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M. J. GROMIEC*, M. VALVE**

NITROGEN REMOVAL FROM WASTEWATERS BY THE SINGLE-STAGE ACTIVATED SLUDGE SYSTEMS

Technology for removal of nitrogen from wastewaters by single sludge systems is reviewed. These systems developed and applied in different countries are described in order to show the variety of options available. The emphasis is given to their performance under different operating conditions.

1. INTRODUCTION

The presence of nitrogenous substances in wastewater discharged to receiving waters creates numerous problems. Very serious amounts of nitrogen usually come from municipal wastewaters, feedlots and particularly, from waste loads of nitrogen fertilizer production plants [19], [22]. Therefore, special attention is paid to control environmental pollution by nitrogen from these and other sources. The removal of nitrogenous substances from wastewaters is, however, a complex problem.

In the recent years many practical biological processes have been developed for nitrogen removal. Nitrogen compounds can be converted in other ones or removed from wastewaters by various types of biological nitrification and denitrification processes [1], [12], [21], [31], [33]. Activated sludge nitrification–denitrification processes are most frequently applied in nitrogen control. These processes are usually designed in relation to their kinetics [4], [19]. Since nitrogen removal is rather expensive process, its different variants should

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* Institute of Meteorology and Water Management, Podleśna 61, 01–673 Warsaw, Poland.

** Technical Research Office, National Board of Waters, Helsinki, Finland.

be throughly investigated [13], [20], [38], [40]. Energy is a factor limiting the construction and operation of multi-stage activated sludge systems of nitrogen removal. Therefore, many efforts are made to develop single-stage systems. Their various modifications are possible, and some of them are presently under investigation.

2. SYSTEMS OF NITROGEN REMOVAL BY ACTIVATED SLUDGE PROCESS

Conversion of nitrogen compounds and their removal may proceed in separate sludge reactors or in one reactor simultaneously. Therefore, total nitrogen removal can be accomplished in multi-stage sludge systems with external carbon source [10], [11] or in single-stage systems with internal carbon source used for denitrification [41], [42]. Many external carbon sources can be applied to denitrification [32]; wastewaters or endogenous carbon sources may be also used. The following main single-stage activated sludge systems of nitrogen removal can be distinguished: a single-stage sludge system followed by denitrification, a single-stage sludge system preceded by denitrification, a single-stage sludge system preceded and followed by denitrification, a single-stage sludge system preceded by separation and with simultaneous denitrification, and a single-stage sludge system with simultaneous denitrification. In the last system aerobic and anaerobic zones occur along the path of flow. There is, however, a number of processes in which alternate aerobic/anaerobic modes of operation are applied.

3. SINGLE SLUDGE SYSTEMS

A review of single sludge systems for nitrogen removal and the modes of their operations are presented in this section to show available options and to indicate that due to the lack of universally applicable system the selected one must suit the local conditions.

3.1. DENITRIFICATION-NITRIFICATION AND NITRIFICATION-DENITRIFICATION PROCESSES

A single activated sludge reactor with alternate anaerobic and aerobic zones was proposed by Ludzack and Ettinger [25]. In the laboratory-scale reactor (fig. 1), the mixed liquor from the aerobic (second) zone was recycled to the anaerobic (first) zone. The denitrification rate was controlled by the rate of mixed liquor recycling from the second to the first zone. The reported

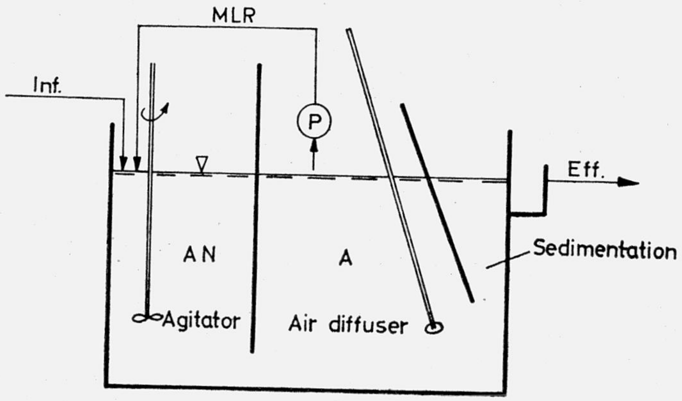

Fig. 1. Schematic of the anaerobic–aerobic reactor unit

Rys. 1. Schemat reaktora beztlenowo–tlenowego w skali laboratoryjnej

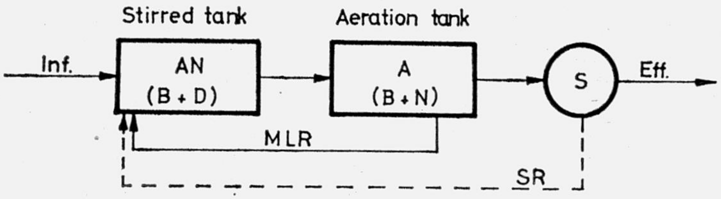

Fig. 2. Anaerobic–aerobic process (dn-process) proposed by LUDZAK and ETTINGER [25]

Rys. 2. Proces beztlenowo–tlenowy (proces dn) zaproponowany przez LUDZAKA i ETTINGERA [25]

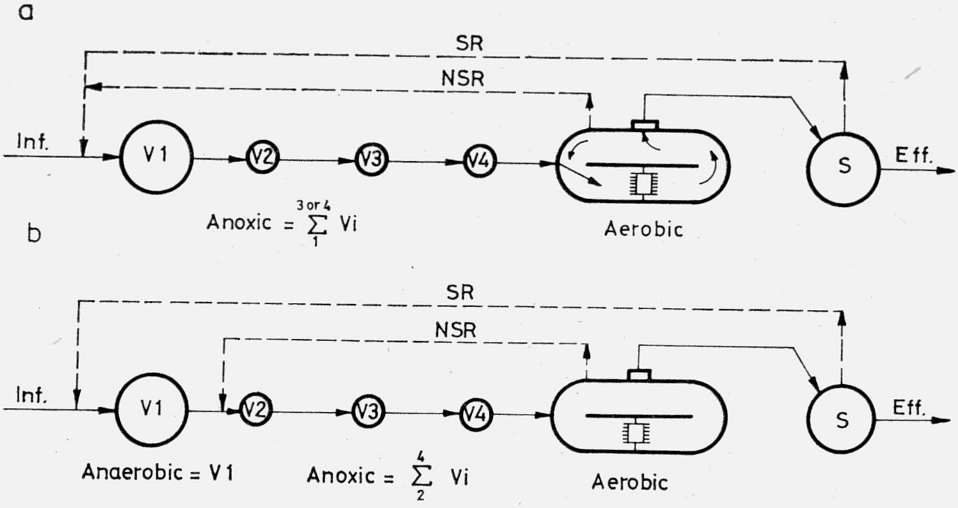

Fig. 3. Flow diagram of experimental plant of Reading [3]

a – 1st, 2nd, 3rd periods, b – 4th period

Rys. 3. Schemat doświadczalnej oczyszczalni w Reading [3]

a – okres 1, 2, 3, b – okres 4

Table I

Operating conditions of the Reading experimental plant. Weekly average data for four operation periods in 1976–1979 [3]

Warunki pracy doświadczalnej oczyszczalni ścieków w Reading. Średnie wyniki dla czterech okresów w latach 1976–1979 [3]

Operating conditions	Period 1 (18 weeks) Summer (low load season)	Period 2 (16 weeks) Winter (high load season)	Period 3 (15 weeks) Summer (low load season)	Period 4 (15 weeks) Winter (high load season)
Anoxic volume (Vi), m^3	6.9	5.4	6.5	4.7
Anaerobic volume (V1), m^3	—	—	—	—
Aerobic volume (VOR), m^3	17.6	17.7	17.8	17.8
Diss. oxygen in OR, mg/dm^3	3.1	2.0	1.5	1.5
MLSS*, mg/dm^3	4310	5320	4000	6010
SRT, d	15.4	14.3	4.8	6.5
HRT*, d	24.5	16.1	11.1	12.1
Vol. BOD load*, kg/m^3·d	0.34	0.61	0.73	0.81
Sludge load*, g BOD/g MLSS·d	0.084	0.117	0.183	0.137
Nitrified sludge recycle ratio	23.1	23.5	14	14
Settled sludge recycle ratio	2.4	1.9	1.4	1.4
Temperature, °C	27.5	23.3	29.2	19.1
DO in OR, mg/dm^3	3.1	2.0	1.5	1.5

* Workday averages.

nitrogen removal exceeded 60%. A schematic representation of single sludge two-basin dn-process is presented in fig. 2.

Two technical-scale demonstration plants consisting of an anaerobic zone with four circular tanks connected in series and an aerobic zone with one orbital circulating flow tank (fig. 3) were tested in Israel by Arueste [3]. These plants, located near the Reading Pump Station, North Tel Aviv, operated under various loading conditions. The operating conditions and performance of the Reading Demonstration Plants are summarized in tables 1 and 2, respectively. The total nitrogen removal ranged from 86% to 95%.

An alternate approach to the Ludzack–Ettinger system was used by Wuhrman [47], who applying a two-zone laboratory-scale sludge reactor with the anaerobic zone located after the aerobic zone obtained the nitrogen removal as high as 90%. In other experiments made by Barnard [5] this result could

Table 2

Average results of the Reading experimental plant operation. Weekly average data for four operation periods in 1976–1979 [3]

Średnie wyniki pracy doświadczalnej oczyszczalni ścieków w Reading dla czterech okresów w latach 1976–1979 [3]

	Period 1 (18 weeks) Summer (low load season)	Period 2 (16 weeks) Winter (high load season)	Period 3 (15 weeks) Summer (low load season)	Period 4 (15 weeks) Winter (high load season)
Influent				
BOD$_5$ (total), mg/dm^3	325 ± 44	327 ± 37	303 ± 39	370 ± 61
BOD$_5$ (filt.), mg/dm^3	162 ± 19	171 ± 25	133 ± 19	191 ± 29
COD (total) mg/dm^3	718 ± 88	716 ± 69	647 ± 53	759 ± 92
COD (filt.), mg/dm^3	284 ± 44	263 ± 51	205 ± 26	324 ± 36
Nitrogen (total), mg/dm^3	59 ± 4.1	53.6 ± 4.1	44.9 ± 4.0	51.4 ± 2.2
Ammonia nitrogen, mg/dm^3	49.2 ± 3.3	41.8 ± 3.5	37.0 ± 3.1	40.6 ± 3.1
Phosphorus (total), mg/dm^3	14.2 ± 1.9	12.6 ± 1.1	14.2 ± 1.2	12.8 ± 1.7
Effluent				
BOD$_5$ (total), mg/dm^3	5.7 ± 1.3	N/A	N/A	N/A
BOD$_5$ (filt.), mg/dm^3	3.9 ± 0.9	4.3 ± 1.0	4.4 ± 0.9	4.6 ± 0.6
COD (total), mg/dm^3	57.6 ± 11.0	68.5 ± 21.3	62.1 ± 7.5	77.3 ± 7.9
COD (filt.), mg/dm^3	44.1 ± 10.8	49.4 ± 19.5	44.4 ± 5.3	53.4 ± 7.4
Nitrogen (total), mg/dm^3	8.2 ± 2.6	9.6 ± 5.1	3.0 ± 0.6	3.7 ± 0.7
Ammonia nitrogen, mg/dm^3	1.1 ± 0.3	3.1 ± 0.6	1.1 ± 0.4	1.2 ± 0.3
Nitrate nitrogen, mg/dm^3	6.2 ± 2.8	1.2 ± 0.7	1.0 ± 0.4	1.5 ± 0.7
Phosphorus, mg/dm^3	5.3 ± 0.8	3.7 ± 0.9	3.2 ± 0.9	0.6 ± 0.2
Nitrogen (total) removal, %	86.1	94.2	95.6	92.0
Ammonia nitrogen removal, %	97.8	97.8	96.9	96.3
Phosphorus removal, %	62.7	70.6	77.7	95.3

N/A = not analyzed.

not, however, be obtained. A schematic diagram of nd-process (one-basin with zones or two-basin) is shown in fig. 4.

The possibility of a simultaneous precipitation of phosphorus by using ferrous sulphate to the nd-process, as proposed by WUHRMAN [47] and to the dn-process as proposed by BRINGMAN et al. [15], was studied in Finland by VALVE [45]. In the nd-process no effective removal of nitrogen or phosphorus was achiveed, while in the dn-process the highest removal of the total nitrogen

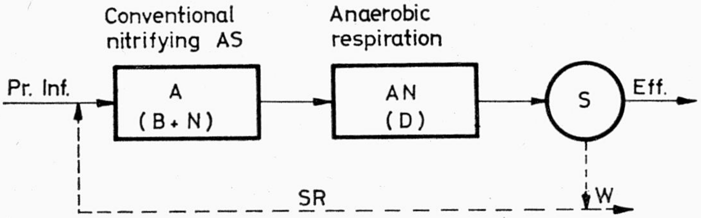

Fig. 4. Aerobic–anaerobic process (nd-process) proposed by Wuhrman [47]

Rys. 4. Proces tlenowo–beztlenowy (proces nd) zaproponowany przez Wuhrmana [47]

reached 58% at about 12 °C, the total phosphorus in effluent being about 1.5 mg/dm³. The dn-process combined with simultaneous precipitation was considered to be most appropriate method for Finnish conditions.

3.2. OXIDATION DITCHES

Oxidation ditches (fig. 5) employ aeration devices such as Kessner brushes, cage aerators and vertical turbine mechanical aerators, and operate under extended aeration conditions. Nitrogen removal is possible due to presence of anaerobic zones established between the aerators. Aerobic/anaerobic zones are created by controlling the intensity of aeration and by a proper spacing of aerators. The mixed liquor is recirculated through these zones prior to their discharge.

Nitrogen removal in oxidation ditches was investigated by Pasveer [36], and the reported efficiency of nitrogen removal reached 90%. Significant removals of nitrogen in activated sludge treatment plants of an oxidation ditch type in Vienna–Blumental were reported by Matsché [26], [27]. This is the largest plant of this type employed for nitrogen removal. The municipal wastewater from the population of about 200,000 is treated without primary sedimentation in two aeration tanks (each of 6,000 m³) with 6 pairs of mammoth rotors (fig. 6). The results of special tests (shown in tab. 3) indicate that removal

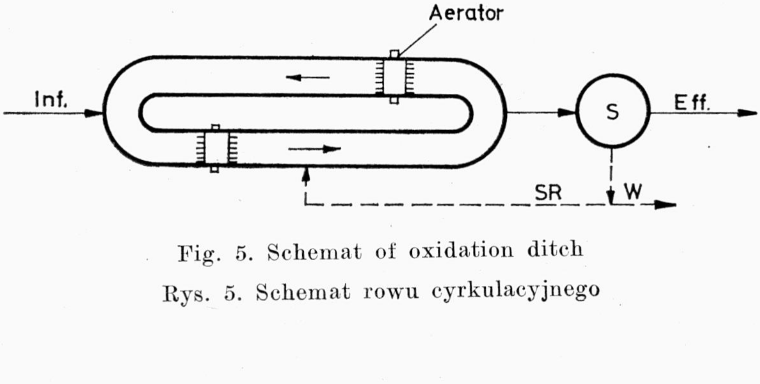

Fig. 5. Schemat of oxidation ditch

Rys. 5. Schemat rowu cyrkulacyjnego

Table 3

Conditions and results of the Vienna–Blumental Plant operation [29]

Warunki i wyniki pracy oczyszczalni Vienna–Blumental [29]

	Sept. 2 1971	Feb. 17 1972	June 6 1974	July 16 1974	July 31 1974	Aug. 7 1974
Operational data						
Wastewater flow, m^3/s	0.42	0.61	0.54	0.48	0.42	0.40
Aeration water temp., °C	18	12	18	20	19	20
Aeration detention time, h	8.0	5.5	6.1	7.0	8.0	8.4
MLSS, g/dm^3	6.7	6.2	5.3	5.9	5.4	5.4
Return sludge SS, g/dm^3	10.0	10.3	8.0	9.0	7.9	8.4
Sludge loading, g BOD_5/gMLSS·d	0.11	0.13	0.20	0.19	0.16	0.24
Operating rotors,						
tank 1	4	3	3	4	4	4
tank 2	2	3	3	2	3	4
Clarifier overlow rate, m^3/m^2d	11.4	16.6	14.7	13.0	11.4	10.9
Performance data						
BOD_5						
Influent, mg/dm^3	268	200	268	239*	294*	445*
Effluent, mg/dm^3	13	13	10	13**	12**	14**
Removal, %	95	93	96	36	96	97
COD						
Influent, mg/dm^3	475	384	463	575	515	778
Effluent, mg/dm^3	49	50	39	39	35	58
Removal, %	90	87	92	93	93	92
TOC						
Influent, mg/dm^3	155	126	128	143	134	208
Effluent, mg/dm^3	14	13	12	14	13	15
Removal, %	91	90	91	90	90	93
Ammonia nitrogen						
Influent, mg/dm^3	21.8	9.0	21.8	16.6	17.2	21.2
Effluent, mg/dm^3	3.8	2.7	6.3	3.9	2.4	2.7
Removal, %	83	70	71	76	76	87
Total nitrogen						
Influent, mg/dm^3	36	24	—	—	—	—
Effluent, mg/dm^3	4	4	—	—	—	—
Removal. %	88	82	—	—	—	—

* Recalculated from COD.

** Recalculated from TOC.

of ammonia nitrogen ranged from 70% to 87%, and that of total nitrogen exceeded 80%.

The mechanism of the total nitrogen removal was explained by the simultaneous presence of aerobic and anaerobic zones in the channels. At first the

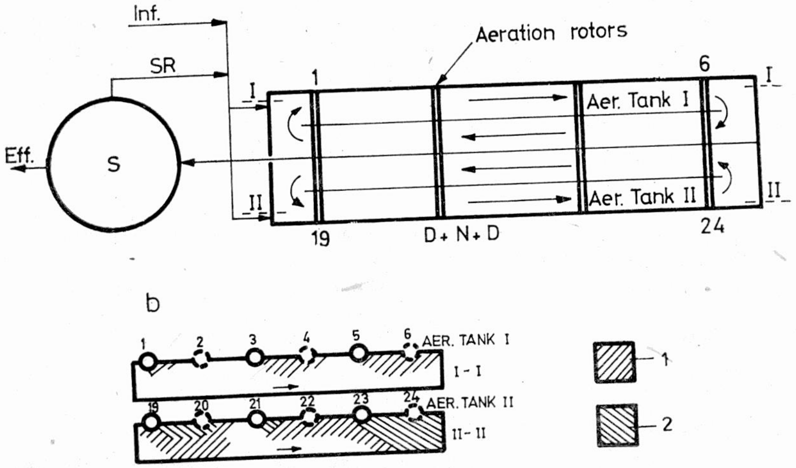

Fig. 6. Single-stage aerobic oxidation ditch process [29]

a – flow diagram

B – oxidation of organics, N – nitrification, D – denitrification, S – sedimentation, SR – sludge recycle

b – profiles of dissolved oxygen

1 – 0.5–1.5 mg O_2/dm^3, 2 – > 1.5 mg O_2/dm^3

Rys. 6. Tlenowo-beztlenowy rów cyrkulacyjny [29]

a – schemat doświadczalny

B – utlenianie związków organicznych, N – nitryfikacja, D – denitryfikacja, S – sedymentacja, SR – obieg osadu ściekowego

b – profile rozpuszczonego tlenu

1 – 0,5–1,5 mg O_2/dm^3, 2 – > 1,5 mg O_2/dm^3

aeration was controlled manually [29], [30], later on an automatic control system was applied [44].

The results of the plant operation with the automatic DO control are given in tab. 4. The total nitrogen removal varied from 32% to 96%. It has been stated that for the optimal performance of such a plant the oxygen supply should be in balance with its uptake [28].

3.3. "ORBAL" ACTIVATED SLUDGE SYSTEMS

A high degree of total nitrogen removal can also be obtained in "Orbal" type activated sludge systems by alternating the channels with aerobic and anaerobic conditions. This type of plant was described by DREWS et al. [18], its schematic representation is shown in fig. 7. This plant consists of four oval, concentrically arranged aeration channels with disc aerators and a clarifier. These plants can operatie in different modes, but DREWS and GREEFF [17]

Table 4

Conditions and results of the Vienna–Blumental treatment plant operation [28]

Warunki i wyniki pracy oczyszczalni ścieków Wiedeń–Blumental [28]

	Period					
	1	2	3	4	5	6
Operation						
Flow, m^3/dm^3	54500	66400	58200	61200	75500	61700
Aeration time, h	5.3	2.2	4.9	4.7	3.8	2.3
MLSS, mg/dm^3	6800	6000	3000	5700	6900	5700
Vol. load, kg BOD/m^3d	0.84	1.51	0.86	1.80	0.98	1.36
Sludge load, g BOD/g MLSS · d	0.12	0.25	0.29	0.19	0.14	0.24
Temperature, °C	20	20	20	20	12.5	15.5
Influent						
BOD_5, mg/dm^3	194	144	186	223	155	132
COD, mg/dm^3	355	238	342	369	394	349
Kjeldahl nitrogen, mg/dm^3	25	26	24	28	27	23
Ammonia nitrogen, mg/dm^3	13	12	14	15	17	14
Phosphorus (total), mg/dm^3	7.9	6.6	8.9	9.3	10.2	11.3
Effluent						
BOD_5, mg/dm^3	9	8	9	1	5	9
COD, mg/dm^3	31	27	41	39	28	52
Ammonia nitrogen, mg/dm^3	0.2	3	2	7	1.7	14
Org. nitrogen mg/dm^3	2.5	4.2	6	1	3	0
Phosphorus (total), mg/dm^3	6.0	5.1	6.1	5.9	6.2	7.4
BOD_5 removal, %	95	94	95	95	97	93
Total nitrogen removal, %	86	72	60	70	81	32
Total phosphorus removal, %	22	23	32	38	39	35

have shown that the mode with two disc aerators in the first channel and with one disc aerator in each of the remaining channels gave the best results. Data for two runs performed in summer and winter (presented in tab. 5) show that the total nitrogen removals in winter were about 70–80 % and in summer 80–85 %, and that effluent quality was always very good.

3.4. CARROUSEL ACTIVATED SLUDGE SYSTEM

The Carrousel system, developed in the Netherlands, can be applied to nitrogenous material removal [39]. The typical layout of this system, in which surface aerators are located at one end of the Carrousel basin, is depicted in fig. 8A. The aerators can, however, be placed in a variety of configurations (fig. 8B). Due to the type of flow the DO level in this system along some length of the channels is reduced to zero and denitrification is promoted. Nitrification

Table 5

Conditions and results of the "Orbal" pilot plant operation [17]

Warunki i wyniki pracy doświadczalnych oczyszczalni ścieków typu „Orbal" [17]

	Summer		Winter	
Operation				
Feed, dm³/h	4800	8000	5000	6000–6500
Retention time, h	23.2	13.9	22.2	17.1–18.5
Return sludge ratio	2:1	1.5:1	2:1	2:1
MLSS, mg/dm³	4330	4280	3720	3660
Wastewater temp., °C	21–22.5	20–22	14–17	14–15.5
SVI, cm³/g	213	212	263	268
Sludge load, g COD/g MLVSS·d	0.155	0.28	0.20	0.26
Influent				
COD, mg/dm³	749	791	678	723
Kjeldahl nitrogen, mg/dm³	39.5	39.4	43.1	45.0
Ammonia nitrogen, mg/dm³	21.3	20.7	28.2	29.2
Effluent				
COD, mg/dm³	28.2	30.9	34.4	37.4
Kjeldahl nitrogen, mg/dm³	4.5	4.05	6.4	5.0
Ammonia nitrogen, mg/dm³	3.4	3.3	3.4	2.1
Nitrate nitrogen, mg/dm³	1.4	2.65	3.4	7.1
COD removal, %	96.2	96.0	94.6	94.5
Nitrogen removal, %	85.2	81.6	77.3	72.0

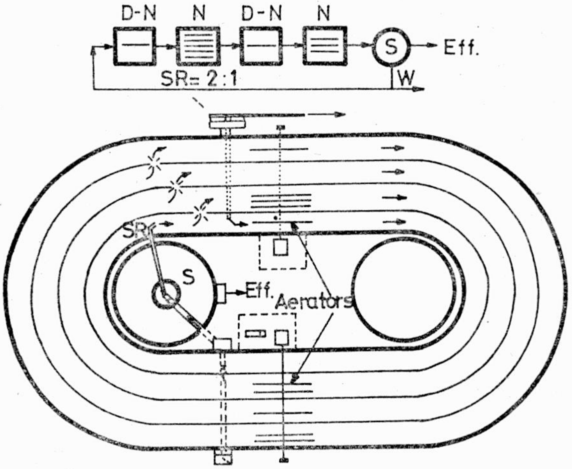

Fig. 7. "Orbal" extended aeration activated sludge process [17]

Rys. 7. Proces osadu czynnego z przedłużonym napowietrzaniem typu „Orbal" [17]

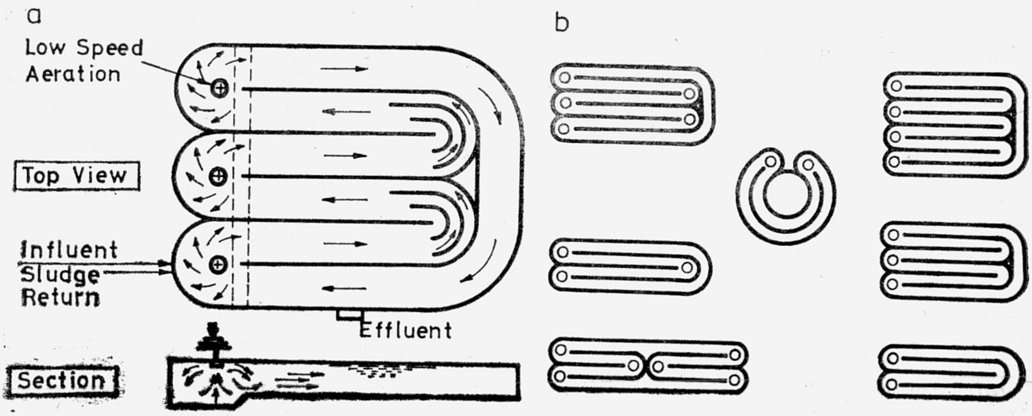

Fig. 8. Schematic plant of the Carrousel activated sludge system [39]
a – typical lay-out, b – the Carrousel tank configurations

Rys. 8. Schemat systemu osadu czynnego typu Carrousel [39]
a – typowa instalacja, b – zbiornikowe układy Carrousela

Table 6
Average operation results of selected Carrousel systems [39]
Średnie wyniki pracy wybranych systemów typu Carrousel [39]

	Influent mg/dm^3	Effluent mg/dm^3	Removal %
Winterswijk			
BOD$_5$	343	6.0	98.3
COD	714	53.0	92.6
Kjeldahl nitrogen	59.5	3.9	93.4
Ammonia nitrogen	–	1.9	–
Nitrate nitrogen	–	8.3	–
Total nitrogen	59.5	12.2	79.5
Zutphen			
BOD$_5$	312	3.1	99.0
COD	738	38.0	94.9
Kjeldahl nitrogen	56.5	3.3	94.2
Ammonia nitrogen	–	0.5	–
Nitrate nitrogen	–	12.4	–
Total nitrogen	56.5	15.7	72.2
Lichtenvoorde			
BOD$_5$	663	4.6	99.3
COD	1316	54.9	95.8
Kjeldahl nitrogen	108.3	3.1	97.1
Ammonia nitrogen	–	0.8	–
Nitrate nitrogen	–	43.5	–
Total nitrogen	108.3	48.6	57.0

occurs within aerobic zone of the channels. It was also proposed to remove phosphorus by addition of chemicals to the Carrousel tank.

The average operating results from some conventional Carrousel systems in The Netherlands are given in tab. 6. The data show that the total nitrogen removal ranges within 60–80%. A higher level of nitrogen removal can be achieved with the optimization of such systems. Systems of similar type are designed in Poland for dairy wastewaters.

3.5. BARDENPHO PROCESS

A single reactor–clarifier system with four in series basins, alternating from anaerobic to aerobic conditions and with a clarifier, was developed at the National Institute for Water Research in Pretoria by BARNARD [5], [6]. A schematic representation of the process, termed the Bardenpho Process, is shown in fig. 9. The first two tanks in this system operate according to the Ludzack–Ettinger mode, and nitrofication takes place in the second tank, the DO concentration being about 2 mg/dm³. The mixed liquor from this tank is recirculated to the first tank. Anaerobic conditions are kept where the endogenous respiration takes place. In the final tank the mixed liquor is aerated in order to remove gaseous nitrogen. Typical retention times in these tanks, being 3 h, 6 h, 2 h and 1 h, respectively, are based on the average influent flow rate, and the mixed liquor temperature was 14 °C [7].

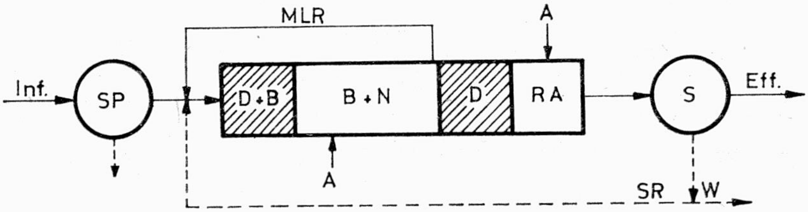

Fig. 9. Bardenpho process [7]

Rys. 9. Proces Bardenpho [7]

In test performed in a 100 m³/d pilot plant in Pretoria, nitrogen removal exceeded 90%, and the average total nitrogen concentration in the effluent less than 3.0 mg/dm³ was obtained [8]. This process when applied in South Africa yielded 80–90% removal of nitrogen, average phosphorus content in the final effluent being 0.8 ± 0.5. In order to employ this process, some large scale plants (fig. 10) have been modified and new ones designed [8], [9]. Significant removals were reported in the modified plants. For example, an extended aeration plant in Alexandria with an average in dry season flow of 27,000 m³/d was modified by switching off the aerators near the inlet zone, the other aerators being kept running. The total nitrogen removal in this plant was 85 ± 5% [34].

Also, wastewater treatment facilities in Johannesburg were extended by building three new plants with anaerobic zones, each of which treated 150,000 m^3/d [35].

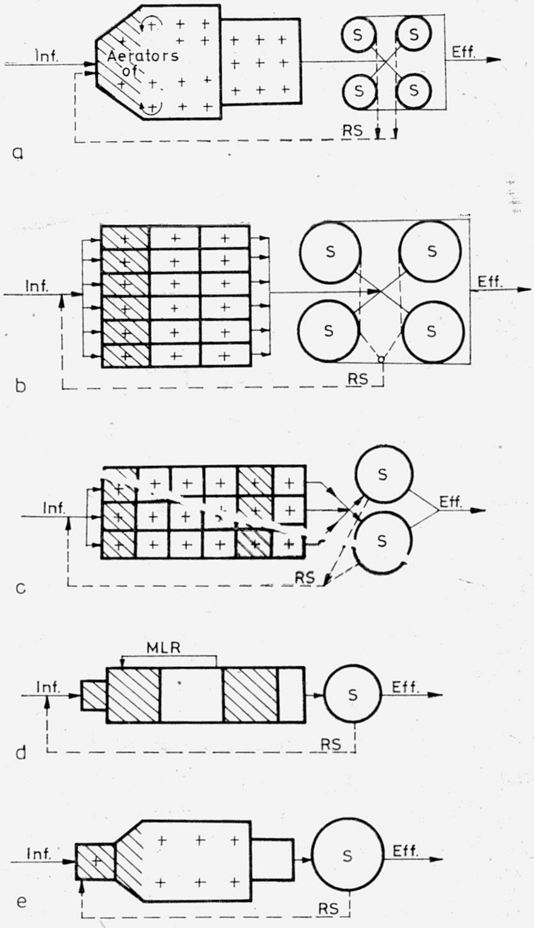

Fig. 10. Schematic plans of treatment plants based on the Bardenpho process [8]

a – lay-out of Alexandra Plant, Johannesburg; b – lay-out of Daspoort Plant, Pretoria; c – lay-out of Brasilia North Plant; d – lay-out of Goudkoppies Plant, Johannesburg; e – lay-out of Secunda Plant

Rys. 10. Schematy oczyszczalni ścieków opartych na procesie Bardenpho [8]

a – instalacja w oczyszczalni „Alexandra", Johannesburg; b – instalacja w oczyszczalni „Daspoort", Pretoria; c – instalacja w oczyszczalni „Brasilia North"; d – instalacja w oczyszczalni „Goudkoppies", Johannesburg; e – instalacja w oczyszczalni „Secunda"

3.6. ALTERNATING CONTACT PROCESS

An alternating contact aerobic–anaerobic process was proposed by Christensen [16]. Basically, the system consists of a two-basin, single sludge reactor–clarifier, and the process proceeds in four phases (fig. 11). This process requires neither external carbon source, nor continuous recirculation of mixed liquor. In order to produce the alternate high or near zero oxygen concentration, alternating aeration takes place in the first tank and then in the second one.

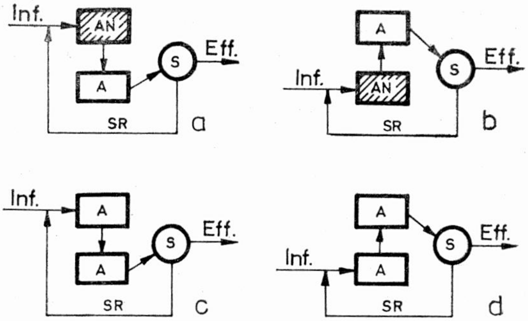

Fig. 11. Alternating contact process [16]

a – 1st phase, N/D; b – 3rd phase, N/D; c – 2nd phase, intermediate aeration; d – 4th phase, intermediate aeration

Rys. 11. Proces „przemiennego kontaktu" [16]

a – faza 1, N/D; b – faza 3, N/D; c – faza 2, przejściowe napowietrzanie; d – faza 4, przejściowe napowietrzanie

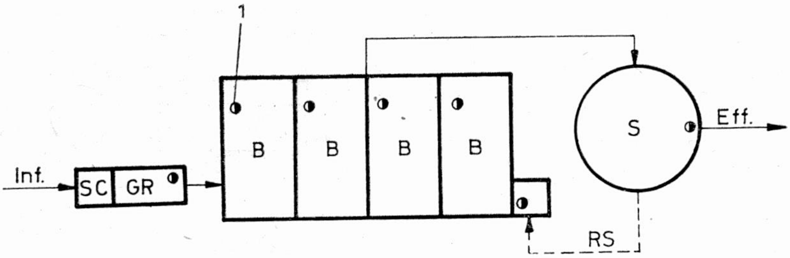

Fig. 12. Schematic plan of Frederikssund Plant [24]

SC – screen, GR – grit chamber, B – biological reactors, S – sedimentation position, 1 – sampling position

Rys. 12. Schemat oczyszczalni ścieków w Frederikssund [24]

SC – sito, GR – komora piaskowa, B – reaktory biologiczne, S – stanowisko sedymentacji, 1 – stanowisko pobierania próbek

Organic carbon is provided by alternate addition of influent wastewater and the sludge from the clarifier to either of the two tanks.

In Denmark, the process was investigated both on laboratory- and full-scales, and several plants are now in operation. The largest plant based on this process was designed for about 100,000 people. In the Frederikssund wastewater treatment plant (fig. 12) with a load corresponding to 33,000 people, the removal of total nitrogen was higher than 90% (tab. 7), and that of the total phosphorus equaled to 74% [24].

3.7. SEQUENCING BATCH REACTOR PROCESS

The sequencing batch reactor (SBR) process is a revival of a very well known "fill and draw" concept, which can be traced back to the beginning of this century. A schematic representation of this process with the sequential

Table 7
Average operation results* of the 24 h test performed at the Frederikssund treatment plant [24]

Średnie wyniki pracy oczyszczalni ścieków w Frederikssund uzyskane podczas 24 godz. badań [24]

	Influent mg/dm³	Effluent mg/dm³	Removal %
BOD	303	6.0	98.0
Ammonia nitrogen	21.2	2.2	98.5
Nitrate nitrogen	< 0.1	0.3	—
Total nitrogen	46.9	3.5**	92.5
Total phosphorus	13.3	0.9	93.0
Suspended solids	—	14.0	—

* Average temperature 16° C.
** Value based on one 24 h sample.

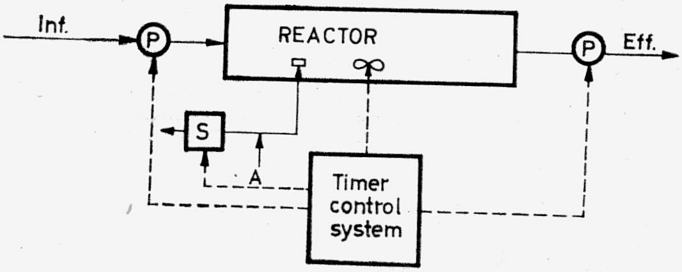

Fig. 13. Sequencing batch reactor
A – air, P – pumps, S – selenoid

Rys. 13. Reaktor o działaniu okresowym w ustalonej kolejności
A – powietrze, P – pompy, S – selenoid

mode of operation is presented in fig. 13. This sequence of events is then alternatively repeated, and the operating time depends on the wastewater characteristics and the treatment objectives. Various operations during these cycles may be automatically controlled by the use of a microprocessor or an electromechanical timer. Bench-scale studies on a synthetic wastewater with soluble BOD_5 of 400 mg/dm³ and organic nitrogen concentration of 60 mg/dm³ have shown a consistent (98 %) oxidation of both organic carbon and nitrogen [2].

This process has been tested in a 5,640 m³/d municipal treatment plant at Culver, Indiana, with a sludge loading between 0.1 to 0.5 g BOD_5/g MLVSS · d. So far, however, the sequencing batch reactor process seems to be appropriate of small wastewater treatment plants only.

3.8. SINGLE-STAGE TWO-BASIN PROCESS WITH ALTERNATING AERATION

For the total nitrogen removal a single-state two-basin process with alternating aeration was evaluated at the U.S. EPA Blue Plains pilot plant [14].

The 189 m^3/d pilot plant consisted of a two-basin reactor with aeration and mixing aquipment and a clarifier (fig. 14). Mechanical mixers were operated at 30 rpm. The basins were operated alternatively in order to create in each the corresponding either aerobic or anaerobic conditions. During the aeration period the DO concentration was between 2 and 3 mg/dm^3, and decreased to near zero during the anaerobic time.

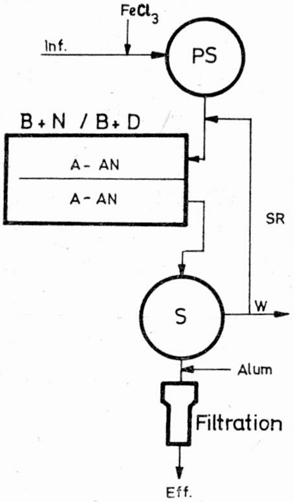

Fig. 14. Alternating aerobic–anaerobic process [14]

A – aerobic, AN – anaerobic, SR – sludge recycle, W – sludge waste, G – sedimentation, PS – primary sedimentation. B – oxidation of organics, N – nitrification, D – denitrification

Rys. 14. Proces przemienny tlenowo–beztlenowy [14]

A – tlenowy, AN – beztlenowy, SR – obieg osadu ściekowego, W – odpady osadu, G – sedymentacja, PS – początkowa sedymentacja, B – utlenianie związków organicznych, N – nitryfikacja, D – denitryfikacja

A primary treated municipal wastewater from the D.C. Wastewater Pollution Control Plants was fed at various steady flows to the aeration tank. The reactor was operated with an F/M ratio of approximately 0.1 g BOD$_5$/g MLVSS·d. With this loading the process of total nitrogen removal could proceed without the additional supply of organic carbon. For phosphorus removal the dose of 45 mg FeCl$_3$/dm^3 was added to the influent wastewater, and the dose of 20 mg of alum/dm^3 was introduced to the secondary effluent.

The results obtained are presented in tabs. 8 and 9. The total nitrogen removals (without an external carbon source) ranged from 49 to 84 %, depending on the wastewater temperature and the COD/TKN ratio in the wastewater entering the reactor. At 296 K and the COD/TKN ratio equal to 10.3, the removal of total nitrogen entering the biological reactor amounted to 84 %. By the addition of FeCl$_3$, the COD/TKN ratio decreased to 7.5, and the total nitrogen removal (at 298.8 K) decreased to 67 %. Some bulking of the sludge observed in winter disappeared during summer operations.

Table 8

Conditions and results of the Blue Plains Pilot Plant [14]

Warunki i wyniki pracy doświadczalnej oczyszczalni Blue Plains [14]

Month, 1973	Det. time h	F/M ratio g BOD/ g MLSS·d	MLSS mg/dm^3	COD/ TKN	Temp. °C	Primary influent mg/dm^3			Secondary effluent* mg/dm^3				
						BOD$_5$	SS	TKN	BOD$_5$	SS	TKN	NH$_4$	NO$_3^-$, NO$_2^-$
Jan.	12.3	0.072	3510	9.6	14.0	96.5	110	25.7	20.4**	15.4	2.28	0.53	3.99
Feb.	12.3	0.066	3980	9.9	14.2	99.0	108	23.2	14.0**	14.3	1.52	0.31	4.41
March	12.3	0.100	2950	10.5	15.5	110.0	128	24.8	6.5	15.0	4.20	2.40	2.30
April	12.4	0.081	3540	10.5	—	98.0	120	21.7	5.3	13.0	5.20	3.90	6.03
May	10.5	0.089	4270	10.0	—	115.0	109	23.3	3.3	11.8	1.36	0.31	8.25
June	8.8	0.105	4010	10.3	23.0	107.0	112	24.0	3.2	7.8	1.51	0.45	2.30
July	6.8	0.093	3040	7.9	25.0	51.0	153	15.0	3.8	9.0	2.14	1.63	2.72
August	6.6	0.089	3200	7.5	25.5	44.2	197	14.9	2.6	10.0	1.23	0.59	3.74
Sept.	8.7	0.101	3700	10.0	26.0	99.0	110	26.6	7.2	16.0	10.20	9.40	0.22

* Prior to filtration.

** Without inhibition of nitrification (BOD$_5$ test with 0.5 mg/dm^3 of thiourea).

Table 9

Organics, solids, nitrogen and phosphorus removals at Blue Plains Pilot Plant [14]

Usuwanie związków organicznych, zawiesin, azotu i fosforu w doświadczalnej oczyszczalni w Blue Plains [14]

Month, 1973	Removals, %				
	BOD	COD	SS	Total N	P
Jan.	79(2)	84	85	76	33
Feb.	86(2)	89	87	75	39
March	94	88	88	74	47
April	95	88	89	49	41
May	97	90	89	59	27
June	97	91	93	84	26
July(1)	93	83	94	67	81
August(1)	94	85	95	67	85
Sept.	93	86	85	54(3)	45

(1) With $FeCl_3$ in the primary process, the removals of solids and phosphorus are based on the raw wastewater.

(2) Without inhibition of nitrification (BOD_5 test with 0.5 mg/dm^3 of thiourea).

(3) Methanol addition inhibited nitrification.

3.9. EXTENDED AERATION ACTIVATED SLUDGE SYSTEMS WITH ALTERNATING AERATION

Results obtained in the Blue Plains pilot plant have intensified the studies on nitrogen removal in full-scale extended aeration plants. An extended aeration municipal plant in Owego N.Y. was tested for nitrogen removal by SCHWINN

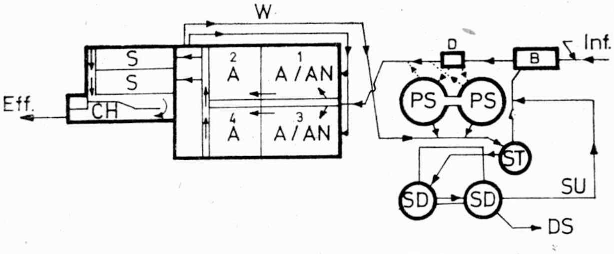

Fig. 15. Single-stage nitrogen removal extended aeration process [37]

A — aerobic, AN — anaerobic, B — influent chamber, CH — chlorination, D — distribution box, DS — digested sludge, PS — primary sedimentation, S — sedimentation, SD — sludge digester, ST — sludge thickener, SU — digested supernatant

Rys. 15. Jednostopniowy proces osadu czynnego z przedłużonym napowietrzaniem do usuwania azotu [37]

A — tlenowy, AN — beztlenowy, B — komora wpływu, CH — chlorowanie, D — skrzynia rozdziału, DS — przetrawiony osad, PS — początkowa sedymentacja, S — sedymentacja, SD — aparat ekstrakcyjny, ST — zagęszczony supernatant

Table 10

Operation parameters, organics and solids removals at Owego, New York [37]

Warunki pracy, usuwanie związków organicznych i zawiesin w oczyszczalni ścieków w Owego, Nowy Jork [37]

	Phase IA – 1975			Phase IB – 1975			Phase IIA – 1976		Phase IIB – 1976	
	May 5–31	June 1–30	July 1–16	July 17–31	Aug. 1–31	Sept. 1–8	March 10–31	April 1–30	May 1–9	May 10–28
Operational data										
Wastewater flow, m^3/d	1830	1730	1430	1480	1650	1750	2380	1990	2010	1980
MLSS, mg/dm^3	3340	3260	2660	3250	3810	3990	3860	3020	3200	3020
SRT, d	69	41	44	19	18	13	32	20	12	10
Aeration tank HRT, h	25.7	27.3	32.8	15.9	14.3	13.4	19.8	23.6	11.7	11.9
Sludge loading, g BOD_5/g MLSS · d	0.057	0.049	0.045	0.097	0.085	0.073	0.055	0.065	0.100	0.120
Clarifier overflow rate, $m^3/m^3 \cdot d$	7.5	7.0	5.9	6.0	6.7	7.1	9.7	8.1	8.2	8.1
Clarifire HRT, d	7.8	8.3	10.5	9.7	8.7	8.2	6.0	7.2	7.2	7.2
Wastewater temperature, °C	14	16	18	19	20	19	9	10	12	12
Performance data										
BOD_5										
Influent, mg/dm^3	204	183	163	208	194	162	176	194	157	186
Effluent, mg/dm^3	18	5	5	6	8	11	11	7	9	26
Removal, %	91.2	97.3	96.9	97.1	95.9	93.2	93.8	96.4	94.3	86.0
COD										
Influent, mg/dm^3	522	474	293	423	467	391	346	388	351	374
Effluent, mg/dm^3	63	57	55	35	58	78	35	48	36	63
Removal, %	87.9	88.0	81.2	91.7	87.6	80.1	89.9	87.6	89.7	83.2
SS										
Influent, mg/dm^3	228	187	155	234	241	198	149	196	156	209
Effluent, mg/dm^3	13	4	4	5	6	7	17	6	6	15
Removal, %	94.3	97.9	97.9	97.9	97.5	96.5	88.6	96.3	96.2	92.8

Table 11

Nitrogen removal at Owego, New York [39]

Usuwanie azotu w oczyszczalni ścieków w Owego, Nowy Jork [39]

Parameter	Phase I A – 1975			Phase I B – 1975			Phase II A – 1976		Phase II B – 1976	
	May 5–31	June 1–30	July 1–16	July 17–31	Aug. 1–31	Sept. 1–8	March	April	May 1–9	May 10–28
Ammonia nitrogen										
Influent, mg/dm^3	27.9	30.4	34.4	31.7	33.2	26.1	16.9	0.6	22.0	1.0
Effluent, mg/dm^3	2.2	1.3	1.7	2.1	1.9	1.5	21.1	9.3	19.7	7.1
Removal, %	92	96	95	93	94	94	—	50	10	—
Organic nitrogen										
Influent, mg/dm^3	12.5	12.0	12.4	13.2	13.0	11.6	16.6	16.1	14.4	15.5
Effluent, mg/dm^3	2.5	2.2	2.7	2.3	2.4	3.2	1.7	1.4	1.5	1.4
Removal, %	80	82	78	83	82	72	90	91	90	91
$NO_2^- + NO_3^-$										
Influent, mg/dm^3	0.3	0.3	0,3	0.6	0.4	0.3	1.4	0.8	0.4	1.1
Effluent, mg/dm^3	4.9	4.8	11.3	1.9	2.7	4.0	5.3	6.9	7.6	5.1
Total nitrogen										
Influent, mg/dm^3	40.7	42.7	47.1	45.5	46.6	38.0	34.9	38.0	36.8	36.3
Effluent, mg/dm^3	9.6	8.3	15.7	6.3	7.0	8.7	7.6	8.6	10.1	13.6
Removal, %	76.4	80.6	66.7	86.2	85.0	77.1	78.6	77.4	71.2	57.8

and STORRIER [37]. This plant had some desirable features, namely:

a) a long aeration time of the extended aeration promoting nitrification,
b) the temperature at this location ranging from 8 °C to 22 °C,
c) no, but a minor modifications.

The chief modification was that in order to maintain a relatively high BOD/TKN ratio, raw sewage was passed directly to the aeration tanks.

This plant was designed in 1980 for a flow of 7600 m^3/d, but currently it amounts to 1900 m^3/d approximately. A schematic flow diagram of the modified plant is shown in fig. 19. Automatic timers on the mechanical aerators in compartments *1* and *2* (fig. 15) were operated in a 30 min on-off cycle to provide the alternating aerobic–anaerobic conditions. Operation data, removals of organic and solid materials as well as nitrogen removals are presented in tabs.

10 and 11, respectively. The results have indicated that by operating at sufficiently low loading (high SRT's) high efficiency of nitrogen removal can be achieved, however, with careful control of solids inventory.

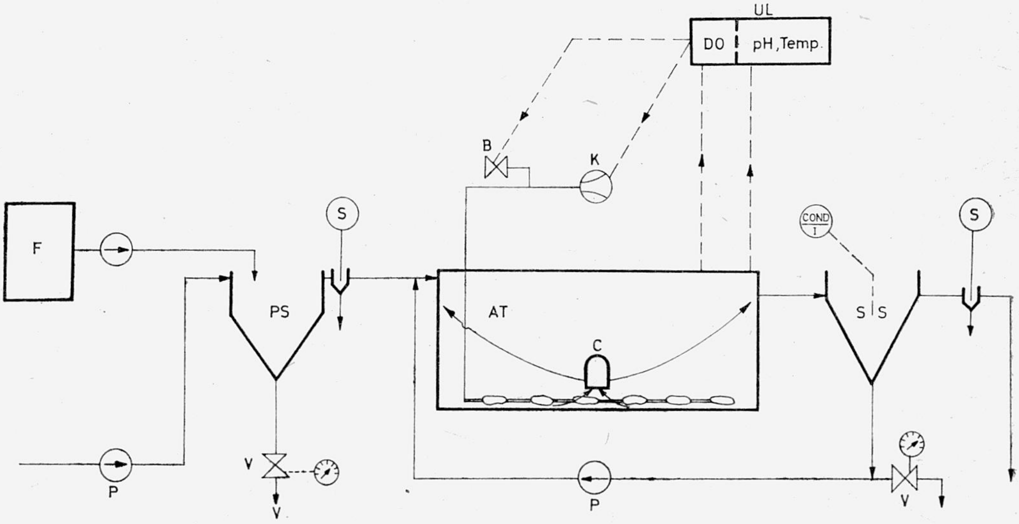

Fig. 16. Schematic representation of experimental plant at the Suomenoja Research Station [23]

F – ferrous sulfate feed tank, P – process pump, PS – primary sedimentation, S – sampler, V – time controlled sludge valve, AT – reactor, C – mixing pump, B – by-pass valve, K – compressor, UL – microprocessor, SS – secondary sedimentator
DO, temperature, pH, conductivity – continuous measurements
– – – – signals

Rys. 16. Schemat oczyszczalni eksperymentalnej w Stacji Badawczej Suomenoja [23]

F – zbiornik zasilający z siarczanem żelaza, P – pompa procesowa, PS – początkowa sedymentacja, S – próbnik, V – zawór, AT – reaktor, C – pompa mieszająca, B – zawór bocznikowy, K – kompresor, UL – mikroprocesor, SS – wtórny sedymentator
rozpuszczony tlen, temperatura, pH, przewodnictwo – pomiary ciągłe
– – – – sygnały

The effect of intermittent aeration on the extended aeration process with respect to nitrogen removal was previously reported in Finland by VIITASAARI [46]. The tested extended aeration plant, in which simultaneaus precipitation with ferrous sulphate was used, was located at Monninkylä, Askola. The total nitrogen removal ranged from 60 % (February 1974) to 76 % (September 1974). These results were obtained in only one 30 min/30 min cycle without any special arrangements.

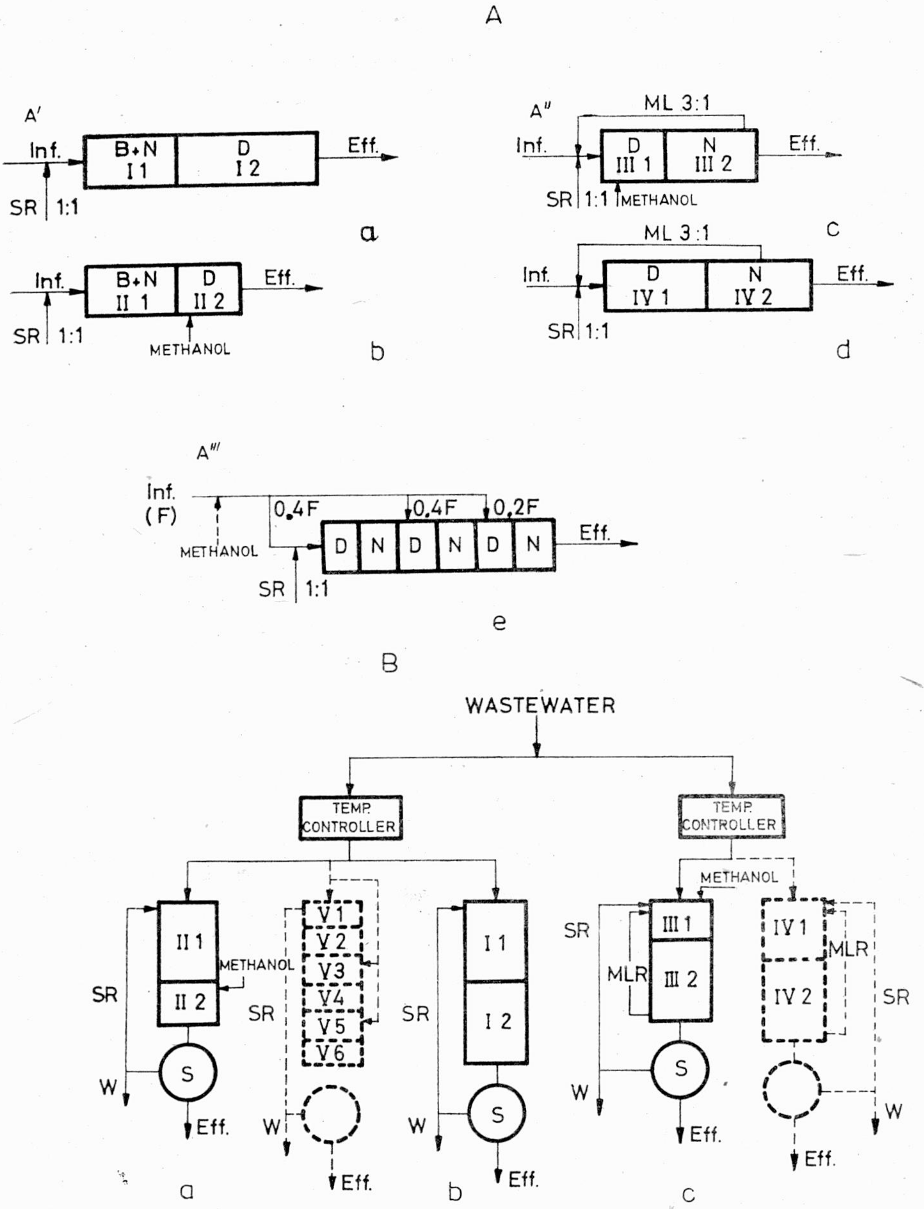

Fig. 17. Single-stage activated sludge nitrogen removal at the Burlington Skyway Treatment Plant [41]

A – single sludge systems

A' – carbon oxidation–nitrification, post-denitrification; A'' – pre-denitrification–nitrification; A''' – step-feed nitrification–denitrification; a, b, c, d, e – 1st, 2nd, 3rd, 4th, 5th systems, respectively; B – carbon oxidation; N – nitrification; D – denitrification; F – feed; SR – sludge recycle; MLR – mixed liquor recycle; W – waste sludge

B – single sludge pilot plants

a – 1st pilot plant, II or V system; b – 1st pilot plant, I system; c – 3rd pilot plant, III or IV system

3.10. SINGLE SLUDGE NITRIFICATION–DENITRIFICATION

A novel technological system based on the single sludge principle was tested for the removal of organics, nitrogen and phosphorus [23]. The system consists in the single sludge nitrification–denitrification process at intermittent aeration and is combined with simultaneous precipitation of phosphorus due to the addition of ferrous sulphate. The process proceeds at low organic loads in a continuous-flow stirred tank reactor with an automatic control of dissolved oxygen (DO) and a clarifier. Preliminary operating runs were performed in a pilot plant at the Suomenoja Research Station, Espoo, Finland. A schematic representation of the plant is shown in fig. 16. In this plant, DO is controlled by a microprocessor with a PID-regulator and a time switch for timing the intermittent aeration cycle. The preliminary results indicate that the process should be additionally tested in a full-scale plant.

4. EXAMINATION OF SINGLE SLUDGE PROCESS CONFIGURATIONS

Various configurations of the single sludge process (fig. 17A) were studied in the Wastewater Technology Centre, Canada Centre for Inland Waters at Burlington using three parallel pilot plants, presented in fig. 17B [41]. In the first phase the systems I, II and III or IV were examined, and in the second phase the tests involved the systems I, V or III, or IV. The effects of various factors affecting nitrification–denitrification in single sludge systems were studied.

The maximum volume of biological reactors was 2.18 m^3, the volumes of clarifiers ranged between 0.36 m^3 to 0.52 m^3. As the influent to the reactors degritted municipal wastewater, the following parameters were used: BOD_5 = 106 mg/dm^3, COD = 325 mg/dm^3, NH_4–N = 17.3 mg/dm^3, and TKN (filtreable) = 20.6 mg/dm^3.

The results have indicated that the nitrification degree depends on the aerobic solids retention time (SRT). The efficiency of NH_3–N removal increased

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Rys. 17. Jednostopniowe systemy osadu czynnego do usuwania azotu w oczyszczalni ścieków w Burlington [41]

A — Systemy jednostopniowe

A′ — utlenianie–nitryfikacja węgla, ponitryfikacja; A″ — wstępna denitryfikacja–nitryfikacja; A‴ — stopniowo zasilana nitryfikacja–denitryfikacja; a, b, c, d, e, — system 1, 2, 3, 4, 5; B — utlenianie węgla; N — nitryfikacja; D — denitryfikacja; F — zasilanie; SR — obieg osadu ściekowego; MLR — powtórny cykl zmieszanego roztworu; W — osad odpadowy

B — oczyszczanie doświadczalne z jednostopniowym systemem

a — oczyszczalnia 1, II lub V system; b — oczyszczalnia 1, I system; c — oczyszczalnia 3, III lub IV system when the operating aerobic SRT exceeded the minimum required for nitrification. The denitrification rates depend on carbon or non-carbon limiting operation conditions. The endogenous denitrification rates increased with the increasing SRT of the system. It has been concluded that maintaining the anaerobic conditions for time up to 4 h has no effect on nitrifying organisms. It has been also found that the effluent quality achieved in these systems ranges from 2 to 3 mg/dm^3 of total nitrogen, depending on the single sludge process configuration.

5. CONCLUSIONS

The single slugde nitrification–denitrification systems appear to be an efficient method of solution for nitrogen removal. In numerous countries these systems have operated successfully without the use of external carbon sources (petrochemicals). When propertly operated, the single sludge systems are simple, efficient and economical. The concentration of total nitrogen in the effluent has not exceeded 3 mg/dm^3. Optimization of these systems requires, however, additional full-scale research.

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USUWANIE AZOTU ZE ŚCIEKÓW ZA POMOCĄ JEDNOSTOPNIOWYCH PROCESÓW OSADU CZYNNEGO

Przedstawiono technologię usuwania azotu ze ścieków za pomocą jednostopniowych procesów osadu czynnego. Systemy te rozwinięte i stosowane w różnych krajach opisano, aby przedstawić różnorodność dostępnych alternatyw. Nacisk położono na ich wykorzystanie w różnych warunkach pracy.

DIE STICKSTOFFBESEITIGUNG AUS ABWÄSSERN IN EINSTUFIGEN BELEBTSCHLAMMSYSTEMEN

Gegeben wird eine Übersicht der Möglichkeiten der Stickstoffbeseitigung anhand von einstufigen Belebtschlammsystemen. Beschrieben werden die bisher erarbeiteten Systeme und ihre Anwendung in verschiedenen Ländern. Sie dienen zur Illustration der unterschiedlichen Lösungen dieses Problems. Im Aufsatz wird die Wirkung dieser Systeme unter verschiedenen Betriebsbedingungen erörtert.

УДАЛЕНИЕ АЗОТА ИЗ СТОЧНЫХ ВОД С ПОМОЩЬЮ ОДНОБАКОВЫХ СИСТЕМ МЕТОДА АКТИВНОГО ИЛА

Проведен обзор технологии удаления азота из сточных вод с помощью однобаковых систем метода активного ила. Представлены обработанные системы и их применение в разных странах для иллюстрации различных существующих решений. В работе уделено внимание действию этих систем в различных эксплуатационных условиях.