

Study on Efficiency Increasing of Biological Stage by Sequential Operating of Aeration Reactors

DANIELA ANGELA BUZOIANU¹, CASEN PANAITESCU^{1*}, MIHAELA BOMBOS², MONICA EMANUELA STOICA¹

¹ Petroleum-Gas University of Ploiesti, 39 Bucuresti Blvd., 100680, Ploiesti, Romania

²National Research Institute for Chemistry and Petrochemistry, ICECHIM, 202 Spl. Independentei, 06002, Bucharest, Romania

Classical method of biological treatment creates problems due to necessity of phosphorus and nitrogen removal from wastewater, as well as with reduction of chemical oxygen demand. Biological treatment by sequential treatment in a plant with four reactors leads to great flexibility in operation and increase the degree of purification compared to classical operation in a plant with two reactors. The performances of the process depends on the way of stages succession in the four reactors. Increasing the volume hourly space velocities of wastewater from $0,11 \text{ h}^{-1}$ to $0,42 \text{ h}^{-1}$ not diminish the performance of the biological treatment by sequential treatment. Correct distribution of the maximum load in the aeration reactors will lead to maximum degrees of purification highlighted by 90% for COD, 96% for BOD, 90% for nitrates and 95% for suspended solids.

Keywords: sequential operation, aeration reactors, biological stage, wastewater

Biological treatment represents an efficient treatment in case of a relative constant load with industrial wastewater pollutants [1]. Classical method of biological treatment creates problems due to necessity of phosphorus and nitrogen removal from wastewater, as well as with reduction of chemical oxygen demand (COD). The nonuniform aeration process, specific for the conventional process can create in the aeration reactor both aerobic and anaerobic zones [2,3]. This drawback combined with sudden variations of flow and composition may lead to uncontrolled lower degrees of treatment. The elimination of these deficiencies of classical bioscrubbers can be achieved by operating sequential aeration tanks [3]. Application of aerobe-anaerobe treatment by introducing sequential batch reactors (SBR) leads to high efficiency in removing of nitrates and phosphorus from wastewater. Initially applied for purifying small flow of wastewater [4] and then extended to industrial

wastewater, process keeps the same working technology with five basic steps [2]. In addition the value of the parameters that intervene in the process of biological treatment were calculated with equations specific for SBR process [4-6]. Each stage is important, duration of the main stages, namely filling -being approximately 25% of total cyclic time and aeration - being about 25% of total cyclic time.

A comparison of standard system and sequential system is presented in table 1 [5, 6].

The advantages of this system created the premises for its extension to all types of industrial wastewater [7]. The most important advantages of this process are: reducing the volume of sewage reactors which allows dividing them into several units; high process flexibility; low operating costs; low maintenance; superior quality of treated wastewater compared to treatment classic [8]. Another important application of this process has been presented

Parameter	Sequential-operated aeration reactor	Conventional water treatment plant
Biologic system volume	Volume similar to other biologic reactors	Requires final sedimentation reactor
Input flow	Continuous or alternating flow	Continuous flow
Substrate concentration in the biological system	At first, high concentration, at the end of the cycle, lower concentration	Constant concentration
Adjustments for various influent flow conditions	Flexible due to the possibility of adjusting the cycles	Not flexible
The influence of hydraulic loading on the sludge/water ratio	Reduced	Very high
Sludge circulation system	Not necessary	Necessary

Table 1
COMPARISON BETWEEN CONVENTIONAL AND SEQUENTIAL WATER TREATMENT PLANTS

* email: c.panaitescu@gmail.com

Parameter physico-chemical	The analysis method
BOD, mg/L [12]	SR EN 1899 3/2003
COD, mg/L [13]	SR EN 6060:1996
P, mg/L [14]	STAS 6878/2005
Nitrates, mg/L [15]	SR ISO 7890-3:2000
Suspended solids, g/L [16]	SR EN 872:2005

Table 2
CHARACTERISTIC PARAMETERS AND THEIR ANALYSIS METHODS

Parameter physico-chemical	Value
BOD, mg/L	314
COD, mg/L	421
P, mg/L	5.19
Nitrates, mg/L	35.2
Temperature, °C	12
Suspended solids, g/L	270

Table 3
PHYSICO-CHEMICAL PARAMETERS VALUES OF WASTEWATER

by Ke X. and all [9] which demonstrated the application of SBR in removing metals in wastewater. Using the adequate microorganisms and operating at pH below 6.5 [3,10, 11] favors the removal of nickel and lead from wastewater if their maximum concentration not exceed 5 mg /L. Along with these metals can be removed the suspended matter, the maximum acceptable concentration for this being 4500 mg /L.

In wastewater treatment plants from Romania are used conventional biological treatment for industrial processes. Small degrees of treatment, necessity of sewage treatment by minimizing environmental impact, minimum investment costs led to the necessity of finding adequate treatment solutions. The present work describes a study for upgrading of a wastewater treatment plant ascribed to a industrial platform. Variation of flow in broad limits, wastewater charging with pollutants over the limits imposed at the entrance of biological treatment plant, require replacing of conventional biological treatment with sequential process operation.

Experimental part

Chemicals and reagents

The reagents used in this methods was Sigma Aldrich products: sulfuric acid-, silver sulfate, iron(II) sulfate-heptahydrate, ammonium sulfate, potassium dihydrogen phosphate, potassium nitrate, dihydrogenofosfat de potasiu, sodium chloride, calcium chloride, ammonium chloride, glacial acetic acid, calcium chloride and iron (III) chloride.

Study of the biologic treatment was carried out on a industrial wastewater. Analysis of the wastewater at the entrance in biological step was done according to the current standards (table 2), the physico-chemical parameters analyzed and specific methods of analysis are presented in table 3.

Working equipment

Processing by conventional process was been achieved in two aeration vessels and two batch decanters. Sequential operating process for water treatment was performed in four reactors with continuous operation. The four reactors were noted B1, B2, B3, B4. The relative maximum filling height of wastewater on each reactor in sequential operation was 85% compared to the height of wastewater in conventional process. The maximum working time per cycle of treatment was 400 min. The purification process of wastewater takes place throughout the transiting of the four reactors. The volume hourly space velocity of wastewater reported to the total volume of reactors had values between 0.11 h⁻¹ and a maximum of

0.42 h⁻¹. The air bubbling was carried out using a membrane made in the laboratory. Calculation of sparging system was performed according to the methodology [17]. The air was introduced into the reactor with two blowers associated of reactors B1 and B2 and respectively of reactors B3 and B4. The operating cycle comprised five successive phases which have alternated in order to optimize purge treatment parameters.

Modeling the sequential process

Biological treatment process with sequential processing took place at 10 - 12°C. In sequential treatment the denitrification capacity at temperatures between 10°C and 12°C must to be approximately 0.09 kg NO₃⁻ - ND / kg BOD [9]. The concentration of activated sludge from reactors should be about 4.5 kg /m³ and the sludge volume index (ISV) should be approximately 110 mg /L. Relative height layer of sludge in reactors must be maximum 25% to the height of reactors.

The minimum age for nitrification expressed in days, was calculated with equation 1:

$$MAN = C * 4.1 * 1.54^{(14-T)} \quad (1)$$

where:

MAN - the minimum age of sludge for nitrification, days;
C - safety factor (1.15);

T - the water temperature in the aeration reactor, °C.

The relationship was determined by the authors, being determined after correlation derived from measurements made in experiments conducted in aeration reactors and is applicable for temperature lower or equal to 12°C.

Specific sludge production (SE), respectively the amount of excess sludge, kg dry matter /kg BOD, was calculated using the equation 2:

$$SE = \left(0.8 + \frac{0.7SS}{BOD} - \frac{0.1 * MAN * K_T}{1 + 0.1 * MAN * K_T} \right) \quad (2)$$

where:

SS - amount of suspended solids, kg/day;

K_T - temperature coefficient (1.04) ;

BOD - biochemical oxygen demand, kg/day;

Denitrification capacity (CD) of the biological treatment process, expressed in kg nitrogen/kg BOD, was calculated using the equation 3:

$$CD = B/BOD \quad (3)$$

where:

B - represents the concentration of nitrogen in the biological stage effluent, kg/day;

BOD - biochemical oxygen demand, respectively concentration of organic matter input in treatment stage, expressed in kg/day.

Variant operating	Reactor	Working time, min			
		100	200	300	400
S1	B1	Fill	Nitrification Settle	Discharge	Idle
	B2	Nitrification	Settle Discharge idle	Fill	Nitrification
	B3	Nitrification settle	Fill	Nitrification	Settle Discharge
	B4	Discharge Idle	Fill Nitrification	Settle	Discharge Idle
S2	B1	Fill	Nitrification Settle	Idle	Discharge
	B2	Nitrification Settle	Discharge Idle	Fill	Nitrification
	B3	Settle Discharge	Fill	Nitrification	Idle
	B4	Discharge	Nitrification	Settle Idle	Discharge
S3	B1	Fill	Settle	Nitrification	Idle
	B2	Nitrification	Idle	Settle	Discharge
	B3	Settle	Fill	Nitrification	Discharge
	B4	Idle	Fill	Nitrification Settle	Discharge Idle

Table 4
VARIANTS FOR SEQUENTIAL
OPERATING OF TREATMENT
REACTORS
AT VOLUME HOURLY SPACE
VELOCITIES 0.11 h⁻¹

Wastewater treatment effectiveness, respectively efficiency of the biological stage in sequential or conventional process (*GE*) was calculated with relation 4:

$$GE = \frac{A - B}{A} * 100 \quad (4)$$

where:

A - influent concentration, mg/L;
B - effluent concentration, mg/L.

Results and discussions

Wastewater characteristics used to perform experimental study are presented in table 3.

From experiments proposed were analyzed three variants of sequential operation both for the minimum and for the maximum volume hourly space velocity of wastewater. In table 4 and 5 are presents the variants of sequential operation in the four reactors B1, B2, B3 and respectively B4, with corresponding stage of the water treatment.

The performances in all versions of sequential operating are presented in table 6.

Variant S1 is the variant with the best results from the point of view of operating parameters for sequential operating at volume hourly space velocities of wastewater 0.11 h⁻¹. For this variant of operating the filling of B1 reactor takes place in parallel with the nitrification in B2 reactor, the nitrification and sedimentation in B3 reactor and the appeasement - discharging in the B4 reactor. The productivity in sludge for this version of sequential operating is 3.904 kg/m³, the minimum amount of solids suspended (SS) after removal of sludge is 5.3 mg/L, the minimum time of sludge exhaust 0.82 h and the maximum time of sludge exhaust 1 h.

For sequential operating at 0.42 h⁻¹ volume hourly space velocities of wastewater, the operating variant with the best results is S5 variant where in the first step in the B1 reactor occurs simultaneously the filling - nitrification process, in B2 reactor occurs the appeasement -

Variant operating	Reactor	Working time, min.			
		100	200	300	400
S4	B1	Fill	Nitrification	Discharge Settle	Idle
	B2	Nitrification	Settle Idle	Discharge	Nitrification
	B3	Settle	Fill Nitrification	Settle	Discharge
	B4	Idle	Discharge	Nitrification	Discharge Settle
S5	B1	Fill Nitrification	Settle	Discharge	Idle
	B2	Nitrification Idle	Settle Nitrification	Discharge	Settle
	B3	Nitrification	Settle	Nitrification	Idle
	B4	Discharge	Nitrification Discharge	Idle	Nitrification
S6	B1	Fill Settle	Nitrification	Settle Idle	Settle Idle
	B2	Nitrification	Settle Idle	Discharge	
	B3	Settle	Nitrification	Discharge	idle
	B4	Discharge	Nitrification Discharge	Settle	Settle

Table 5
VARIANTS FOR SEQUENTIAL
OPERATING OF TREATMENT
REACTORS
AT VOLUME HOURLY SPACE
VELOCITIES 0.42 h⁻¹

Parameters	Operating Variants					
	S1	S2	S3	S4	S5	S6
Productivity in sludge (SE), kg/m ³	3.904	4.200	5.490	1.382	5.128	5.411
Velocity mass of sludge evacuation kg/ m ³	0.163	420	0.171	0.209	0.196	0.231
concentration in reactor after sludge evacuation (SS), kg/m ³	5.3	6.8	7.4	7.8	5.9	8.6
Minimum time for evacuation, h	0.82	0.99	0.91	0.99	0.86	0.91
Minimum age for nitrification (MAN), h	1.00	1.1	1.3	1.5	1.1	1.3

Table 6
THE PERFORMANCES IN ALL VERSIONS OF SEQUENTIAL BIOLOGICAL TREATMENT

Nitrogen balance	U.M.	S1	S5	Conventional treatment	
				VHSV 0.11 h ⁻¹	VHSV 0.42 h ⁻¹
Total nitrogen in <u>influent</u>	mg/L	55.88	72.83	55.88	72.83
Nitrogen absorbed in the process	mg/L	12.56	25.12	8.4	7.1
Ammonia nitrogen in effluent	mg/L	3	3	3.4	3.8
Organic nitrogen in effluent	mg/L	3.9	3.05	3.7	4.1
Nitrogen converted (in nitrification)	mg/L	36.42	41.66	40.38	44.1
NO ₃ ⁻ in effluent	mg/L	8.4	8.9	9.1	10.3
Nitrogen removed by denitrification, (NO ₃ ⁻ - N _D)	mg/L	28.02	32.76	31.28	33.8
Denitrification capacity (CD)	kg NO ₃ ⁻ - N _D / kg BOD ₅	0.089	0.093	0.051	0.044

Table 7
COMPARATIVE NITROGEN BALANCE BETWEEN THE BIOLOGICAL TREATMENT PROCESS WITH SEQUENTIAL AND CONVENTIONAL OPERATION

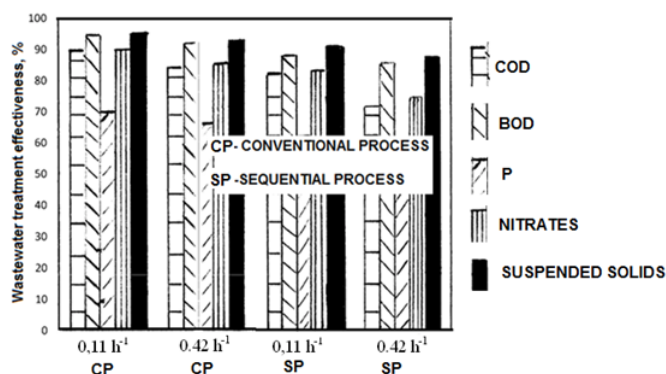


Fig.1. Efficiency of the biological stage for sequential and conventional process

discharging, in B3 reactor occurs the nitrification, in reactors B3 and B4 occurs the discharging. The minimum sludge productivity was 5.128 kg sludge / m³ treated water, the minimum amount of suspended solids after sludge disposal was 5.9 mg/L sludge, the minimum time of sludge disposal was 0.86 h and the maximum disposal time was 1.1 h.

In the two optimal versions of operating, the anaerobic conditions favor the fermentation products of microorganisms which used the sludge substrate to produce biodegradable products.

The installation is designed for complete nitrification, denitrification of nitrates not being required. Nevertheless, during the interruption of aeration process, occurs the denitrification. In contrast to the classic biological treatment, for sequential operating the denitrification is not monitored, but it is necessary in nitrogen balance due to the transformation process of nitrates from wastewater.

Nitrogen balance for optimal variants chosen (S1 and S5) compared with conventional variant is presented in table 7.

It is noticed that the denitrification capacity of variant S1 (0.089 kg NO₃⁻ N_D/kg BOD) and of variant S5 (0.093 kg

NO₃⁻ /kg BOD) are very close to optimal value of 0.090. This demonstrates a higher efficiency of sequential operating unlike conventional treatment where denitrification capacity is only 0.051 kg NO₃⁻ /kg BOD for S1 and 0.044 kg NO₃⁻ /kg BOD for S5.

In figure 1 is represented the effectiveness of purification (GE) in sequential versus conventional treatment for the two volume hourly space velocities. It is noticed that in both cases the degrees of purification treatment increase even if volume hourly space velocities increase. Thus for volume hourly space velocities of 0.11 h⁻¹ were obtained higher degree of purification compared to classical operation at the same time:

-COD of from 85% at classical operation to 90% at sequential operation;

-BOD of from 88% at classical operation to 96% at sequential operation;

-P from 66% at classical operation to 71% at sequential operation;

-nitrates from 86% at classical operation to 90% at sequential operation;

-suspended solids from 93% at classical operation to 95% at sequential operation.

For volume hourly space velocities of 0.42 h⁻¹ were obtained also increased degree of purification compared to classical operation:

-COD of from 74% at classical operation to 82% at sequential operation;

-BOD of from 87% at classical operation to 89% at sequential operation;

-P from 58% at classical operation to 67% at sequential operation;

-nitrates from 77% at classical operation to 85% at sequential operation;

-suspended solids from 88% at classical operation to 92% at sequential operation.

Conclusions

Biological treatment by sequential treatment in a plant with four reactors leads to great flexibility in operation and increase the degree of purification compared to classical operation in a plant with two reactors. The performances of the process depends on the way of stages succession in the four reactors.

Increasing the volume hourly space velocities of wastewater from 0.11 h^{-1} to 0.42 h^{-1} not diminish the performance of the biological treatment by sequential treatment. Correct distribution of the maximum load in the aeration reactors will lead to maximum degrees of purification highlighted by 90% for COD, 96% for BOD, 90% for nitrates and 95% for suspended solids.

References

1. PANAITESCU, C., STOICA, M.E., *Rev. Chim. (Bucharest)*, **66**, no. 5, 2015, p. 728;
2. ANDREOTTOLA, G., FOLADURI, P., RAGAZZI, M., *Water Sci. Technol.*, **43**, no. 3, 2001, p.93;
3. HOPKINS, L.N., LANT, PA., NEWELL, R.B., *Water Sci. Technol.*, **43**, no. 3, 2001, p.35;
4. NORCROSS, K.L., *Water Sci. Technol.*, **26**, 1992, p. 9;
5. LEE, L.Y., HU, J.Y., ONG, S.L., NG, W.I., REN, I.H., WONG, S.H., *Water Sci. Technol.*, **50**, no. 10, 2004, p. 243;
6. MERLO, R., PARKER, D., WAHLBERG, E., *Clarifying CFD Modeling's Benefits. Water and Environment Technology*, no.19, 2007, p.48;
7. HELMREICH, B., SCHREFF, D., WILDERER, P., *Water Sci. Technol.*, **41**, no. 1, 2000, p.896;
8. MIRBAGHERI, S.A., BAGHERI, M., EHTESHAMI, M., BAGHERI, ZA., POURASGHAR, M., *Journal of Urban and Environmental Engineering*, **9**, no. 1, 2015, p. 54;
9. ZHAO, C.H., PENG, Y.Z., WANG, S.Y., TANG XG., *Water Sci. Technol.*, **58**(4):803 no. 10, 2008. p.392;
10. Ke, X., Zhang, G., Wan, T., Gao, F., *J. Environ. Eng.*, 10.1061/(ASCE)EE.1943-7870.0000418, 2012, p.248;
11. PANAITESCU, C., BUCUROIU, R., *EEMJ*, **13**, no.7, 2014, p. 1567;
12. *** SR EN 1899 2/2003, *Water quality - Determination of biochemical oxygen demand after n days (BODn) - Part 1*, 2003, Romanian Standard;
13. *** SR EN 6060:1996, *Water quality. Determination of the chemical oxygen demand*, 1996 Romanian Standard;
14. *** SR EN 6878:2005 - *Water quality - Determination of phosphorus - Ammonium molybdate spectrometric method (ISO 6878:2004)*, 2005, Romanian Standard;
15. *** SR ISO 7890-3:2000, *Water quality. Determination of nitrate. Part 3: Spectrometric method using sulfosalicylic acid*, 2000, Romanian Standard;
16. *** SR EN 872:2005- *Water quality - Determination of suspended solids - Method by filtration through glass fibre filters*, 2005, Romanian Standard;
17. PANAITESCU, C., STOICA M.E., FEHIMAN C., *Applied Mechanics and Materials Journal*, **809**, p.1573.

Manuscript received: 7.03.2016