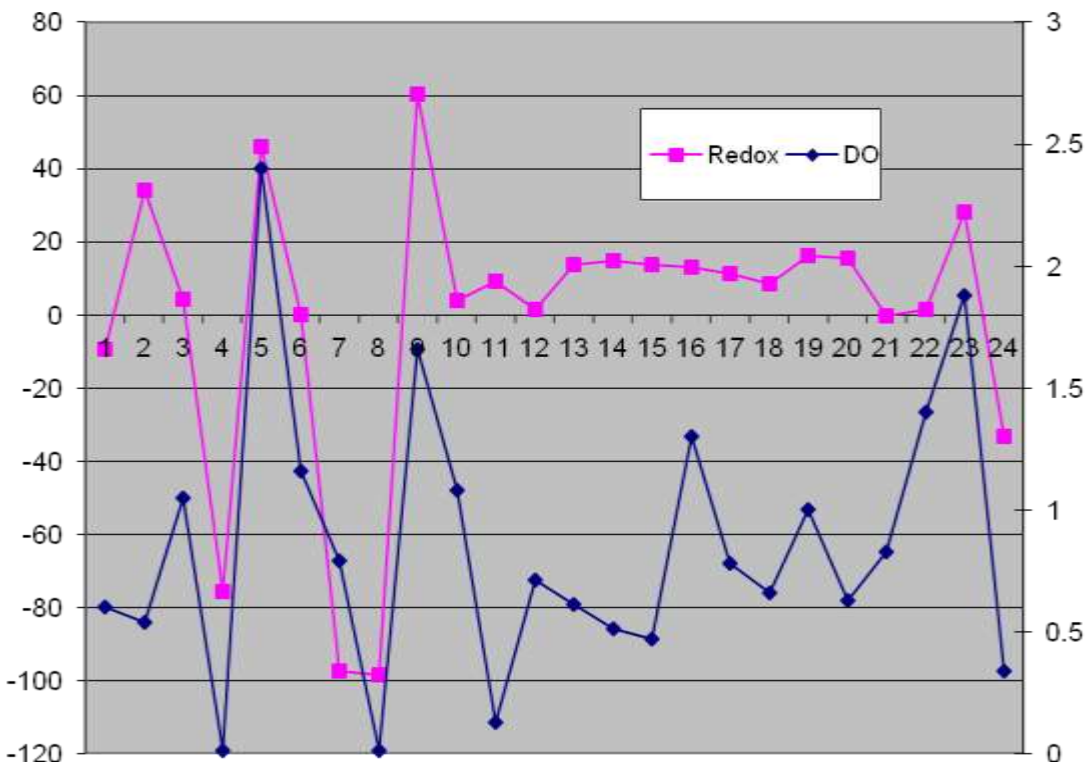
Parameter	Average	Range
Flow (m^3/day)	2521	2415 – 2753
HRT (days)	3.14	2.87-3.27
Anoxic time (hr) (Zone 1)	1.91	1.74 – 1.99
Anaerobic Time (Zone 2), (hr)	2.86	2.62 – 2.98
Time in zones 1 and 2 (hrs)	4.77	4.36 – 4.97
MLSS	3787	3000 – 5810
MLVSS (mg/L)	2878.125	2330 – 4190
F/M (kg BOD/kg MLSS/day	0.075	0.035 - 0.098
F/M (kg COD/Kg MLVSS/day)	0.26	0.11 - 0.40

Table 2: Plant average influent and effluent concentrations during the study period.

	Influent		Effluent	
Parameter	**Average**	**Range**	**Average**	**Range**
BOD (mg/L)	904	470 - 1180	10	5 – 16
COD (mg/L)	2338	1188 - 3977	72	31 – 164
NH_4-N (mg/L)	90	58 - 135	1.0	0.5 – 2.0
NO_3-N (mg/L)	1.5	0.37 – 2.6	4.1	1.4 – 7.0
NH_4-N+NO_3-N (mg/L)	91	60 - 136	5.1	2.9 – 7.7
PO_4-P (mg/L)	17.3	14 – 25	10	6 – 15
TSS (mg/L)	745	340 - 1236	31	25 – 47

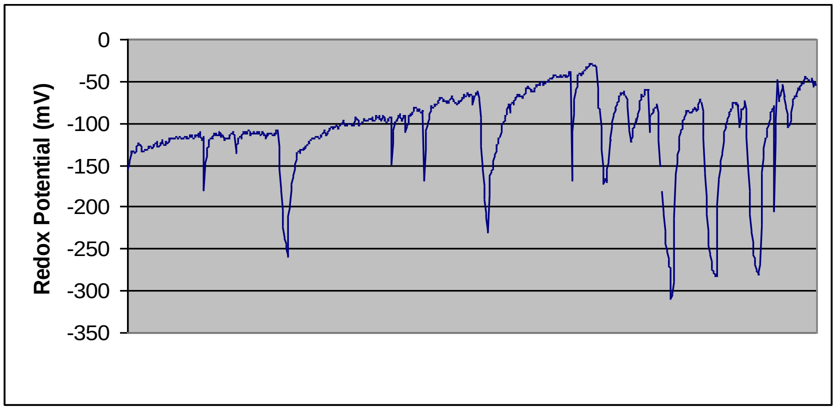


(a)



(b)

Figure 1: DO (right axis) and ORP (left axis) during SND for 2 different days. Only representative points are shown.



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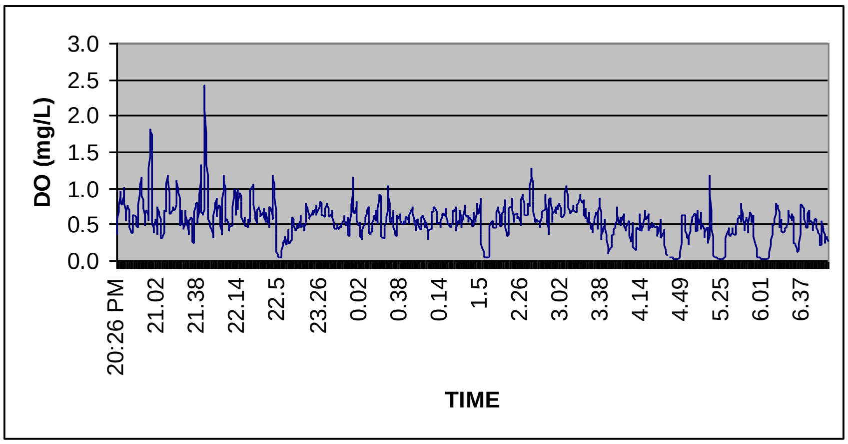

(b)

Figure 2: ORP (a) and DO (b) changes with time during long air-off period operation.

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