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OPERATION EXPERIENCE OF OXYTANKS

Operation experience of a new type of aeration tank, in which pure oxygen is used and further referred as an oxytank, is summarized in this paper. The method of design and principle of operation of the unit are presented. The construction of oxytank is based on complete-mixing reactor principle and is characterized by a high efficiency of oxygen utilization (93–96%) and by reduced size of the structure since such processes as settling, flotation and biochemical oxidation take place in a sludge separation tank. Full-scale plant studies have shown that the capacity of oxytank oxygenation with respect to basic components is 3.5 times higher than that of aeration tank at complete biological treatment of wastewaters. The use pure oxygen makes possible the concentration of activated sludge ranging within 6–10 g/dm^3 at the dissolved oxygen concentration of 10–12 mg/dm^3. In this way the settled properties of activated sludge improved. Technological and economical evaluation obtained for the treatment of wastewater from nitrogenous industry has shown that the oxygen utilization in oxytanks is advantageous from an economic point of view. Therewith capital investment for biological treatment works is 1.5 to 2 times reduced and operating expenditures decreased 1.4–1.6 times.

The VODGEO Institute has developed a construction and a system design method for an efficient biological treatment of wastewater by using pure oxygen and high concentrations of activated sludge. The system is termed "an oxytank".

The oxytank system allows us to achieve a high utilization efficiency of the supplied oxygen and a significant reduction in the total structural volume by combining biological oxidation with the mixed liquor separation taking place in the same unit. This system enables also to promote the automatically controlled system of oxygen supply, proportional to quantity and quality of the influent wastewater.

The oxytank (fig. 1) includes a cylindrical container in which a hermetically sealed reactor *2* is positioned. The reactor is equipped with a surface turbo-aerator *5* put in rotation by an electric motor located on the cover. The aerator shaft is hermetic due to the application of a rotary hydraulic valve. A sludge separation tank *3*, in which acti-

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vated sludge and treated water are separated, is installed in the annular space between the reactor and the external wall of the container. The middle part of the partition separating the reactor is equipped with ports with directed tangential nozzles *7* and gates for delivery of mixed liquor from the reactor to the sludge separation tank. The activated sludge is returned to the reactor via the annular aperture *8* in the lower part of the partition.

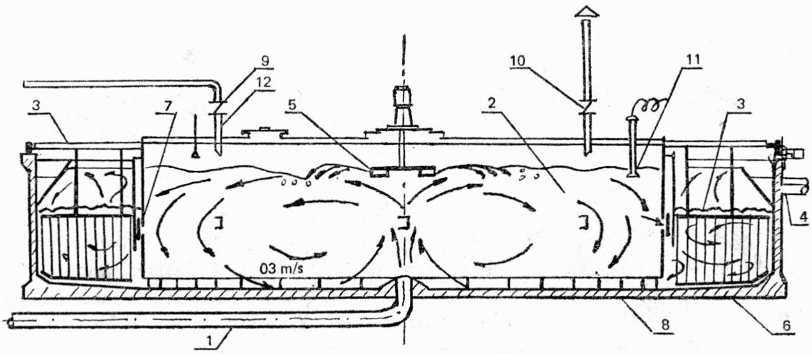

Fig. 1. Scheme of oxytank

Rys. 1. Schemat zbiornika natleniania

Thus, in order to intensify the sludge separation and prevent the unwanted sedimentation of sludge at the bottom of the sludge separation tank, the mixing device is mounted in the foım of grid with rods of 30–50 mm in diameter. The scrapers *6* are hinged in the lower part of grids. The wastewater passes to the reactor through the pipe *1* and is mixed with activated sludge of the aerator *5*; then the mixed liquor is saturated with gas present under the reactor cover. The oxygen is fed to the reactor through the pipe *9* equipped with an automatic valve actuated by a pressure sensor *12*. The treated wastewater and activated sludge are introduced simultaneously to the sludge separation tank via the nozzles under the action of speed head developed by the aerator. The clarified liquor is removed through the annular collecting gutter *4*. The settled activated sludge returns to the reactor through the annular aperture *8*.

The concentration of dissolved oxygen in the reaction chamber is kept constant automatically. As the oxygen is being consumed by the mixed liquor, the pressure of gaseous mixture decreases in the reactor over the liquid surface.

At that moment the pressure sensor *12* gives a signal for opening the valve located on the pipe *9* through which oxygen is fed. The oxygen starts to be introduced into the system. When the gaseous mixture pressure in the reactor achieves the set level, the valve is automatically closed.

Due to gradually accumulated carbon dioxide formed during the biochemical oxidation process and nitrogen released from the wastewater as well as to inert gases supplied simultaneously with pure oxygen, the composition of gaseous mixture in the reactor is changed. In this case the partial pressure of oxygen reduces, while that of carbon dioxide and of other components increases. The decrease of oxygen partical pressure results in the reduction of oxygen concentration in the mixed liquor, hence in order to stabilize gaseous mixture composition in the reactor, the accumulated gases must be removed periodically by blowing the oxygen through the system.

As the partial pressure of oxygen in gaseous mixture drops below the set level, the dissolved oxygen concentration sensor *11* gives a signal for opening the automatic valve *10*. The gaseous mixture from the operating chamber is released into atmosphere. The oxygen is fed to the reactor through the pipe *9* instead of being withdrawn from the gaseous mixture. As the set level of dissolved oxygen concentration in mixed liquor is achieved, the valve *11* is closed.

On the basis of pilot plant investigations in oxytank, the method has been developed for estimating the above type of treatment plants capable to operate in a regime of reactor with a complete mixing.

The wastewater retention time in oxytank reactor may be determined by the following equation

$$t = \frac{L_0 - L_1}{K_{O_2} K_s C_s} \alpha \qquad (1)$$

where:

t — average retention time for wastewater in oxytank reactor, h,
L_0 — influent wastewater BOD fed to oxytank, mg/dm^3,
L_1 — effluent wastewater BOD, mg/dm^3,
α — specific oxygenation rate at $C_u = 3$ g/dm^3 and at oxygen concentration of 2 mg/dm^3,
K_{O_2} — coefficient determining the effect of dissolved oxygen concentration on specific oxygenation rate,

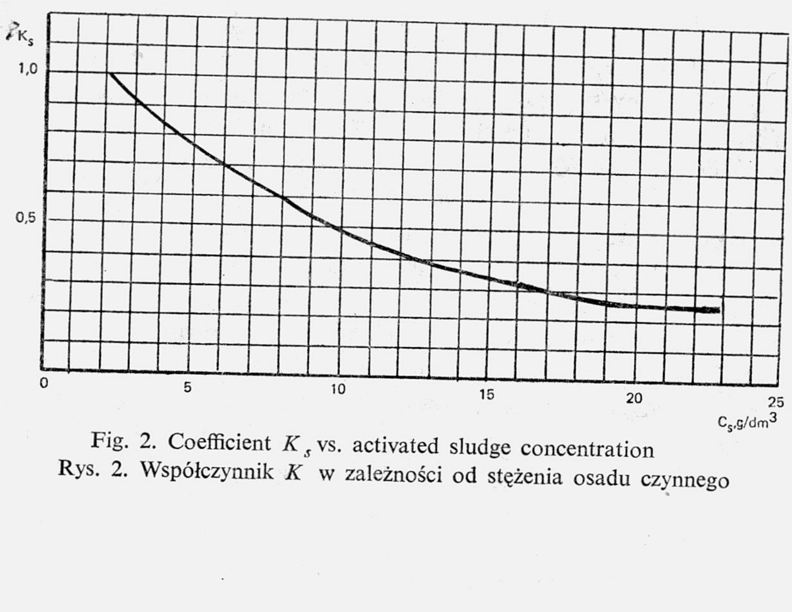

Fig. 2. Coefficient K_s vs. activated sludge concentration
Rys. 2. Współczynnik K w zależności od stężenia osadu czynnego

K_s — coefficient determining the effect of activated sludge concentration on specific oxygenation rate,

C_s — activated sludge concentration, g/dm^3.

The values of both K_{O_2} and K_s coefficients were experimentally defined and the corresponding curves are given in figs. 2 and 3.

Fig. 3. Coefficient K_{O_2} vs. dissolved oxygen concentration

Rys. 3. Współczynnik K_{O_2} w zależności od stężenia rozpuszczonego tlenu

The design of sludge separation tank is based on determining the ultimate hydraulic load. In the course of investigations performed at the VODGEO Institute, the effect of the assumed hydraulic load on the sludge separation tank was presented as a function of dimensionless criterion of IC where I — sludge index value (cm^3/g) and C — activated sludge concentration in solution (g/cm^3).

The curve in fig. 4 represents this relationship. To improve the quality of treated water, the sludge separation tank operates as a settling tank. Oxytanks are constructed in such a way that the depth of suspended solid beds can be stabilized and its exchange is ensured.

One of the features of oxytank is a high oxygen concentration in the mixed liquor supplied to the sludge separation tank from the reactor. Due to signicant reserve of dissolved oxygen in recycling zone of sludge separation tank and to favourable hydrodynamic operating conditions, biochemical processes can occur in this zone. The total volume of oxytank may be divided into several zones depending on their functions (fig. 5).

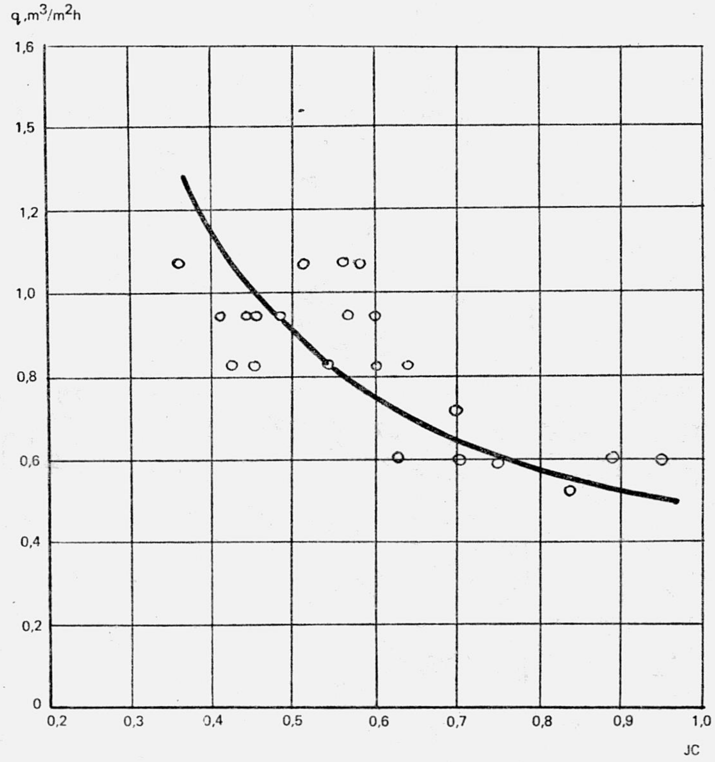

Fig. 4. Hydraulic load acting on sludge separation tank vs. dimensionless parameter K

Rys. 4. Ładunek hydrauliczny działający na zbiornik separacji osadu w zależności od bezwymiarowego parametru K

The scheme given in this figure shows that the largest part of sludge separation tank volume in oxytank performs two functions, i.e. thickening of mixed liquor and biochemical oxydation, therefore the total volume is reduced considerably.

The experimental oxytanks constructed at wastewater treatment plants of Industrial Complex "Azot" were put into operation in 1974. According to the VNII VODGEO recommended actions, the design of oxytanks should be based on the data obtained from operation of a pilot plant of a capacity o 150–200 m^3/day.

The oxytanks each of the volume of 270 m^3 and 9.6 m in diameter were built at Schekinsk Industrial Complex "Azot". The values of estimated parameters for oxytanks are presented below:

1. Oxygenation capacity (OC), $BOD_{compl.}$ — 2.04 kg/m^3/day, oxygenation capacity OC), COD — 2.73 kg/m^3/day.
2. Wastewater flow rate — 59 m^3/h (at influent wastewater BOD of 300 mg/dm^3).
3. Effluent $BOD_{compl.}$ — 15 mg/dm^3.
4. Suspended solids in effluent — 15–20 mg/dm^3.

The average data of the operation of both oxytank and aeration tank during a long period of service are summarized in tab. 1.

As shown in the table, the oxytank generation capacity was close to the estimated one and exceeded 3.5 times the oxygenation capacity of full-scale aeration tanks operating in parallel. In this cases the removal efficiency of main components from wastewater was in accordance with the complete biological treatment.

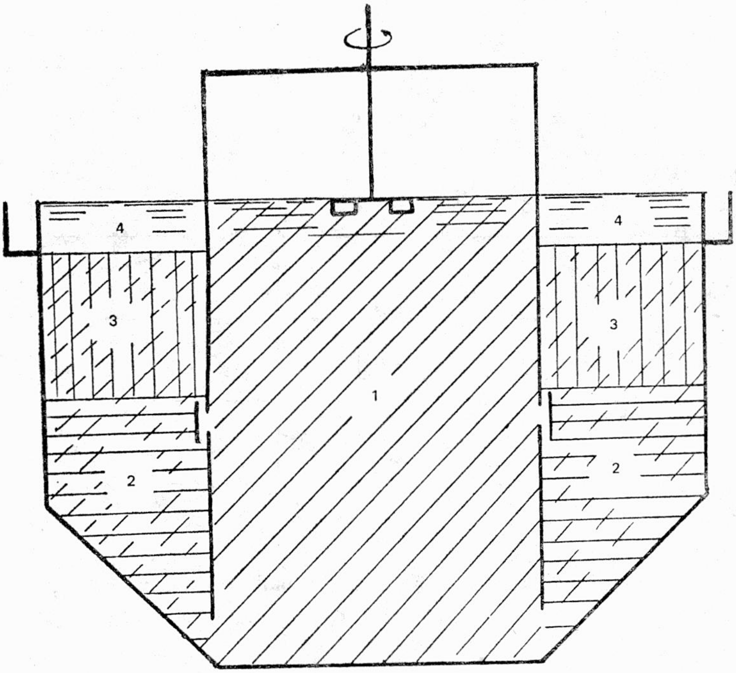

Fig. 5. Scheme of oxytank divided into the process zones:

1 — reactor — biochemical oxidation and mixed liquor saturation by oxygen; *2* — recycle zone of sludge separation tank — biological oxidation and mixed liquor separation; *3* — zone of suspended solids filtration — water treatment by filtration and oxidation of organic matter; *4* — protective zone

Rys. 5. Schemat zbiornika natleniania podzielonego na strefy:

1 — reaktor — biochemiczne utlenianie i nasycanie cieczy tlenem, *2* — strefa obiegowa zbiornika separacji osadu — biologiczne utlenianie i separacja cieczy, *3* — strefa filtracji zawiesin ciała stałego — oczyszczanie wody przez filtrowanie i natlenianie substancji organicznej, *4* — strefa ochronna

The operation efficiency of oxytank does not practically vary during its long overload, evaluated by organic impurities. At the average 3.9 h duration of flow retention time in reaction zone, the oxytank oxygenation capacity was equal to 3700 g COD m^3/day. Over this period of time the oxytank ensured a complete biological treatment of wastewater. Effluent $BOD_{compl.}$ was not higher than 15 mg/dm^3, COD averaged 77 mg/dm^3 and suspended solids were maintained at the level of 22 mg/dm^3. At an initial content of nitrogen stripped from ammonia salts at a dose of 73 mg/dm^3 in the effluent, the average amount of ammonia nitrogen was 29.8 mg/dm^3.

Table 1

Comparative data for oxytank and aeration tank performance
Porównanie danych eksploatacyjnych zbiornika natleniania i napowietrzania

Parameters	Average month data		Average week data	
	Aeration tank	Oxytank	Aeration tank	Oxytank
Estimated aeration time, h	20	5.5	20	3.9
Activated sludge concentration, g/dm^3	2.5	7.8	2.5	7.4
Dissolved oxygen, mg/dm^3	3–4	12	3–4	12
Sludge index, cm^3/g	90	66		73
Removed BOD, %	97.4	97.4		
Oxygenation capacity, g $COD/m^3/day$	743	2610	965	3720
Load effect on sludge, g COD/g day	298	335	302	503
Wastewater				
COD, mg/dm^3	663	663	686	686
$BOD_{compl.} mg/dm^3$	487	497	512	512
Treated water				
COD, mg/dm^3	45	65	48	78
$BOD_{compl.} mg/dm^3$	13	13	13	13
Suspended solids, mg/dm^3	20	18	20	22

It should be noted that short time overloads of oxytank 1.6–1.9 times higher than the estimated loads have no adverse effect on the effluent quality.

From the oxytank operation data it follows that at the same extent of treatment, the sludge index value in oxytank can be 1.4–1.6 times smaller than that in aeration tank.

The efficiency of oxygen supplied to oxytanks was not lower than 80% and averaged 93–96%.

Both high efficiency and economical advantages of oxytanks may speak for their application in wastewater treatment in industry.

For economical comparison the treatment plants have been considered in the following combination:

Combination I — aeration tanks with air supply by compressors.

Combination II — combined hermetical aeration tanks (oxytanks) with oxygen supply from air separation installation at the industrial plant.

In the above examples the plants of mechanical wastewater treatment and hence of sludge disposal were assumed to be identical and therefore were neglected in calculations.

These combinations were compared by referring them to biological treatment plant efficiencies of order of 50,000–300,000 m^3/day.

The treatment plants are designed so as to ensure a complete biological treatment.

To determine the estimated parameters of aeration tanks for wastewater treatment the following performance data are used:

influent BOD — 300 mg/dm³,

effluent BOD — 15 mg/dm³,

aeration time — 16 h,

sludge dose — 1.5–3 g/dm³,

aeration intensity — 4–5 m³/m²/h.

In design of oxytank, the assumed retention time was 3 h (including $\frac{1}{2}$ h retention time in sludge separation tank). Oxytank capacity may be increased by increasing the sludge dose up to 10–12 g/dm³ and dissolved oxygen concentration up to 12–14 g/dm³.

Technological data for the compared combinations are summarized in tab. 2.

Table 2

Technological data for I and II combinations
Dane technologiczne dla kombinacji I i II

Example	Capacity	Removed BOD	Duration		Volume		Gas flow rate	
			Aeration	Settling	Aeration tank	Settling tank	Air	Oxygen
	1000 t/day	t/day	h	h	1000 m³	1000 m³	m³/h	m³/h
I	50	18.8	16	1.5	45.0	4.2	70.000	—
	100	37.6	16	1.5	90.0	8.4	140.000	—
	200	75.2	16	1.5	180.0	16.8	280.000	—
	300	113.8	16	1.5	270.0	25.2	420.000	—
II	50	18.8	3.0	1.5	8.4	4.2	—	708
	100	37.6	3.0	1.5	16.8	8.4	—	1416
	200	75.2	3.0	1.5	33.6	16.8	—	2832
	300	113.8	3.0	1.5	50.0	25.0	—	4248

By determining the capital expenditures for oxytank at wastewater treatment it has been accepted that the oxygen is supplied from air separation installation. In this case the capital investment was defined by specific investment based on cryogenic plant cost amounting to 303 roubles/m³/h.

By estimating the energy consumption, when mechanical type of aerators in oxytank are used, the specific rate was accepted to be

$$\frac{0.32\ \mathrm{kW \cdot h}}{\mathrm{kg}\ (O_2)}$$

with regard to aerator capacity increase and energy cost decrease, respectively. The oxygen was dissolved due to its partial pressure elevation.

Results of technological and economical calculation are summarized in tab. 3.

Table 3

Results of technological and economical evaluation
Wyniki analizy techniczno-ekonomicznej

Examples	Capacity of treatment plant	Volume of aeration tanks or oxytanks	Air or oxygen rate	Capital cost: Aeration tank or oxytanks – Unit	Capital cost: Aeration tank or oxytanks – Total	Capital cost: Air flowing and oxygen plants – Unit	Capital cost: Air flowing and oxygen plants – Total	Total K
	1000 m³/day	1000 m³	1000 m³/h	roubles/m³	1000 roubles	roubles/m³/h	1000 roubles	1000 roubles
I Aeration tanks	50	45.0	70	20.4	920	—	150	1070
	100	90	140	15.9	1430	—	190	1620
	200	180	280	14.1	2530	—	240	2770
	300	270	420	13.0	3510	—	260	3770
II Oxytanks	50	8.4	0.71	31.0	260	303	215	575
	100	16.8	1.42	21.5	362	303	430	792
	200	33.6	2.73	21.5	723	303	860	1583
	300	50.0	4.25	21.5	1120	303	1290	2490

Operating costs: Amortization costs – Construction 3.9%	Operating costs: Amortization costs – Equipment 5.3%	Operating costs: Amortization costs – Total	Operating costs: Energy cost – Unit	Operating costs: Energy cost – Per year	General	Biochemical treatment	Compared expenditures	Economical effect
1000 roubles per year	1000 roubles per year	1000 roubles	roubles 1000 m³	1000 roubles per year	1000 roubles per year	roubles 1000 m³	1000 roubles per year	1000 roubles per year
36.0	7.9	43.9	—	257	300.9	16.5	464	—
55.7	10.1	55.8	—	512	567.8	15.6	784	—
98.5	12.7	111.2	—	1024	1135.2	15.5	1505	—
137.0	13.8	150.8	—	1540	1690.8	15.5	2183	—
10.1	11.4	21.5	16.9	178	199.5	6.1	280	177
14.3	22.8	37.1	16.9	365	393.1	5.9	703	266
28.2	45.6	73.8	16.9	712	785.8	5.9	981	475
43.7	78.4	122.1	16.9	1070	1192.1	5.9	1540	625

CONCLUSIONS

1. The construction of oxytank is based on reactor complete mixing principle and is most suitable for wastewater treatment. The considered system is characterized by a high degree of oxygen utilization which is due to the reduction of the system size achieved by combining three processes, i.e. settling, filtering through activated sludge suspended

solid bed and biochemical oxydation in a sludge separation tank, as well as to automatic control system for oxygen supply that is proportional to the amount of organic impurities fed with wastewater.

2. The studies of a full-scale plant have shown that the technological data related to oxytank performance agree with the estimated results. In this, case as far as the basic components are concerned, oxygenation capacity of oxytank is 3.5 times higher than that of aeration tank at complete biochemical treatment of wastewater.

3. The use of pure oxygen allows us to maintain the activated sludge concentration in oxytank at the level of 6–10 g/dm³ and at high concentration of dissolved oxygen of 10–12 mg/dm³. In this way the settling properties of activated sludge are improved.

4. Oxytank system yields a high quality of treated water at the overloads 1.6–1.9 times and 1.3–1.4 times higher than the estimated loads for short and long periods of time, respectively.

5. The distinguishing feature of oxytanks is that the volatile components are removed, thus the atmosphere is not polluted with harmful substances. At the same time if large amounts of ammonia nitrogen are present in wastewater influent, the ammonia nitrogen content in oxytank effluent was higher than that in aeration tank.

6. Technological and economical evaluation of treatment of nitrogenous industry wastewater showed an economically advantageous utilization of oxygen in oxytanks. Therewith capital investment for biological treatment works are 1.5–2 times reduced, operating expenditures decreased 1.4–1.6 times, and economical effect for plants with capacity of 50,000–300,000 m³ of wastewater per day was 177,000–625,000 rubles per year.

DOŚWIADCZENIA EKSPLOATACYJNE ZBIORNIKÓW NATLENIANIA

Podsumowano doświadczenia eksploatacyjne nowego typu zbiornika natleniania, w którym stosuje się czysty tlen zamiast powietrza. Zaprezentowano metodę projektowania i zasady eksploatacyjne jednostki, której konstrukcja oparta została na zasadach reaktora o całkowitym wymieszaniu. Jednostka ta charakteryzuje się wysokim wykorzystaniem tlenu (93–96%) i zredukowanymi wymiarami, gdyż procesy sedymentacji, flotacji i biochemicznego utleniania prowadzone są w zbiorniku oddzielania osadu czynnego.

Badania wykonane w pełnej skali wykazały, że zdolność utleniania podstawowych składników ścieków w takim zbiorniku natleniania jest 3,5 razy większa niż w zbiornikach napowietrzania stosowanych w biologicznym oczyszczaniu ścieków. Zastosowanie tlenu zamiast powietrza pozwala również na zwiększenie stężenia osadu czynnego do 6–10 g/dm³ przy 10–12 mg/dm³ rozpuszczonego tlenu. Poprawia się w ten sposób własności sedymentacyjne osadu.

Zastosowanie zbiorników natleniania jest korzystne także z ekonomicznego punktu widzenia; redukuje się 1,5–2 razy koszty inwestycyjne i 1,4–1,6 razy koszty eksploatacyjne.

BETRIEBSVERSUCHE AN SAUERSTOFFBEGASUNGSBECKEN

Zusammengefasst werden die Betriebsergebnisse eines neuartigen Sauerstoff-Begasungsbeckens in welchem Sauerstoff anstatt Luft angewandt wird. Wiedergegeben werden die Methoden der Projektierung und die Betriebsgrundlagen eines komplett durchmischten Reaktors. Der Sauerstoff wird bis zu

93–96% ausgenutzt und dadurch das Beckenvolumen stark reduziert. Sedimentation, Flotation und biochemische Oxydation erfolgen in einem anderen Becken.

Die Versuche im technischen Maßstab haben erwiesen, daß die Oxydation der Abwasserinhaltsstoffe im erwähnten Sauerstoffbecken 3,5 mal so schnell vorgeht wie im klassischen und mit Luft begastem Becken. Die Anwendung des Sauerstoffs ermöglicht auch eine Erhöhung der Biomassekonzentration bis zu 6–10 kg/m^3 bei einer durchschnittlichen Sauerstoffkonzentration von 10–12 mg/dm^3. Beide Parameter bewirken eine bessere Sedimentation des belebten Schlammes.

Die beschriebene Methode ist auch wirtschaftlich genug: die Investitionskosten sind 1,5 bis 2-mal niedriger als bei klassischen Lösungen, die Betriebskosten sind 1,4 bis 1,6-mal niedriger.

ЭКСПЛУАТАЦИОННЫЕ ОПЫТЫ РЕЗЕРВУАРОВ НАСЫЩЕНИЯ КИСЛОРОДОМ

Подитожены эксплуатационные опыты нового типа резервуара насыщения кислородом, в котором используется чистый кислород, вместо воздуха. Представлен метод проектирования и эксплуатационные принципы единицы, сконструированной на принципе реактора с полным перемешиванием. Эта единица характеризуется большим использованием кислорода (93–96%) и уменьшенными размерами, так как процессы седиментации, флотации и биохимического окисления проводятся в резервуаре отделения активного ила.

Исследования, проведенные в полном масштабе, показали, что способность окисления основных компонентов сточных вод в таком резервуаре в 3,5 раза больше, чем в аэротенках, применяемых при биологической очистке сточных вод. Применение кислорода, вместо воздуха, позволяет также повысить концентрацию активного ила до 6–10 г/дм^3 при 10–12 мг/дм^3 растворенного кислорода. Улучшаются таким образом седиментационные свойства ила.

Применение резервуаров насыщения кислородом выгодно также с экономической точки зрения; уменьшаются в 1,5–2 раз капитальные расходы и в 1,4–1,6 раз эксплуатационные затраты.