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THE EFFECT OF SUDDEN TEMPERATURE DROP ON NITRIFICATION

WPŁYW NAGŁEGO OBNIŻENIA TEMPERATURY NA NITRYFIKACJE

The removal of nutrients from wastewater is now an accepted standard treatment around the world, with developing countries and Canada catching up by imposing emission-based effluent permits, typically 1 to 1.5 mg TP/L and 10 to 15 mg TN/L. In the most fragile ecological regions in the United States and a few other locations regulators impose imission-based "limit of treatment" permits typically TP < 0.1 mg/L and TN < 3 mg/L. One of the challenges to achieve these low limits would be the temperature fluctuation over seasons, which can not be controlled. Strong dependence of the growth rate of nitrifying bacteria on temperature has received considerable attention as the nitrification process defines the size of reactors. Recent studies however have reported higher temperature sensitivity in case of sudden temperature drops, such as caused by cold shock due to wet weather and snow-melt events. The purpose of this study was to investigate the effect of temperature on nitrification growth rate in case of various temperature decrease situations and to model the impact of the temperature correction factor (TCF) on the nitrification rate during cold shock and wet weather flows, using BIOWIN simulation software. It was found that a sudden temperature decrease impacted nitrification much more than predicted by the default TCF = 1.072. The results show that the extent of temperature impact is proportional to the magnitude of the temperature decrease. Temperature dependency became large as the degree of temperature drop became larger. It was shown that the cold shock effect can be replicated when the experimental conditions are identical. Recovery from cold shock also was dependent upon the degree of temperature drop. BIOWIN simulation compared the effluent NH_4-N concentrations for different TCFs, one of which was found experimentally in this study. Higher TCF would result in higher predicted effluent concentration during cold-shock days and slower recovery, which translates to a longer period of potential autotroph washout. This study showed that a nitrifying activated sludge will suffer from the cold shock more seriously than predicted by the current default TCF. The washout of nitrifiers will be severe at lower solid residence time (SRT) and should be mitigated by increasing the biomass inventory.

1. Introduction and Objective

The removal of nutrients from wastewater is now an accepted standard treatment around the world, with developing countries and Canada catching up by imposing emission-based effluent permits, typically 1 to 1.5 mg TP/L and 10 to 15 mg TN/L. In the most fragile ecological regions in the United States and a few other locations regulators impose imission-based "limit of treatment" permits typically TP < 0.1 mg/L and TN < 3 mg/L. The latter limits require going beyond the standard biological nutrient removal (BNR) and employment of, what the industry calls, "enhanced nutrient removal' (ENR), typically involving a multi-biomass process and a combination of chemical treatment and external carbon addition. In extremely fragile areas (for example Florida Everglades) and in case of water reuse, the "ultimate nutrient removal" (UNR) is necessary to satisfy the permits which may ask for effluent concentrations in the range of 0.01 mg TP/L and 1 mg TN/L.

One of the key challenges to achieve the low effluent concentration is is fluctuation of temperature fluctuation which can not be controlled. Nitrification is known to be the most sensitive to low temperatures.

The sudden temperature drop in the incoming wastewater to the wastewater treatment plant (WWTP) is not uncommon during the Spring snow melt. In Winnipeg MB the dry weather flow temperature in winter is 14°C and during a sudden snow meltdown it can drop down to 8°C in one day. The snow meltdown also leads to the higher wastewater flow rates further aggarvating the difficult situation for the nitrifying biomass.

The effect of temperature on nitrification can be expressed by the Arrhenius equation and its own temperature correction factor- abbreviated TCF (Tchobanoglous, Burton, and Stensel, 2003; Oleszkiewicz and Berquist, 1988). TCF of 1.072 is widely used to predict the nitrification efficiency in temperature-changing situation for modeling and designing the treatment plant. (WERF, 2003; Painter and Loveless, 1983; Downing and Hopwood, 1964; Oleszkiewicz and Berquist, 1988; EnviroSim and Associates Ltd., 2006).

There are however some studies that report higher temperature dependency of nitrification than what would be predicted by the current TCF. Jones *et al.* (2003) studied the temperature correction factor obtained in the high F/M tests, recommended by WERF for measuring the nitrifiers' growth rate, under two different temperature conditions. It was concluded that the higher TCF, ranging from 1.09 to 1.1, should be used for abrupt temperature change cases, even though they reported there were no lasting temperature shock effects. Head and Oleszkiewicz (2004) found the temperature correction factor of 1.088 when they seeded nitrifying bacteria for bio-augmentation purposes, acclimated at 20°C, into non-nitrifying SBR reactor, operated at 10°C. In that study the temperature drop was instantenous.

The authors found that higher nitrification temperature correction factor, 1.116 should be considered when the temperature drops abruptly from 20°C to 10°C (Hwang and Oleszkiewicz, 2007). The TCF found in this research was higher than 1.088, which was found by Head and Oleszkiewicz (2004), even though the temperature drop was same. The wastewater treated was different in these two studies and it is possible that the increased portion of nitrifying bacteria added in the course of bioaugmentation by Head and Oleszkiewicz (2004) absorbed some of the cold shock effect.

If it is true that nitrification would be inhibited more than predicted by the current TCF of 1.072 by abrupt temperature change, a sharp decrease of wastewater temperature during winter or spring would affect the nitrification efficiency more drastically. During operation the operator may contribute to the washout of the fragile autotrophic biomass by overestimating their growth rate.

The objective of this research is to investigate the effect of various temperature drop patterns on nitrification and prove the validity of previously published results. The study will also address the impact of nitrifiers' TCF on the performance of wastewater treatment system by using a commercial modeling software BIOWIN.

2. Materials and methods

2.1. Experimental methods

A sequencing batch reactor (SBR) was installed inside an incubator with temperature controlled at 20°C. The SBR was operated at an HRT (hydraulic retention time) of 24 h and SRT (solids retention time) of 15 d and provided nitrifying biomass for all experiments. Series of nitrification batch tests were performed in designated temperatures (see Table 1), and pH, NH_4-N, NO_2-N and NO_3-N were measured during 8 hours of each batch test. And the specific nitrification rate (mg NH_4-N/mg VSS·d) was used to investigate the temperature effect.

Total 3 sets of experiments were performed in August 2007, October, 2007 and December 2007. Each set of experiments consisted of 2 to 3 nitrification batch tests. Biomass were acclimated for 5 to 6 weeks after previous set of experiment to assure full and adequate acclimation. Initial batch test in each set was around 20°C and the temperature was droped suddenly to 6°C to 9°C next day, when the second batch test was started. Table 1 shows the temperature at which the nitrification tests were performed.

Tab. 1. Temperature of Each Batch Test

Set #1		**Set #2**		**Set #3**	
Day	Temperature	Day	Temperature	Day	Temperature
Day 0	20.5°C	Day 0	21°C	Day 0	20°C
Day 1	9°C	Day 1	8.5°C	Day 1	6°C
Day 2	9°C	Day 2	8.5°C	Day 2	9°C
Day 5	9°C				

The incubator temperature setting was continuously controlled to keep the operating temperature steady as continuous mixing and aeration tends to increase the reactor operating temperature. Enough alkalinity was initially provided and the pH was controlled using sodium bicarbonate. The slopes of decreasing NH_4-N concentration during the batch tests have a linear relationship with the decrease of the maximum growth rate of nitrifiers due to the temperature change (Head and Oleszkiewicz, 2004). Other experimental conditions were the same as described in Hwang and Oleszkiewicz (2007).

As shown in Table 1, set #1 and set #2 has similar temperature drop pattern, while set #2 experiences slightly more severe temperature drop. And set #3 was designed to investigate the effect of more severe temperature drop and the effect of slight temperature recovery in a next day, which would be similar to full scale conditions.

2.2. Modeling methods

The second part of the paper will focus on the effect of the abrupt temperature change on the performance of wastewater treatment plant – simulating the performance with the commercially available BIOWIN software.

To simulate the effect of abrupt temperature drop, a conventional activated sludge system model with HRT of 6 hours, was generated. The influent after primary settling was assumed to have 250 mg/L of COD and 40 mg/L of TKN, and the default values in BIOWIN (Envirosim/Lemtech 2006) for every other parameters related with influent characteristics were used. The objectives of simulation were to 1) examine the deterioration of effluent concentration; 2) monitor the change of autotrophic biomass in aeration tanks, and 3) define the recovery time after the cold shock to investigate the washout effect of nitrifiers.

Two temperature correction factors; 1.072, BIOWIN default, and 1.116, found from 10°C sudden temperature decrease case, were used for simulation. In the simulation, the activated sludge system was operated at 20°C, and it would experience a sudden temperature decrease after 10 days of operation, in a day to 10°C, and the temperature will increase back gradually to 20°C in three days.

3. Results and discussion

3.1. Experimental results and discussion

Tab. 2 Shows specific nitrification rates (SNR) obtained in each of the batch tests.

Tab. 2. SNR from each batch test.

Day	Set #1		Set #2		Set #3	
	Temp. (°C)	SNR (mg NH_4-N / mg VSS• d)	Temp. (°C)	SNR (mg NH_4-N / mg VSS• d)	Temp. (°C)	SNR (mg NH_4-N / mg VSS• d)
Day 0	20.5	0.0904	21	0.0995	20	0.0898
Day 1	9	0.0214	8.5	0.0208	6	0.0088
Day 2	9	0.0215	8.5	0.0185	9	0.0179
Day 5	9	0.0243				

In every set, the SNR dropped radically following the cold shock however the pattern of the temperature dependency in each set was slightly different. Figure 1 shows the SNR from experiment set #1. Gray bars show the experimental results from batch tests and the lines indicate the expected SNR at lowered temperature by assigned temperature correction factors.

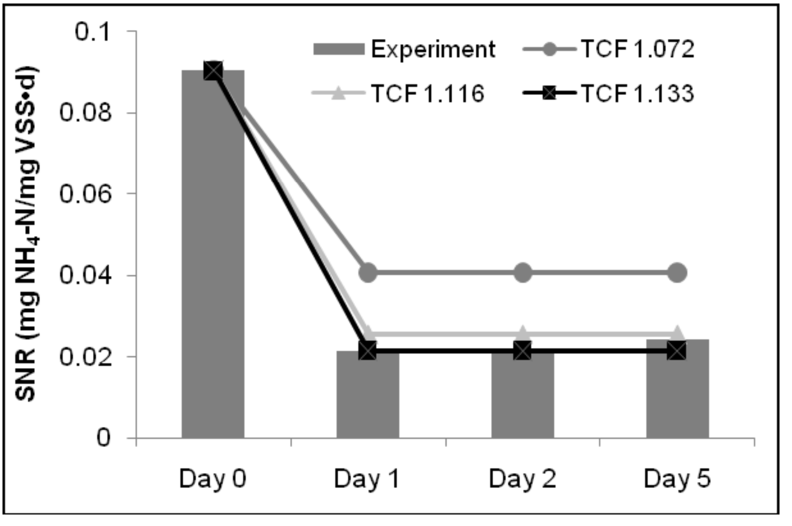

Fig. 1. Results from Experiment Set #1

As shown in Figure 1, it is apparent that the temperature correction factor of 1.072, which is widely used for plant design, fails to predict the nitrification activity in case of sudden temperature drops. The TCF of 1.116, which was found from a 10°C sudden drop in Authors' previous study (Hwang & Oleszkiewicz, 2007), did not predict SNR well in set #1, where the degree of temperature drop was 11.5°C. The TCF of 1.133 could finally match the experimental data. This indicates that the level of nitrification temperature dependency is related to the magnitude of the temperature shock.

SNR tends to recover slightly over time from 0.0214 mg NH_4-N/mg VSS•d in Day 1 to 0.0243 mg NH_4-N/mg VSS•d in Day 5, but the degree was not comparable to what was found earlier (Hwang and Oleszkiewicz, 2007). The recovery in Day 2 was also negligible. This also seems to be related to the degree of temperature drop.

Figure 2 shows the results from experimental set #2. Experimental conditions in Set #2 were the same as in Set #1, except the slight difference of the degree of temperature drop. (11.5°C to 12.5°C). Originally, experimental set #2 was designed to have exactly the same condition as Set #1, to see whether the effect of cold shock is replicable. But, the accurate control of incubator setting to match the temperature with that in Set #1 was not achieved.

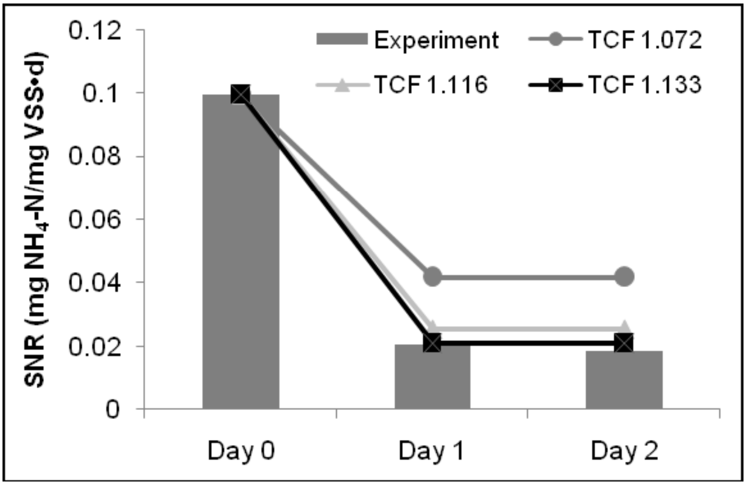

Fig. 2. Results +from Experiment Set #2

Even though the temperature was slightly deeper the SNR showed very similar trend to that in set #1. This might be caused by very small differences between the temperatures and/or analytical error. It can however be concluded that the cold shock effect can be replicated when the experimental conditions are comparable.

Results from Set #3 were shown in Figure 3. Temperature drop pattern in Set #3 was different from other sets. Initial temperature was 20°C as in the other sets, however the temperature suddenly dropped to 6°C and after one day was increased to 9°C, which would be similar to the temperature profile during the actual snow melt. Drop of SNR in Day 1 was higher than expected by TCF of 1.133, which was found from previous two sets of experiment, since the temperature difference was higher than previous sets. The TCF of 1.181 has successfully modeled SNR in Day 1. Considering the temperature difference of only 3°C the increase of TCF may seem high. It is however consistent with earlier findings where the temperature effects increase disproportionally fast as temperature drops below 8°C and particularly below 5°C (Oleszkiewicz & Berquist, 1988; McCartney & Oleszkiewicz 1990).

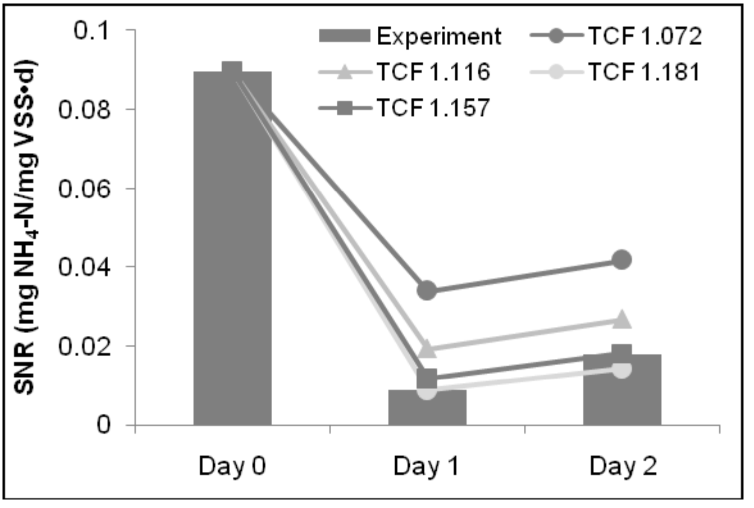

Fig. 3. Results from Experiment Set #3

Increasing the temperature in the second day of the cold shock by 3°C improves nitrification as shown in Figure 3. SNR increased and was well modeled by a TCF of 1.157 - lower than the 1.181 value in Day 1. The TCF of 1.157 from 9°C in Set #3 is however still higher than the TCF of 1.133 obtained from the same temperature in Set #1. This proves that the nitrifiers' temperature vulnerability is more dependent upon the magnitude and form of the sudden temperature shock and less on the final temperature reached by the culture.

3.2. Dynamic Modeling Results and Discussion

3.2.1. Effect of different TCFs

Two different TCFs were tested in case of sudden temperature change in a conventional activated sludge system with SRT of 5 days and DO in aeration tank of 2 mg/L. The effluent NH_4-N concentration and the fraction of autotrophs in MLVSS were monitored. Figure 4 and 5 show the concentration of NH_4-N in effluent and the fraction of autotrophs.

As shown in Figure 4, high temperature correction factor (TCF = 1.116 red line with a higher peak) would result in higher fluctuation during a temperature drop incident and also would result in slower recovery, which translates to a longer lasting effect of nitrifier washout. According to the simulation, higher TCF causes 2.5 times increase of effluent NH_4-N and 60% longer recovery time should washout occur.

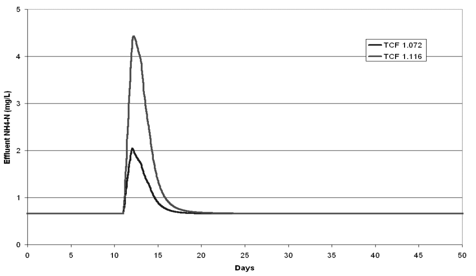

Fig. 4. Concentration of NH_4-N in effluent

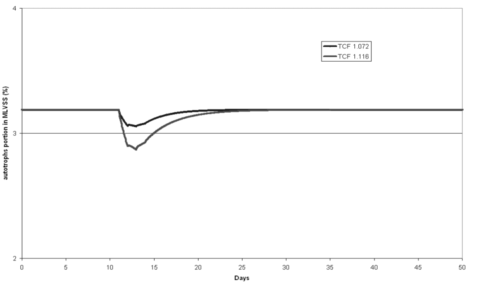

Fig. 5. Fraction of autotrophs in MLVSS

Figure 5 shows the fraction of nitrifier dropping more drastically at higher TCF (red line, lower inverse peak) due to the fact that the nitrifiers' growth rate would be highly reduced even though the biomass would be wasted at the same rate. Therefore, the reduction of nitrification performance with current default TCF during a cold shock would over-estimate the effluent ammonia concentration and result in slower system recovery.

3.2.2. Effect of different SRT

Effluent NH_4-N concentration was simulated and the results were shown in Figure 6 in case of different SRT conditions with a fixed TCF of 1.1116. Activated sludge system, operated at 20°C, would experience a sudden temperature decrease after 10 days of operation, in a day to 10°C, and the temperature will increase back gradually to 20°C in three days.

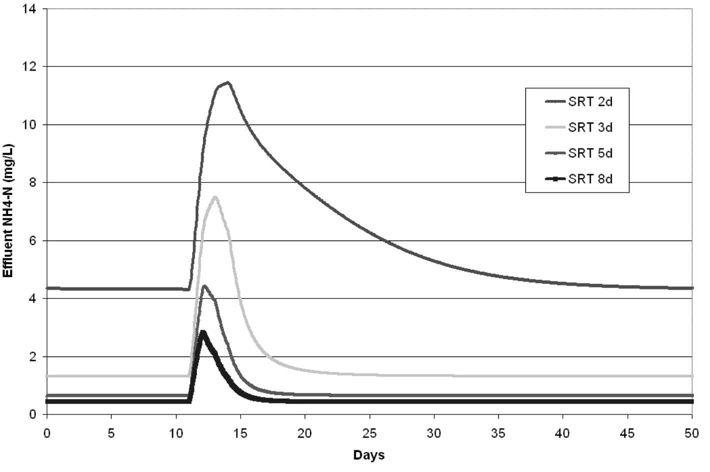

Fig. 6. Concentration of NH_4-N in effluent as dependent on variable SRT

The system with lower SRT was affected more in terms of the effluent quality and recovery time. Because the amount of autotrophs in a low-SRT system would be smaller than in the high-SRT system, therefore the initial effluent ammonia concentration would be higher. The degree of concentration increase and the duration of the cold shock effect would be higher and longer in low SRT system due to the excessive wasting of biomass. Therefore, in case of sudden temperature decrease, maintaining the system with long SRT would be recommended to avoid the deterioration of nitrification. Alternatively, one would increase the SRT only during the cold shock, which should speed up the system recovery from cold shock by preventing excessive wasting of autotrophs.

3.2.3. Effect of the wet weather flow

The wet weather flow scenario was assumed to investigate the effect of high flow and low temperature on the nitrification. 50% higher flow was assumed during the cold shock, lasting for 3 days, and the operating temperature was decreased to 10°C from 20°C in a day and recovered in 3 days. Temperature correction factor TCF = 1.116 and SRT of 5 days were used for simulation. Figure 7 shows the effluent ammonia concentration obtained in the simulation. Effluent ammonia increased during the wet weather event due to the decrease of the hydraulic residence time. The simulation suggests that the recovery from the shock would not be affected due to wet weather flow.

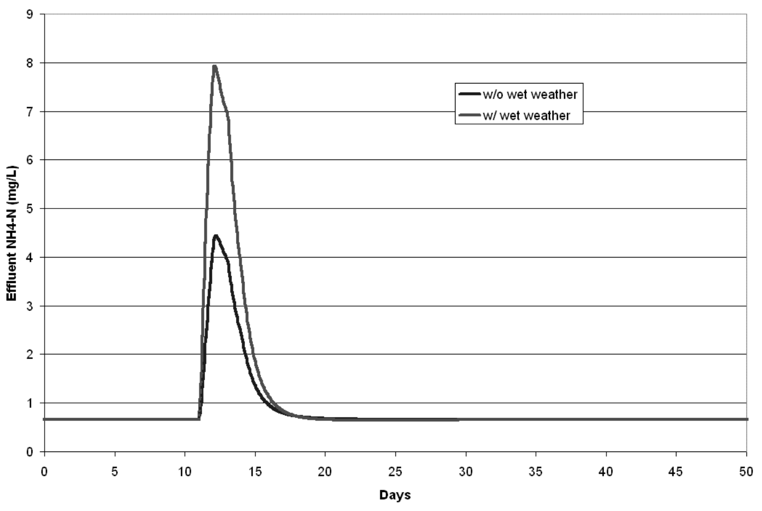

Fig. 7. Concentration of NH_4-N in effluent from different incoming flow rate

4. Conclusion

Experiments were conducted to investigate the effect of sudden temperature drop on nitrification. Two different temperature drops were tested to verify if the cold shock effect is replicable. The impact of the cold shock was also modeled when occurring concommittantly with the wet weather event (such as occuring during March/April snow melt conditions – the most critical design and operational period.

The results show that the magnitude of temperature dependency, expressed by temperature correction factor (TCF) was proportional to the magnitude of the temperature drop (difference between initial and final temperature). It was shown that the cold shock effect can be replicated when the experimental conditions are identical. Duration of the recovery from cold shock was dependent upon the magnitude of the sudden temperature decrease.

The effect of higher TCF during a suddenly occuring cold wet weather event was simulated using BIOWIN software. High TCF values found in this research led to higher effeluent ammoinia fluctuation during temperature change and resulted in slower recovery. This means longer-lasting effects of the nitrifier washout. The current way of predicting the nitrification performance uses a default TCF = 1.072 which would overestimate the effluent ammonia concentration during the sudden temperature decrease and would under-predict the system's recovery time.

Activated sludge systems with high autotrophs inventory will be better fit to sustain a cold shock, therefore increasing SRT is the correct strategy during cold wet-weather events such as occur regularly during Spring snowmelt. It was demonstrated that increased flows during such an event cause further deterioration of effluent quality, however the recovery time will not be affected if the SRT is unchanged; i.e. if the loss of biological solids is prevented.

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