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INVESTIGATIONS ON NITRIFICATION OF AMMONIA RICH WASTEWATER IN ACTIVATED SLUDGE SYSTEMS

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ABSTRACT

Performance of four laboratory single-stage activated sludge units treating a synthetic highly nitrogenous (100-1200 mg N l^{-1}) wastewater with low BOD_5 (100 mgl^{-1}) concentration is presented.

Nitrifiers fraction (Fn) and nitrification rates increased with decreasing BOD/N ratio. At sludge ages (SRT) above 10 days, BOD/N ratio played no role in nitrification process and complete ammonium oxidation was obtained.

Nitrifiers biomass (Xvn) decreased with decreasing sludge age. However, volumetric nitrification rates (qn) remained constant at Xvn greater than 150 mg VSSl^{-1} in all units. At sludge ages below 10 days and BOD/N ratio (1:1) above 0.16 initiated sludge bulking.

Nitrification efficiency of 86% was achieved in reactor A at NH_4-N loading of 0.25 kgNkgoTS^{-1}*d^{-1}, while reactor B, C and D this exeeded 95% at 0.45 kgNkgoTS^{-1}*d^{-1} at a 10 days sludge age. Complete nitrification could be achieved at a wide range of pH between 7 and 9 under optimal operating conditions. The inhibitory effects of NH_3 and HNO_2 were observed at NH_4-N sludge loadings above 0.45 kgN * kgoTS^{-1}* d^{-1}.

KEYWORDS

Activated sludge; Nitrification; Ammonia rich wastewater; Sludge age; Nitrifiers fraction; bulking.

INTRODUCTION

The aesthetic, economic and health considerations involved in the uncontrolled discharge of nitrogen into receiving water bodies has been well recognized.

Among the engineered biological systems are nitrification-denitrification processes the most promissing one for nitrogen control. There have been several models proposed to control and quantify nitrification process kinetic for single-stage activated sludge mode (Eckama and Marais, 1984; IAWPRC Task Group, 1986; Kayser, 1983).

Model suggestions for highly nitrogenous wastewater with low BOD content are still lacking. The results of this study discuss the effects of BOD/N ratio, sludge age, NH_4-N and BOD sludge loading on nitrification performance. Furthermore, the influence of pH as well as possible inhibitory effects of NH_3 and HNO_2 on nitrification will be presented.

MATERIALS AND METHODS

Four identical bench-scale, completely mixed and continuous flow single-stage activated sludge units were operated in parallel. A schematic view of the experimental apparatus is depicted in Fig. 1. The working volume of the aeration basin and the integral clarifier are 14 l and 7 l respectively. Using stone air diffusers, the bulk dissolved oxygen was always above 2 mgl^{-1}. The pH was automatically controlled at 7.5 using a 10% $Na_2CO_3/NaHCO_3$ solution. All units were run at room temperature (20 + 5°C).

The feed consisted of a synthetic wastewater amended with glucose, ammonium chloride, and trace elements (Cd, Cu, Ma, etc.). In most cases BOD_5 and NH_4-N amounted to 100 and 1200 mgl^{-1} respectively to achieve the desired BOD/N ratio. Starting-up, chemical, microbiological and kinetic determination were reported previously (Al-Sa'ed, 1987). The concentrations of all nitrogen forms are expressed in mgl^{-1} as N. Table 1 shows the operating conditions for each unit.

RESULTS and DISCUSSION

The experimental data of this study were obtained from the operation of four bench-scale activated reactors designated A,B,C and D. The units were operated for six months at different BOD/N-ratios of 78:106 Unit (A); 93:34 Unit (B); 93:592 Unit (C) and 91:1200 Unit (D) and at the same sludge age (20 - 5 days). Average values from four periods of steady-state operation are summarized in Table 2. The duration of each period was 6 weeks to ensure that representative steady-state data were obtained.

Utilizing the equations described by Eckama and Marais (1984) und EPA (1975), the nitrifiers fraction (Fn) and biomass (Xvn) were determinated. Figures 2 and 3 show that Fn (%) and nitrification reate per gram volatile suspended solids (qoTSn) per day increased with decreasing BOD/N ratio. Average values of Fn for reactors A (BOD/N = 0,75:1), B (BOD/N = 0,30 :1), C (BOD/N = 0,16:1) and reactor D (BOD/N = 0,08 : 1 were 26%, 49%, 63% and 79% at an average sludge age of 10 days. Figure 3 shows the same tendency. Literature nitrification rate for domestic wastewater is usually expressed in terms of total biomass and this is generally very low. Nitrification rate (qoTSn) obtained in this study compaired with those expressed in terms of Xvn (K_T) are presented in Table 3. The effect of sludge age (SRT) on nitrifiers biomass (Xvn) is illustrated in Fig. 4a. Xvn decreased with decreasing SRT in all units. However, at a critical sludge age (SRT = 8 days the minimum Xvn was about 150 $mgVSSl^{-1}$ below which partial ammonium oxidation was observed. Nearly constant volumetric nitrification rates (qn) were achieved at Xvn above 150 mg $VSSl^{-1}$ and at a SRT greater than 8 days (Fig. 4b). Therefore, BOD_5/N ratio (1 : 1) showed no effect on nitrification performance at SRT above 8 days.

Almost complete nitrification took place at high sludge age (SRT = 10 days), while nitrificaton efficiency decreased rapidly at small SRT values. This is clearly shown in Fig. 5.

At lower sludge ages (below 10 days) and higher BOD/N ratios above (0.16 : 1) caused sludge bulking (reactor A, B and C). Our data are in agreement with those reported in the literature (Fig. 6).

Alleman (1984) reviewed several conditions which could lead to nitrite build-up in biological nitrification systems. In this study it was found that NH_4-loading above 0.45 $kgN * kgoTS^{-1}*d^{-1}$ and SRT below 10 days caused accummulation of ammonium and nitrite more than 5 mg Nl^{-1} in the aeration tank. Under such process conditions, NH_3 concentraitons (Fig. 7) ranged between 0.1 and 83 mgl^{-1}, which might enhance ammonium and nitrite build up occurrence in the nitrified effluent.

These results are in consistent with those reported by Antonisen (1976) and Nyhuis (1985). Al-Sa'ed (1987) reviewed the possible concentration of NH_3 and HNO_2 reported in the literature which caused nitrification inhibition in several nitrification systems. However, under following process conditions ($BoTSn$ = 0.37 $kgN*kgoTS^{-1}*d^{-1}$, BoTSc = 0.14 kg $BOD*kgoTS^{-1}*d^{-1}$; SRT 21 days and 20°C), complete nitrification was obtained at pH range of 7 and 9. Figures 8 and 9 show the effect of pH on nitrification rate (qn) and efficiency (qnp). It is clear that above pH 7 about 500 $mgN * l^{-1}*d^{-1}$ could be achieved and nitrification efficiency exceeded 95% under steady state conditions lasted for two months.

In summary, this work centered on bench-scale experiments showed that nitrifiers biomass fraction increased with decreasing BOD/N ratio. This ratio played an essential role at sludge ages below 10 days.

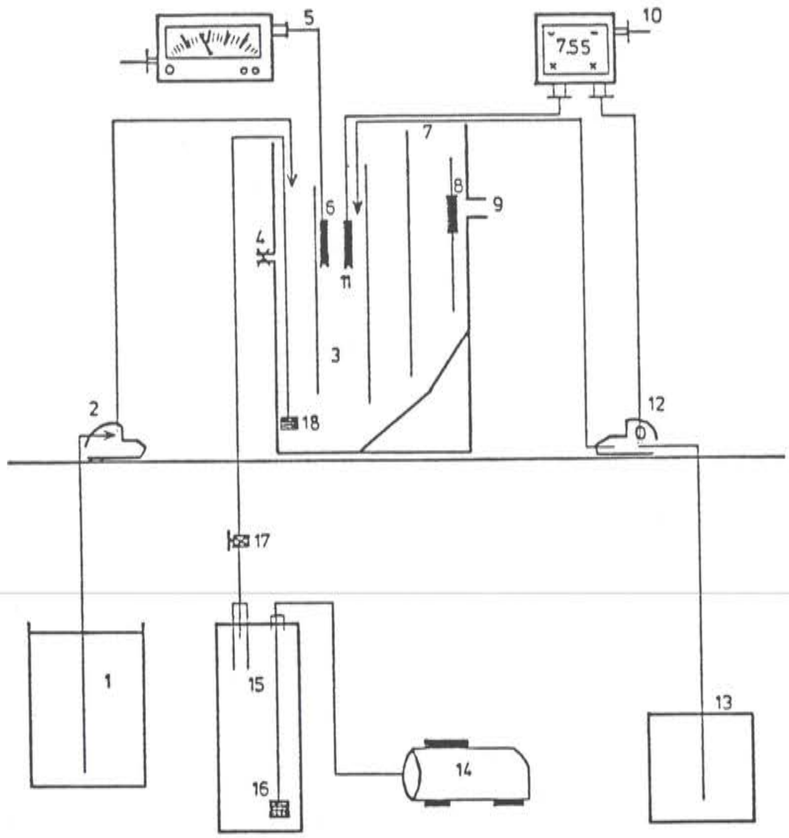

Fig. 1. Schematic of the bench scale single-stage activated sludge system.

1. Influent wastewater
2. Pump
3. Aeration basin
4. Sludge wastage
5. Dissolved oxygen detector
6. Dissolved oxygen probe
7. Clarifier
8. Filter
9. Effluent
10. pH Controller
11. pH Probe
12. Pump
13. HCl or Na_2CO_3
14. Air pump
15. Moistened air
16. Air diffuser
17. Air controller
18. Air diffuser

TABLE 1 Operating Design Parameters of All Reactors

		Reactor											
		A			B			C			D		
Parameter	Dimension	i.M.	Min.	Max.	i.M.	Min.	Max.	i.M.	Min.	Max.	i.M	Min.	Max.
Q	(l/d)	35	-	-	11.62	-	-	5.88	-	-	2.94	-	-
HRT	(d)	0.4	-	-	1.20	-	-	2.88	-	-	4.76	-	-
tTS	(d)	11.9	5.3	20	12.44	6.3	20	12.4	6.2	20	13.	6.9	20
T°C	(°C)	20	16	24	20	16	24	20	16	20	20	16	20
pH	(-)	7.8	7.4	9	7.57	6.2	8.4	7.55	6	9.4	7.62	6	8.4
DO	(mgO_2/l)	2.9	2.	6	3.05	1.8	5	3.3	1.4	6.6	3.5	2	7
MLSS	(gTSS/l)	1.81	0.62	2.99	0.98	0.28	1.91	0.82	0.29	2	0.83	0.3	1.97
MLVSS	(goTS/l)	1.57	0.38	2.53	0.83	0.19	1.61	0.68	0.25	1.73	0.64	0.19	1.59
GV	(%)	86	61	98	87	67	98	80.6	58	95	74.7	49	92
qr	(d^{-1})	2.5	-	-	0.83	-	-	0.42	-	-	0.21	-	-
BR_c	($kgBOD_5/m^3*d$)	0.20	0.08	0.36	0.08	0.03	0.14	0.04	0.01	0.06	0.02	0.01	0.03
$BoTS_c$	($kgBOD_5/kgoTS*d$)	0.15	0.04	0.41	0.12	0.05	0.37	0.07	0.03	0.14	0.04	0.01	0.11
BR_n	(kgN/m^3*d)	0.26	0.24	0.35	0.26	0.22	0.30	0.25	0.21	0.27	0.25	0.17	0.41
$BoTS_n$	(kgN/kgoTS*d)	0.22	0.10	0.73	0.46	0.16	1.43	0.49	0.15	1.03	0.52	0.16	1.12
BOD_5/NH_4-N	(-)	0.75	0.22	1.39	0.30	0.16	0.54	0.16	0.05	0.23	0.08	0.03	0.12

TABLE 2 Summary of Experimental Results

		Reactor											
		A			B			C			D		
Parameter	Dimension	i.M.	Min.	Max.	i.M.	Min.	Max.	i.M.	Min.	Max.	i.M.	Min.	Max.
NH_4-Inf.	(mgN/l)	106	94 -	140	311	261 -	366	592	490 -	640	1200	828 -	1930
NH_4-Bulk	(mgN/l)	14.9	3.5 -	20.6	43.3	3.8 -	96	22.8	3.3 -	50	47.6	9.5 -	123
NH_4-Eff.	(mgN/l)	15	0.18 -	80	7.8	0.13 -	94	45.2	0.22 -	380	59	0.25 -	415
NO_2-Inf.	(mgN/l)	0.45	0.0 -	6.9	0.11	0.0 -	0.61	0.16	0.0 -	1.08	0.09	0.0 -	0.53
NO_2-Bulk	(mgN/l)	55.8	28.6 -	83	19.5	8.9 -	30	6.61	1.6 -	11.62	37.2	14.5 -	60
NO_2-Eff.	(mgN/l)	10.7	0.17 -	79	3.8	0.19 -	27	13.5	0.07 -	87.2	12.9	0.08 -	116
NO_3-Inf.	(mgN/l)	0.44	0.0 -	1.67	0.64	0.0 -	2.2	0.73	0.01 -	2.1	0.81	0.04 -	2.1
NO_3-Eff.	(mgN/l)	121	91.5 -	171	380	121 -	666	700	260 -	1278	1210	404 -	2460
Xvn	(mgVSS/l)	171	35 -	290	198	118 -	319	185	21 -	292	201	66 -	432
qn	(mgN/l*d)	227	75 -	276	251	216 -	292	230	46 -	268	240	125 -	405
qXvn	(mgN/gXvn*d)	1530	930 -	2613	1372	916 -	2023	1382	912 -	2191	1315	908 -	1909
qnp	(%)	86.2	27.3 -	99.8	97.7	74.2 -	99.9	91.8	22.5 -	99.9	94.6	58.9 -	99.9
OURX vn	(mgO_2/gXvn*d)	164	88 -	356	163	104 -	334	156	87.8 -	429	185	69 -	590
BOD_5/N	(-)	0.75	0.22 -	1.39	0.30	0.16 -	0.54	0.16	0.05 -	0.23	0.08	0.03 -	0.12
Fn	(%)	25.8	13.3 -	55.5	49	33.5 -	62.8	62.8	24.4 -	93.8	78.8	63 -	92

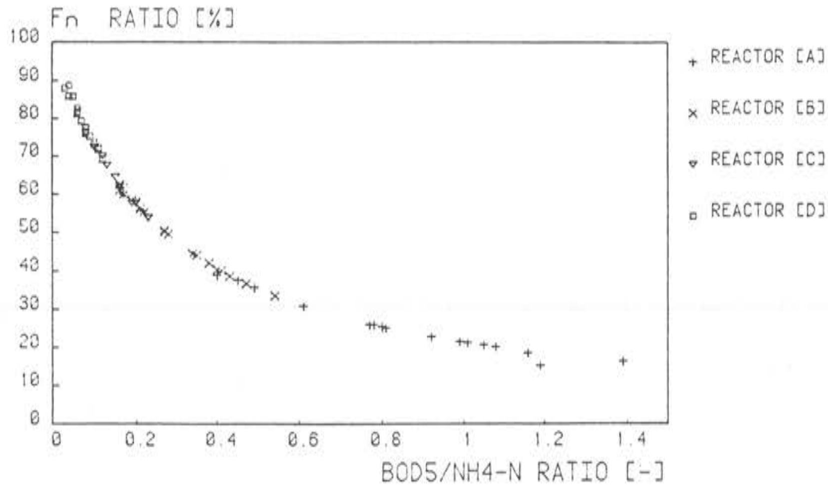

Fig. 2. Relationship between BOD_5/NH_4-N ratio and nitrifier fraction (Fn).

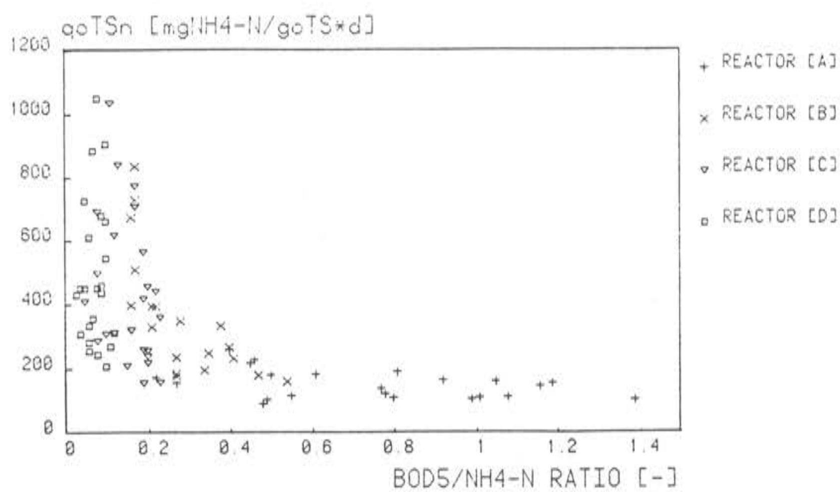

Fig. 3. Effect of BOD_5/NH_4-N ratio on nitrification rate ($qoTS_n$).

TABLE 3 Kinetic Data Analysis of Nitrification Process

		Reactor											
		A			B			C			D		
Parameter	Dimension	i.M.	Min.	Max.	i.M.	Min.	Max.	i.M.	Min.	Max.	i.M.	Min.	Max.
tTS	(d)	11.9	5.3	20	12.4	6.3	20	12.4	6.2	20	13	6.9	20
tTS_m	(d)	10.3	4.5	18.3	11.6	5.9	19	11.6	5.3	19	12.1	6.3	20.6
SF	(-)	1.41	1.18	1.73	1.46	1.24	1.76	1.46	1.22	1.75	1.48	1.26	1.78
tTS^{-1}	(d^{-1})	0.1	0.05	0.19	0.09	0.05	0.16	0.09	0.05	0.16	0.09	0.05	0.14
U_{nm}	(d^{-1})	0.15	0.09	0.26	0.14	0.09	0.2	0.14	0.09	0.22	0.13	0.09	0.19
U_{nmT}	(d^{-1})	0.15	0.09	0.26	0.14	0.09	0.21	0.14	0.09	0.23	0.13	0.09	0.20
U_{nT}	(d^{-1})	0.13	0.07	0.22	0.11	0.06	0.17	0.1	0.05	0.18	0.10	0.05	0.15
b_{nT}	(d^{-1})	0.04			0.04			0.04			0.04		
Y_n theo.	(mg/mg*d)	0.1			0.1			0.1			0.1		
$qoTS_n$	(mgN/goTS*d)	171	85	610	437	155	1417	434	149	1029	474	158	1045
k_n	(mgN/l)	0.08	0.05	0.13	0.07	0.05	0.10	0.07	0.05	0.11	0.07	0.05	0.10
K_{nT}	(mgN/l)	0.08	0.05	0.13	0.07	0.05	0.10	0.07	0.05	0.12	0.07	0.04	0.10
K_{mT}	(mgN/gXvn*d)	1504	947	2613	1359	906	2105	1367	904	2304	1321	864	2004
K_T	(mgN/gXvn*d)	1327	779	2607	1203	811	2023	1298	899	2245	1241	805	1996
G_n	(d)	4.9	2.6	7.3	5.4	3.3	7.7	5.4	3.0	7.7	5.5	3.5	8.0

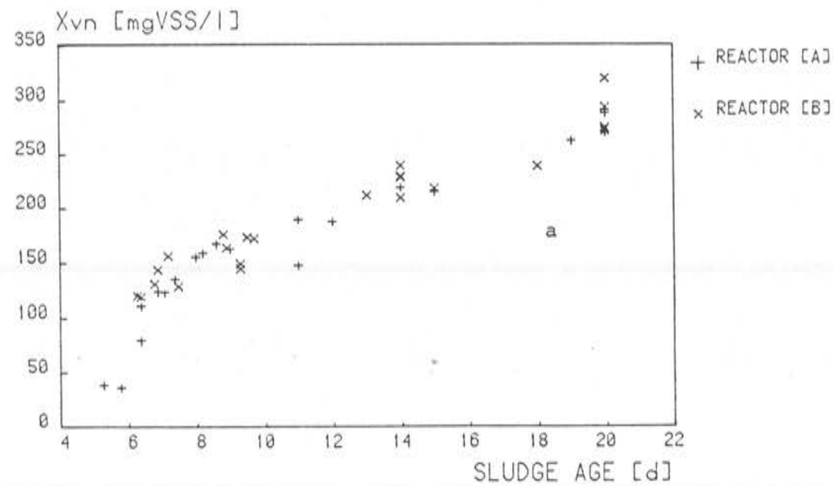

Fig. 4a. Influence of sludge age on nitrifier biomass (Xvn).

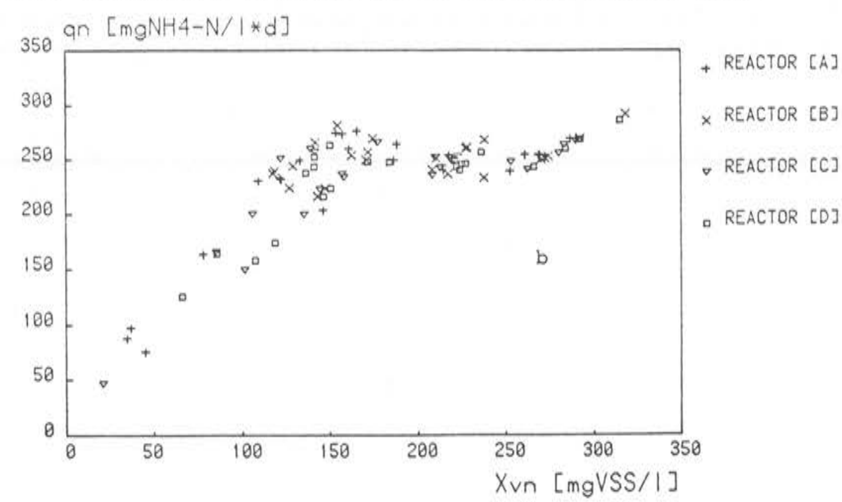

Fig. 4b. Plot of nitrifier biomass (Xvn) against nitrification rate (qn) in all reactors.

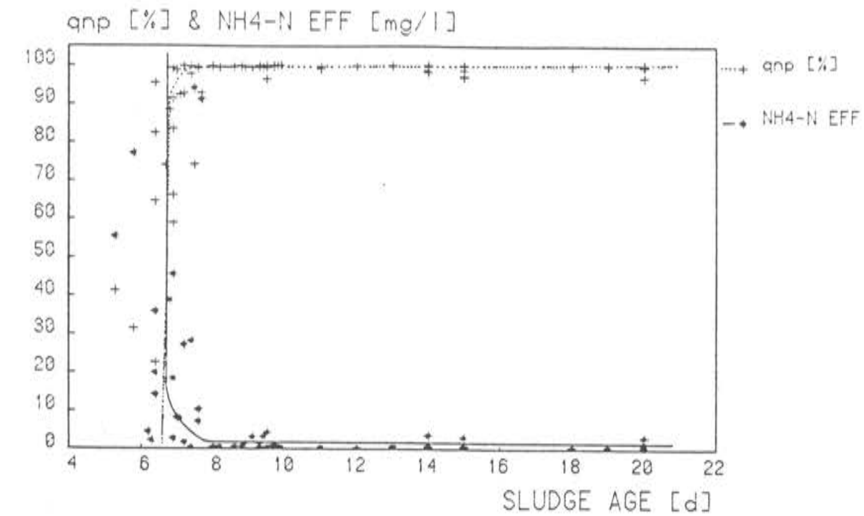

Fig. 5. Effect of sludge age on nitrification performance.

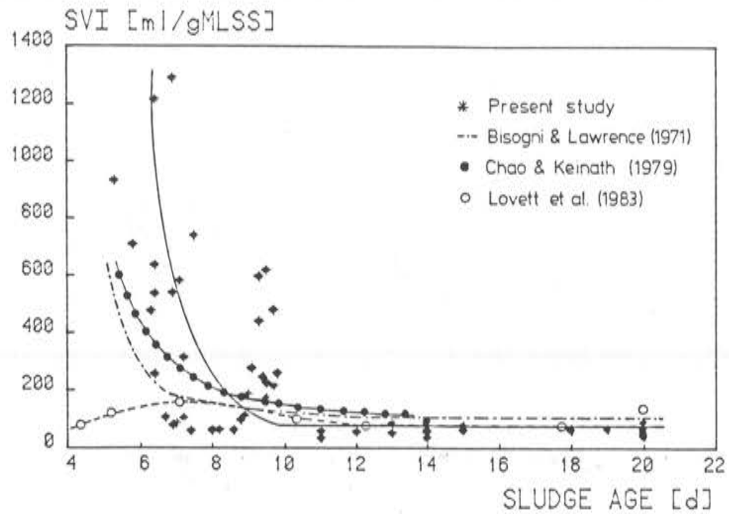

Fig. 6. Effect of sludge age on sludge settleability.

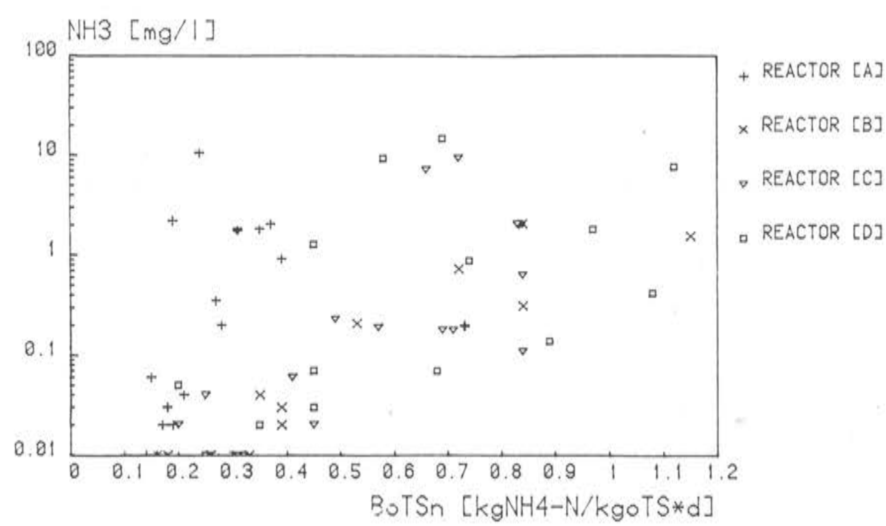

Fig. 7. Plot of NH_4-Sludge loading against NH_3 concentration.

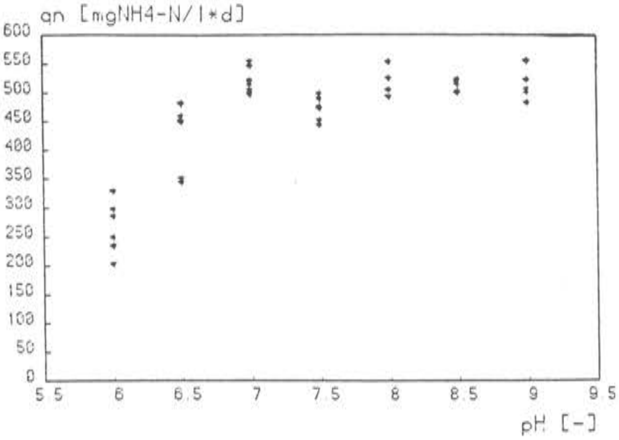

Fig. 8 . Effect of pH on nitrification rate (qn).

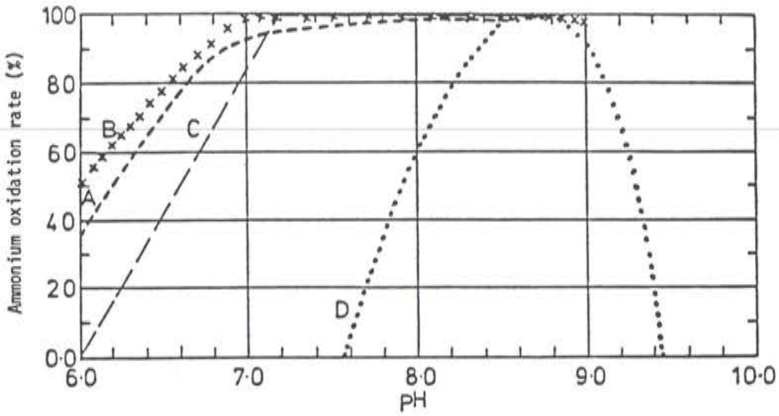

Fig. 9. Effect of pH on nitrification efficiency.

Symbol	Environment	Reference
A	Submerged filter	Haug and McCarty (1971)
B	Activated sludge at 20°C	This study (1987)
C	Activated sludge at 20°C	Sawyer and Others (1973)
D	Pure culture of Nitrosomonas	Meyerhof (1917)

NOMENCLATURE

BOD_5	Biological oxygen demand	(mg/l)
BR_c	BOD_5- Volumetric loading	(kg/m^3*d)
BR_n	NH_4- Volumetric loading	(kgN/m^3*d)
$BoTS_c$	BOD_5- Sludge loading	(kg/kgoTS*d)
$BoTS_n$	NH_4- Sludge loading	(kgN/kgoTS*d)
DO	Dissolved oxygen concentration	(mgO_2/l)
Fn	Nitrifier fraction	(%)
GV	Ignition value	(%)
HRT	Hydraulic retention time	(d)
SVI	Sludge volume index	(ml/gMLSS)
K_T	Specific nitrification rate (Monod equation)	(mgN/gXvn*d)
K_{mT}	Maximum nitrification rate (Monod equation)	(mgN/gXvn*d)
K_{nT}	Half saturation constant	(mgN/l)
MLSS	Mixed liquor (total) suspended solids	(gTSS/l)
MLVSS	Mixed liquor (volatile) suspended solids	(goTS/l)
OURXvn	Oxygen uptake rate (nitrifier)	$(mgO_2/gXvn*d)$
qn	Nitrification rate (volumetric)	(mgN/l*d)
qnp	Nitrification efficiency	(%)
$qoTS_n$	Nitrification rate interms of MLVSS	(mgN/goTS*d)
qXvn	Nitrification rate interms of Xvn	(mgN/gXvn*d)
qr	Influent flow rate	(d^{-1})
SF	Factor of safety	(-)
tTS	Sludge age (solids retention time)	(d)
tTS_m	Minimum sludge age	(d)
T	Temperature	(°C)
U_{nT}	Specific nitrifier growth rate	(d^{-1})
U_{nmT}	Maximum nitrifier growth rate	(d^{-1})
Xvn	Nitrifier biomass	(mgVSS/l)

Nitrifiers biomass decreased inversly proportional to sludge age. Sufficient Xvn lead to complete ammonium oxidation at a critical SRT of 8 days, a safety factor of 1.45 should be recommended to achieve 90% nitrification (Al-Sa'ed, 1987). Under optimal design and operational conditions the pH value between 7 and 9 showed no inhibitory effects.

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