THE EFFECTS OF HYDRAULIC REGIME AND NITROGEN LOADING ON NITRIFICATION RATES IN ACTIVATED SLUDGE PROCESS

Ali Azimi

ABSTRACT

The ability of a well established nitrifying activated sludge to tolerate transient changes in hydraulic and nitrogen loadings was assessed. In addition the relative efficiencies of a completely mixed and a plug flow reactor operated under the same transient conditions were compared. Both reactor systems could tolerate a threefold increase in hydraulic loading rate with no loss of nitrification efficiency. Increases in nitrogen loading (in the form of either ammonium or urea) over the range 50 to 200 mg-N/l produced only slight increases in effluent ammonium concentration. However above 200 mg-N/l the Nitrobacter were inhibited and there was a large increase in both effluent ammonium and nitrite.The completely mixed and plug-flow systems behaved almost identically and the ability of the former to dilute and dampen transient peaks, did not seem to benefit the nitrifying bactaria.

Keywords: Nitrification, nitrifying bacteria , activated sludge , shock loading, plug flow reactor, completely mixed reactor.

INTRODUCTION

Proposed European Community legislation (Anon, 1989) will place strict effluent consents on a range of wastewater discharges in terms of their organic and solids content. In addition the proposed legislation to be effective from 1998, will also limit the nutrient content of discharges where these are made to environmentally sensitive areas. In a European context,the definition of an environmentally sensitive area means that in many cases these are areas which receive a large tourist population. The effects of tourist populations on the daily flow and load to a treatment works is well documented (Gujer and Erni, 1978). Of particular importance to the process of nitrification is the large diurnal flow and load peak, and in particular the elevated nitrogen concentration associated with this peak, where peak to average nitrogen concentrations can be in excess of 5.

The nitrifying fraction of an activated sludge has a relatively slow growth rate determined by the average ammonium- nitrogen loading rate (Bliss and Barnes, 1983). It has also been shown that the rate at which ammonium is removed generally follows zero-order kinetics (Hall and Murphy, 1985; williams and Lewis 1986). Consequently a transient increase in ammonium loading will not be accompanied by a commensurate increase in ammonium oxidation rate and a large fraction of this ammonium will pass untreated into the effluent (US EPA, 1975). In order to accommodate this,a safety factor is usually applied to the solids retention time necessary to achieve nitrification at the average ammonium loading rate. In this way a larger nitrifying fraction is established in the sludge biomass which is capable of responding to the peak concentrations . Safety factors equivalent to the peak/average ammonium loading are generally recommended (Barnes and Bliss, 1983). However such a procedure would not be feasible for the large diurnal voriations typically reported for tourist areas.

It was the aim of this research therefore, to simulate the range of transient loadings experienced at tourist resorts which have highly variable seasonal populations. In view of the wide differences reported for nitrification efficiencies in completely mixed and plug flow activated sludge reactors, and in view of the ability of the former to attenuate the magnitude of the ammonium peak due to dilution, both reactor types were assessed under identical load conditions. It was hoped therefore , to recommend appropriate design and operating criteria for nitrifying activated sludge plants in tourist areas.

MATERIALS AND METHODS

Laboratory Activated Sludge Units

The complete mix reactor comprised a 16L aeration basin with an upward flow sedimentation tank, whereas plug flow conditions were approximated by the use of 8 complete mix reactors operating in series and with a combined volume of 16L. These units have been described in detail by Azimi and Horan (1990) and were shown to have dispersion numbers of 0.6 (equivalent to 1.6 completely mixed tanks in series) and 0.07 (equivalent to 8 completely mixed tanks in series).

Influent feed preparation

A concentrated synthetic medium was prepared in batches as described by Azimi and Horan (1990). After dilution the medium fed to the reactors had a BOD_5:N:P ratio of 40:10:1 and a total Kjeldahl nitrogen of 75 mg N-1.

Transient loading regime

Prior to the imposition of a transient loading, the reactors were operated at steady-state with a mean cell residence time of 10d to ensure complete nitrification, and this was maintained for at least 25d. Two types of transient loading were employed in order to investigate variations in both influent flow-rate and in nitrogen loading rate. Diurnal variations in influent flow rate were accomplished by increasing flow rate from its normal rate of 0.67 L/h to 2.0 L/h for a 3 h period each day. Transient nitrogen loadings were accomplished using either ammonium chloride or urea. These were varied over the range 50 to 500 mg N/L and 125 to 750 mg N/L for ammonium chloride and urea respectively. In both cases the reactors were pulsed with concentrated stock solutions for 3 hours each day. Each transient loading regime was continued for at least 20 days.

Analytical procedures

Analysis of influent, effluent and mixed liquor samples were carried out using the procedures described in Standard Methods (APHA, 1985). All chemicals were of ANALAR grade, when available.

RESULTS

Diurnal variations in influent flow rate

Both the completely mixed and plug flow reactor systems were able to tolerate a three-fold increase in influent flow rate with no observable effect on the effluent quality in terms of COD and nitrate nitrogen. However, the effluent from both reactors showed a slight increase in ammonium nitrogen from 0.3 to 1.0 mg N/L. The concentration of nitrite increased from 0.03

to 0.32 mg N/L three hours after the start of the hydraulic load increase in the complete mix reactor and this was accompanied by an increase in ammonium, reaching a maximum after 6h before gradually decreasing. In the plug flow reactor, this effect was offset by 6h and the nitrite concentration remained low at 0.03 mg N/L.(Fig. 1).

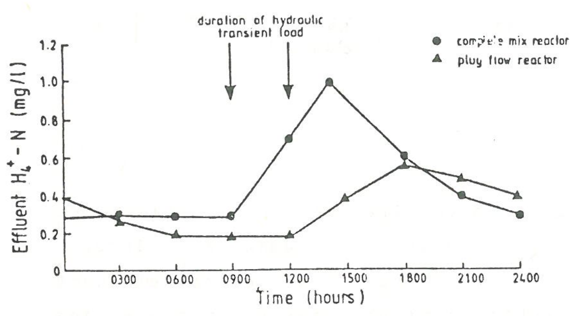

Figure one: The effects of a transient three-fold increase in hydraulic load on nitrification efficiency in a plug flow and completely mixed reactor.

Diurnal variations in ammonium-nitrogen loadings

A total of five different concentrations of ammonium nitrogen were applied to the reactor in a cyclical loading regime. The initial experiment employed a concentration of 50mg/L which was added to the normal influent for a period of 3h/d. Within a period of three weeks the reactor had stabilised to this loading regime and a pseudo steady-state was obtained for effluent quality. Only a slight increase was observed in effluent ammonium - nitrogen concentration (Fig. 2)and in all cases the nitrite concentration was low at 0.05 mg N/L. This experiment was repeated with influent ammonia - nitrogen concentrations of 100 and 200 mg N/L and a similar effect was observed but with the effluent ammonium-N concentration increasing from 2 to 14mg N/L at the peak (Fig. 2). For all three concentrations of ammonium nitrogen, the complete mix and plug flow reactors behaved in a similar way with the latter having the effluent peak offset by 3h. At higher concentrations of influent ammonium nitrogen (>300mg/L) a very high effluent ammonium concentration was observed. In addition the effluent nitrate concentration decreased sharply with a concomitant increase in nitrite. However despite an influent ammonium nitrogen concentration of 500 mg/L, the effluent concentration of ammonium did not exceed 65 mg/L in the complete mix reactor and 70 mg/L in the plug flow one. Again there was no difference in performance between the two reactor types (Fig. 3).

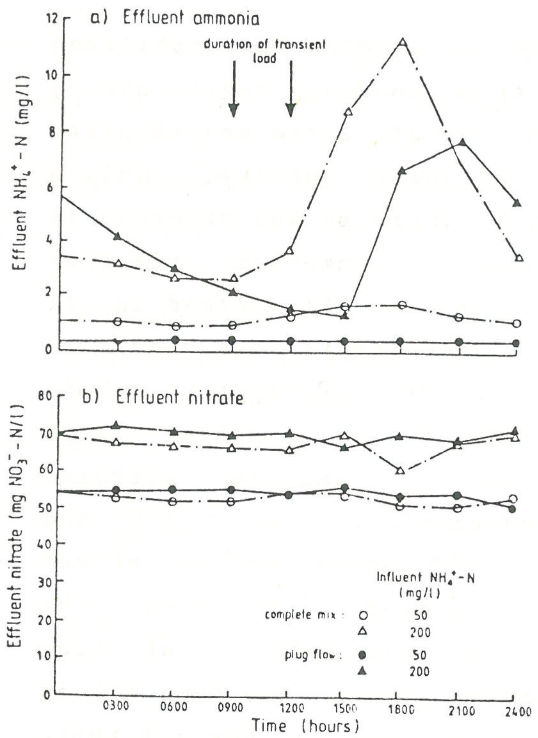

Figure two: The effects of transient increases in influent ammonia nitrogen over a range of concentrations to a plug flow and a completely mixed reactor on:

a) Effluent ammonium nitrogen.
b) Effluent nitrate nitrogen.

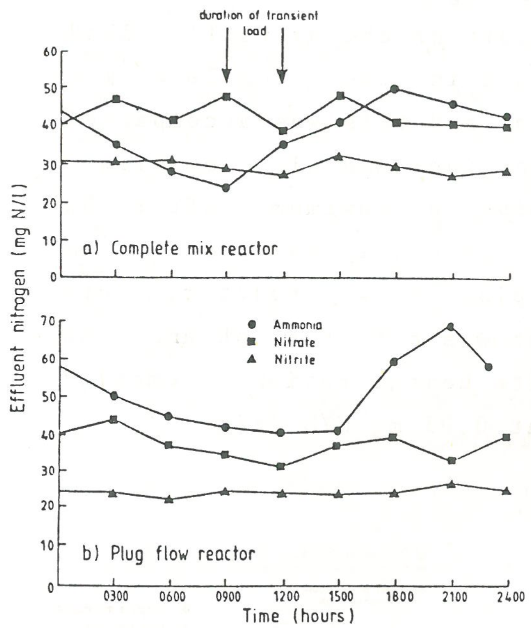

Figure three: The effects of a transient increase in influent ammonia nitrogen from 50 to 500 mg NH_4^+-N/L on the effluent concentrations of ammonia, nitrate and nitrite for:

a) A complete mix reactor.
b) A plug flow reactor.

Diurnal variations in urea-nitrogen loadings

The bulk of the load (both organic and nitrogen) to treatment plants in tourist areas results from domestic activities. In addition the retention time in the sewers is generally low and consequently much of the nitrogen is usually in the form of urea. In order to test the response of the nitrifying biomass to changes in influent urea concentration, the previous transient loading experiments were repeated , replacing ammonium chloride with urea as the nitrogen source. The results of these experiments revealed only slight differences in the behaviour of the nitrifying Bacteria to either ammonium nitrogen or urea nitrogen as a substrate (Fig. 4).

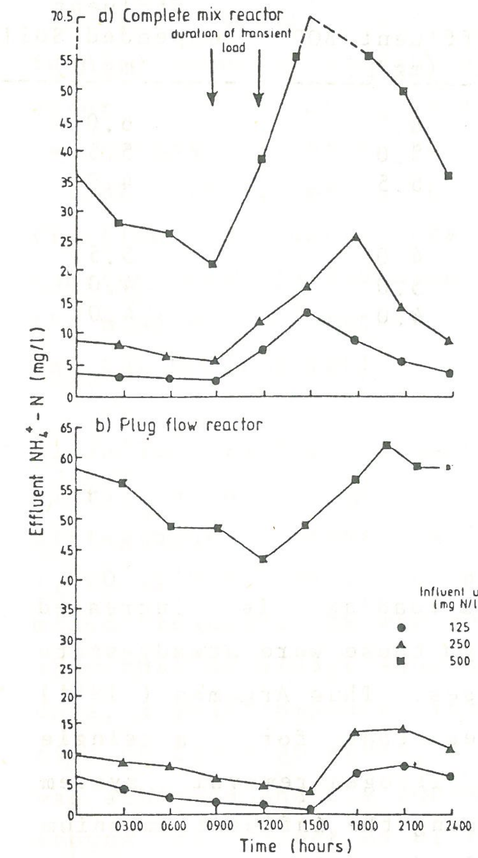

Figure four: The effects of transient increases of influent urea nitrogen over a range of concentrations on the effluent ammonia nitrogen from:

a) A complete mix reactor.
b) A plug flow reactor.

In general the effluent ammonium concentrations were higher when urea was the substrate. For instance at influent nitrogen shock loadings of 100 mg/L the effluent ammonium was 4.3 mg N/L for a complete mix reactor receiving nitrogen in the form of ammonia, but 13 mg N/L when it was in the form of urea. This may have been due to inhibition by urea itself , although analysis of the reactor mixed liquor for the presence of urea and ammonia, suggested that hydrolysis of urea to ammonia (Presumably by extracellular urease) was a very rapid reaction.

During transient load experiments with both ammonium nitrogen and urea, when the ammonium concentration in the mixed liquor was less than 4mg N/L, the rate of ammonia oxidation increased with an increase in the concentration of influent ammonium or urea nitrogen. However, at higher mixed liquor concentration the ammonia oxidation rate was unchanged for a few days before gradually increasing, presumably reflecting an increase in the nitrifying fraction in the sludge. The important plant operating characteristics of the two systems are outlined in Table 1, which indicates an increased mixed liquor solids and a decreased sludge volume index (SVI) as influent ammonia-nitrogen increased.

Table 1 Performance of the completely mixed and plug flow reactors under a transient ammonium load at a sludge age of 10d.

	Determinand				
	Influent ammonium (mg N/L)	MLSS (mg/L)	SVI (mL/g)	Effluent BOD (mg/L)	Effluent Suspended Solids (mg/L)
Completely mixed	50	1345	143	8.5	6.0
	100	1400	110	8.0	5.5
	200	1420	98	6.5	4.0
Plug flow	50	1450	100	4.0	5.5
	100	1510	88	5.0	4.0
	200	1520	80	4.0	4.0

DISCUSSION

The response of a nitrifying activated sludge population to transient loadings has received little attention. In one of the few reported studies poduska and Andrews (1975) reported that a nitrifying activated sludge was able to sustain a twofold increase in flow rate with no increase in effluent ammonium concentration, whereas a three-fold increase substantially increased the effluent concentration. In contrast the results of this present study have shown that an acclimatised sludge can tolerate a threefold transient with a negligible increase in effluent ammonium concentration.

Several authors have reported an increase in the nitrifying fraction of the biomass as ammonia loading is increased although these were steady-state increases. Thus Argaman (1981) reported that for a single sludge nitrogen removal system increasing the influent ammonium from 10mg/L to 100mg/L resulted in an increase in autotrophic biomass and effluent nitrate. Similarly the rate of nitrification and the estimated nitrifying population was shown to increase significantly with increasing TKN loadings and a constant carbon feed (Hall and Murphy, 1985). These findings help to explain the response of the nitrifying population in this study to transient loadings. At influent ammonium concentra - tions below 100mg/L or a mixed liquor concentration below 4mg-N/L) ammonium oxidation is first or mixed order with respect to substrate concentration order. Above this concentration the reaction is zero-order and the nitrifying fraction must increase significantly before further ammonia oxidation will occur. A similar explanation was proposed by Sherrard et al , (1982) who reported that the fraction of nitrifiers is not constant and is dependent upon the mean solids retention time and the COD/TKN ratio.

Al-Sa'Ed (1987) investigated nitrification of highly nitrogenous wastewaters (100 to 1,200 mg N/L) in a completely mixed reactor. He was able to show that at sludge ages above 8 days, almost complete nitrification of the high strength waste was achieved and the BOD/N ratio showed no effect on nitrification performance. Below this sludge age nitrification rate decreased with increasing BOD/N ratio. It was surprising to note that in this study the completely mixed reactor appeared to offer little protection against high nitrogen loadings as compared to a plug flow system. It is generally accepted that a completely mixed reactor offers some degree of dilution to elevated loadings and will act to dampen increased flows. However it has been shown clearly here that these features offer no protection to either the heterotrophic or autotrophic populations. In view of the well documented superiority of plug flow systems in terms of sludge settling characteristics, which have been confirmed in this study, it is difficult to envisage a situation in which the construction of such reactors can be justified. The superiority of plug flow systems in achieving nitrification under steady-state conditions has also been demonstrated by Azimi and Horan (1990).

The increased susceptibility of the Nitrobacter to environmental conditions is well documented and the accumulation of nitrite under high nitrogen loadings observed in both reactor types is thus to be expected. However Turk and Mavinic (1989) encouraged nitrite build up by intermittent contact with high ammonium levels (200 mg N/L) in order to exploit, shortened nitrification / denitrification pathway for the complete elimination of nitrogen. Such a scheme could prove useful in overcoming the problems of achieving nitrification of wastewaters of high or intermittent ammonium concentrations.

This work has demonstrated that

a well established nitrifying population can tolerate the large variations expected in diurnal flow and ammonium nitrogen concentration,with only a negligible loss in nitrification efficiency. However as this ability is dependent upon an active population of nitrifying bacteria in the sludge biomass, for treatment plants subjected to variable seasonal loads, it is important ot preserve the active nitrifying fraction during periods of low loading, despite the increased operating costs that this will incur. A similar conclusion was reached by Andersson and Rosen (1990) who reviewed operating experiences of full scale biological nitrogen removal plants in Sweden. They observed that during the spring period, low wastewater temperatures induced by snow melt caused a decrease in nitrification rate. Consequently at times of high wastewater flow, there was an immediate loss of nitrification. This situation was alleviated by maintaining one nitrifying unit at each plant which was protected from disturbances. This was thus able to provide an active nitrifying opulation to re - establish nitrification almost immediately, even at low temperatures. □

References

Al-Sa'ed, R. (1988) Investigations on nitrification of ammonia rich wastewater in activated sludge systems. Water Supply, 6, 235-242.

Andersson, B. and Rosen, B. (1990) Upgrading for biological nitrogen removal - Some full-scale experiences from Sweden. Water Science and Technology, 22, 93-104.

Anon (1989) Proposal for a Council Directive Concerning Municipal wastewater Treatment. COM (8a) 518, 13 November.

APHA (1985) Standard Methods for the Examination of Water and wastewater. 16th Edition, American Public Health Association.

Argaman, Y. (1981) Design and performance charts for single - sludge nitrogen removal systems. Water Research, 15, 841-847.

Azimi, A.A. and Horan, N.J. (1990) The influence of reactor mixing characterisitics on the rate of nitrification in the activated sludge process. Water Research In Press.

Barnes, D. and Bliss, P.J. (1983) Biological Control of Nitrogen in Wastwater Treatment. E and F.N. Spon., Ltd,, London, UK.

Bliss, P.J. and Barnes, D. (1983) Towards optimal design of the nitrifying activated sludge process. Presented at Tenth Federal Convention of Australian Water and wastewater Association, Sydney, Australia.

Gujer, W. and Esri, P. (1978) The effect of diurnal ammonium load variation on the performance of nitrifying activated sludge process. Prog, Wat. Tech, 10, 391-407.

Hall, E.R. and Murphy, K.L. (1985) Sludge age and substrate effects on nitrification kinetics. J. Wat, Pollut, Cont, Fed. 57, 413-418.

Poduska, R.A. and Andrews, J.F. (1975) Dynamics of nitrification in the activated sludge process. J. Wat, Pollut, Cont, Fed. 47, 2599-2619.

Sherrard, J.H, Asce, M, Manning, D.K. and Smith, D.A.(1982) Nitrification rates in activated sludge. J. Env, Eng, Div.,Amer, Soc, Civ, Eng. 108, 1074-1078.

Turk, O. and Mavinic, D.S. (1990) Stability of nitrite build-up in an activated sludge system. Journal of the Water Pollution Control Federation, 61, 1440-1448.

US EPA (1975) Process Design Manual for Nitrogen Control. US Environmental Protection Agency Office of Technology Transfer,Washington D.C.

Williams, R.E. and Lewis, M.S. (1986) Stream model of benthic nitrification-denitrification. J. Env, Eng , Div.,Amer, Soc, Civ, Eng,112, 367-386.