Environment Protection Engineering

Vol. 11 1985 No. 3–4

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BIOCHEMICAL TREATMENT OF HIGHLY CONCENTRATED WASTEWATERS FROM WOOL-SCOURING OPERATIONS

The paper deals with the biochemical treatment of highly concentrated wastewaters from wool-scouring operations (10–35 g/dm³ COD, 10–20 g/dm³ BOD) in which soap and soda washing is applied. The oxidation kinetics of wastewaters, both untreated and pretreated under anaerobic conditions, measured in digesters and mixing aeration tanks is presented. The values of kinetic constants to be considered in design of wastewaters treatment facilities are determined. As shown technologically the combination of anaerobic and aerobic methods of highly concentrated wastewater treatment permits us to use the advantages of each method and to eliminate its limitations by increasing the efficiency of the process as a whole.

Based on the generalized results of study and economic evaluation of various treatment schemes, the specific recommendations are given for selection of biochemical treatment method of wool-scournig wastewaters.

The problems associated with treatment of highly concentrated wastewater are becoming more noticeable today. A typical example of this kind of wastewater is a highly concentrated wastewater generated from wool-scouring plants. These wastewaters contain substantial amounts of wool grease, wool, dissolved organic matter, inorganic matter and various other impurities. The COD value varies from 10 to 35 g/dm³ and that for total BOD from 5.0 to 20 g/dm³. At present, mechanical, chemical, physicochemical, and biological treatment processes are being used to treat wool-scouring operation wastewaters. In spite of a variety of methods, the treatment of these wastewaters present certain problems. Chemical treatment process requires the use of expensive chemicals, careful control of the process, and accurate dosing of reagents, resulting in large production of waste sludge. At the same time the anaerobic biological treatment in digesters is more and more widely applied due to its efficiency, ease of operation and reduced production of sludge. However, the BOD in effluent from these digesters varies from 800 to

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1000 mg/dm³, requiring its final treatment. It should be noted that the 20 day digestion retention period is needed to produce an effluent with a total BOD of 8000–1000 mg/dm³. In practice, the existing digesters being designed for retention period of 8–10 days resulted in the total BOD in effluents ranging from 1500 to 2000 mg/dm³. Then, the effluent should be treated in municipal biological treatment plants (fig. 1, scheme 1).

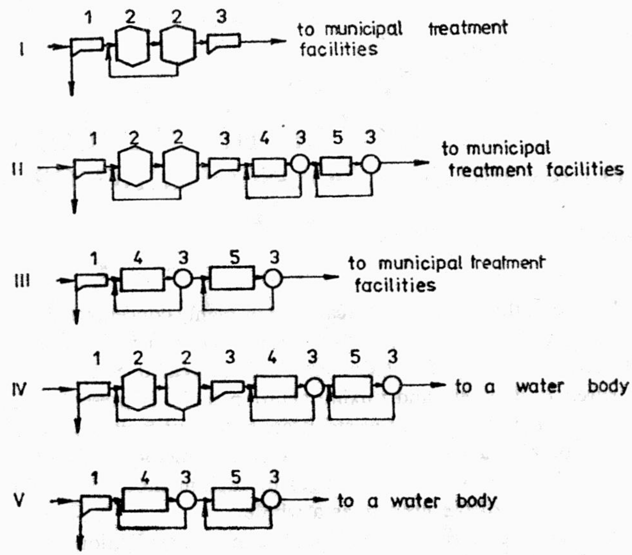

Fig. 1. Biological treatment schemes for wool-scouring operation wastewaters

1 — primary settling tanks, *2* — digestion tanks, *3* — final settling tanks, *4* — first-stage aeration tank, *5* — second-stage aeration tank

Rys. 1. Biologiczne oczyszczanie ścieków powstających podczas prania wełny

1 — osadniki wstępne, *2* — zbiorniki fermentacyjne, *3* — osadniki końcowe, *4* — zbiorniki napowietrzania pierwszego stopnia, *5* — zbiorniki napowietrzania drugiego stopnia

In most cases, however, the capacity of municipal treatment plants do not meet the existing standards and is not sufficient to handle wool-scouring wastewaters without additional dilution after pretreatment in digesters. For this reason it is necessary to seek an additional method of treating wastewaters before discharging them into municipal sewage systems or receiving waters.

The feasibility of wool-scouring wastewaters treatment in digesters, followed by final treatment in aeration tanks without dilution, as well as complete biological treatment under aerobic conditions, were studied at the VODGEO Institute. Studies were conducted on wastewaters generated from a worsted factory where soap and soda are applied.

The experiments were carried out on laboratory-scale continuous-flow models of digesters and complete mixing aeration tanks. The performance of facilities was monitored by analyses of COD, total BOD, pH, concentration of volatile fatty acids, nitrogen and phosphorus contents, concentration of ether-soluble material, anaerobic and aerobic activated sludge concentrations, and the quantity and composition of gas produced from digesters. In order to obtain the criterion for an adequate evaluation of digesters performance, as well as for quantitative evaluation of biodegradable substrate in digesters, the influent and effluent BOD from digesters have been analysed using a special procedure.

As digesters are completely mixed biological reactors, the oxidation rate is determined from the effluent substrate concentration. The relationships between the oxidation capacity of digester and specific oxidation rate and effluent organic concentration were found experimentally. It has been found that oxidation capacity and specific oxidation rate increase with the decreasing degree of treatment. It has been also found that the effect of effluent organic concentration and volatile fatty acid concentration on specific oxidation rate is expressed by hyperbolic function (fig. 2) and may be described by the Michaelis–Menten expression for fermentation reactions

$$S = \frac{V_{max}(S_2)}{K_m + (S_2)}$$

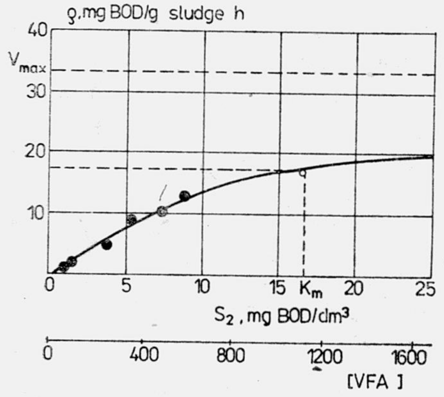

Fig. 2. Specific oxidation rate versus organics concentration (on BOD basis) and volatile fatty acids concentration in effluent

Rys. 2. Specyficzna szybkość utleniania w zależności od stężenia związków organicznych (na podstawie BZT) i lotnych kwasów tłuszczowych w odcieku

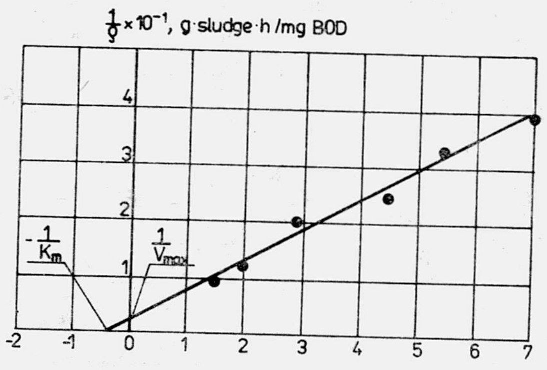

Fig. 3. Specific oxidation rate versus organics concentration in the effluent from digesters

Rys. 3. Specyficzna szybkość utleniania w zależności od stężenia związków organicznych w odcieku z komór fermentacyjnych

where:

S – specific oxidation rate; mg BOD anaerobic per g VSS (oxidizeable materials) per h,

S_2 – substrate concentration, mg BOD anaerobic per dm³ or mg voltatile fatty acids per dm³,

K_m — Michaelis–Menten constant expressed as substrate concentration at which reaction rate is equal to half the maximum rate,

V_{max} — maximum reaction rate, mg BOD anaerobic per g VSS per h.

Method of binary reciprocal values was used to define V_{max} and K_m. It can be seen from fig. 3, that the maximum specific oxidation rate of wool-scouring wastewaters in digesters is 33.3 (mg BOD)·h/(g VSS) and K_m is 16700 mg/dm^3.

As the value of constant K_m depends rather on its nature than on substrate concentration, the high value of K_m obtained for treated effluent from digesters indicates the complexity of wool-scouring wastewater composition. The effect of anaerobic activated sludge concentration on basic technological parameters has been investigated in order to improve the digester performance. The oxidation capacity of digesters and the degree of treatment increase considerably with the increasing dosage of activated sludge, while specific rate decreases. However, due to the increasing overall oxidation rate it decreases slower than the concentration of activated sludge. The decrease in specific oxidation rate with the increasing sludge dosage appeares to be accounted for the changes in prebacterial film under hydrodynamic conditions which, in turn, prevent feeding of substrate to microorganisms and inhibit metabolism.

In order to define the relationship between the concentration of anaerobic activated sludge and specific oxidation rate, the use of coefficient K_{sludge} has been suggested.

This coefficient is equal to the ratio of specific rate at the given sludge concentration to the rate at sludge concentration of 5 g VSS/dm^3.

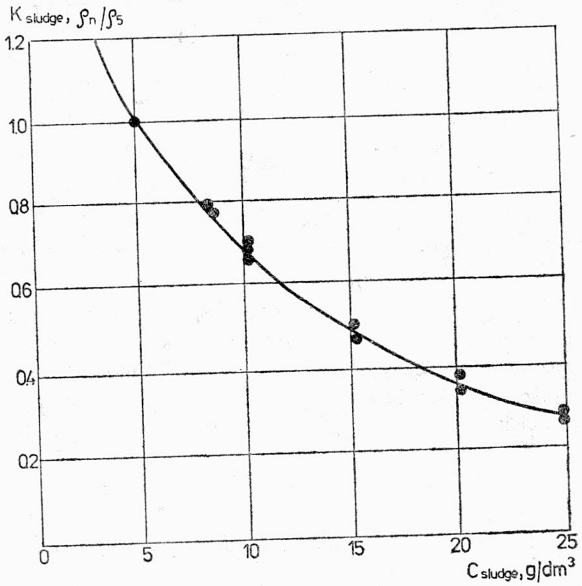

Fig. 4. Coefficient K_{sludge} versus anaerobic activated sludge concentration

Rys. 4. Współczynnik K_{osad} w zależności od stężenia anaerobowego osadu czynnego

The literature data indicate that this coefficient does not depend on substrate concentration, but only on the concentration of anaerobic activated sludge (fig. 4).

Considering specific oxidation rate and K_{sludge} coefficient, technological parameters of digesters treating highly concentrated wastewaters should be calculated by using the equation:

$$T = \frac{S_0 - S_1}{5 \cdot C_{sludge}(1-P) \cdot K_{sludge}}$$

where:

T — retention period in digesters, day,

S_0 — organic concentration in influent, mg/dm³ total BOD,

S_1 — effluent organic concentration mg/dm³ total BOD,

S — specific oxidation rate at sludge concentration on VSS 5 g/dm³, mg total BOD per g VSS,

P — ash content in sludge, parts/unity,

K_{sludge} — coefficient determining the effect of sludge concentration on its activity, determined experimentally.

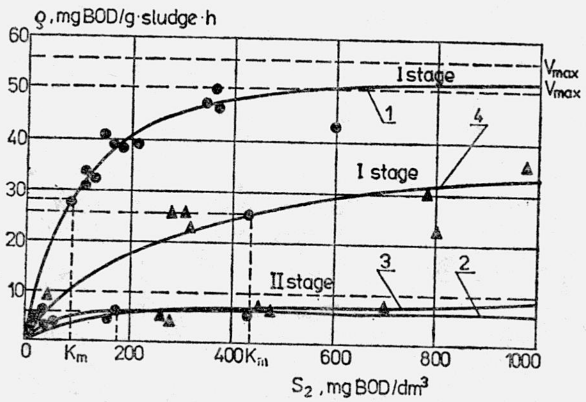

Fig. 5. Specific oxidation rate in first-stage and second-stage aeration tanks versus organics concentration in the effluent

Rys. 5. Specyficzna szybkość utleniania w zbiornikach napowietrzania pierwszego i drugiego stopnia w zależności od stężenia związków organicznych w odcieku

The results of studies on the final treatment of wool-scouring wastewaters have shown that the effluent from digesters containing non-oxidized organic material (3000 mg/dm³) need not be diluted but treated successfully in complete mixing aeration tanks which operate according to a two-stage scheme.

It is evident from fig. 5 that kinetics of wool-scouring wastewater oxidation in complete mixing aeration tanks can be described by Michaelis–Menten expressions for kinetics of digestion.

The values of kinetic constants (figs. 6, 7) have been found experimentally and may be used for calculations of basic technological parameters of aeration tank performance.

From the same figures it can be seen that the maximum specific oxidation rate in a first-stage aeration tank is 55.5 mg BOD/g VSS h.

The value of K_m (83.5 mg/dm³) for the first-stage aeration tank is higher than that (13.8 mg/dm³) for the second-stage aeration tank. From the data obtained, it can be concluded that a high oxidation rate occurring in the first stage aeration tank is due to excess substrate conditions of activated sludge. At the second stage, the required degree of treatment is achieved at lower oxidation rate because of not sufficient amount of substrate. Each stage in the aeration tank is characterized by the development of specific

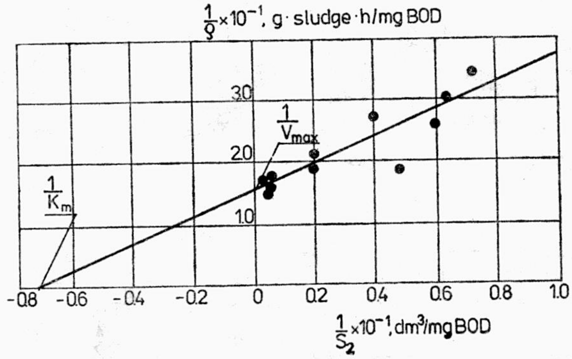

Fig. 6. Specific oxidation rate versus organics concentration in the effluent from first-stage aeration tank

Rys. 6. Specyficzna szybkość utleniania w zależności od stężenia związków organicznych w odcieku ze zbiornika napowietrzania pierwszego stopnia

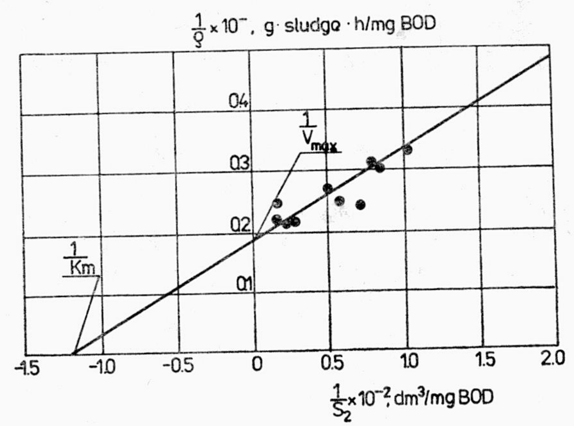

Fig. 7. Specific oxidation rate versus organics concentration in the effluent from second-stage aeration tank

Rys. 7. Specyficzna szybkość utleniania w zależności od stężenia związków organicznych w odcieku ze zbiornika napowietrzania drugiego stopnia microorganisms due to autoselection of best acclimatized individuals and to mutations occurring in the culture. This development affecs both the physical properties of activated sludge (in particular, its settling properties) and the kinetics of the biochemical treatment process. If the amount of substrate in the first stage is not limited, then the autoselection of microorganisms promotes an increase in the maximum oxidation rate. If the amount of substrate in the second stage is limited, the development of the culture encourages the reduction K_m value and a more complete utilization of the substrate. Therefore, by dividing the process into two stages, efficiency of the process in the first stage is improved and the oxidation of organic matters in the second stage is more complete.

Laboratory studies have demonstrated the feasibility of aerobic treatment of wool-scouring wastewaters in two-stage completely mixed aeration tanks without preliminary digestion and dilution under anaerobic conditions.

The results of kinetic studies on wool-scouring wastewater oxidation at a total BOD ranging from 8000 to 9000 mg/dm^3 in completely mixed aeration tanks are presented in fig. 5. From the data obtained it is evident that the oxidation kinetics depends also on the digestion kinetics and may be described by Michaelis-Menten formulae. Kinetic constants V_{max} and K_m for the first-stage aeration-tank are 50 mg BOD/g VSS·h and 460 mg/dm^3, and for the second-stage aeration tank being 10 mg BOD/g VSS·h and 185 mg/dm^3, respectively. From fig. 5 it is seen that pretreatment of wastewaters has a marked effect on the oxidation kinetics in aeration tanks. In both the first and second stage aeration tanks the values of K_m differ significantly, in the former case being 83.5 mg/dm^3 instead of 460 mg/dm^3, and in the latter one 13.5 mg/dm^3 instead of 185 mg/dm^3. These differences affect specific oxidation rate, for instance, wastewaters treated in an anaerobic digester to a total BOD of 200 mg/dm^3 will be oxidized at the rate of 39.2 mg BOD total/g VSS·h in the first aeration tank, without pretreatment being oxidized at the rate of 15.2 mg total BOD/g VSS·h. During the degradation organic pollutants are probably broken in to simpler organic structures, hence the aerobic oxidation rate is higher.

The results obtained allowed us to perform the comparative analysis of various treatment schemes for wool-scouring wastewaters.

For technological and economic comparison the following treatment schemes have been chosen (fig. 1):

I. Preliminary anaerobic treatment in digesters followed by final treatment in municipal biological treatment plants.

II. Preliminary two-stage anaerobic–aerobic treatment producing effluent with a total BOD of 200 mg/dm^3 followed by final treatment in municipal biological treatment plants.

III. Preliminary two-stage aerobic treatment producing effluent with a total BOD of 200 mg/dm^3 followed by final treatment in municipal treatment plants.

IV. Complete two-stage anaerobic–aerobic treatment reducing a total BOD to 15 mg/dm^3.

V. Complete two-stage aerobic treatment producing effluent with a total BOD of 15 mg/dm^3.

For comparative reasons it has been assumed that wool-scouring wastewater flow is 2000 m^3/day, municipal wastewater flow 5000 m^3/day, pollutant concentration in incoming wool-scouring wastewaters ranges from 8000 to 9000 mg/dm^3 and the total BOD of untreated municipal wastewaters is 200 mg/dm^3.

Preliminary assessment of technological and economic feasibility of anaerobic–aerobic and two-stage aerobic treatment processes allowed us to define the optimum relationship between the stages of both schemes and appropriate optimum technological parameters of facility performance.

Concentrations of organics in treated effluent from digesters are as follows: 3000 mg BOD total/dm^3, from the first stage aeration tank in scheme II — 400 mg BOD total/dm^3, in scheme III — 100 mg BOD total/dm^3 in schemes IV and V — 200 mg BOD total/dm^3. Anaerobic activated sludge concentration is 20 g/dm^3, aerobic activated sludge concentration in the first-stage aeration tank is 4.5 g/dm^3 and 10 g/dm^3 in schemes II and IV and in schemes III and IV, respectively. In the second-stage aeration tank the concentration is 4.0 g/dm^3 in all schemes.

Table

Technical and economical comparison of schemes for biological treatment of wool-scouring operation wastewaters

Porównanie technicznych i ekonomicznych schematów biologicznego oczyszczania ścieków z płukania wełny

Scheme	Treatment unit				
	Digestion tank m^3	First-stage aeration tank m^3	Second-stage aeration tank m^3	Municipal treatment plants m^3	Total volume m^3
I	15000	—	—	3800	18800
II	4000	1230	900	630	6760
III	—	2700	3560	630	6900
IV	4000	1560	1200	—	6760
V	—	7700	1200	—	8900

For an approximate economic comparison we assumed the minimum total volume of facility as a criterion of economic effectiveness of treatment schemes because the preliminary evaluation has shown that comparative costs of digesters and aeration tanks are almost equal. From table, in which facility volumes are given for each scheme, it may be concluded that the most advantageous are the schemes II, III, and IV.

It should be noted, however, that while evaluating the treatment process of wastewaters the sludge treatment was neglected.

It also should be noted that the production of activated sludge in an anaerobic digester is lower than in an aeration tank; thus, it should be expected that the schemes II and IV with digesters are the most advantageous. The combination of anaerobic and aerobic processes in the treatment of highly concentrated wastewaters, allowing us to use the advantages of each method and to avoid the shortcomings, enhance the effectiveness and efficiency of the treatment process as a whole.

BIOLOGICZNE OCZYSZCZANIE STĘŻONYCH ŚCIEKÓW POCHODZĄCYCH Z PRANIA WEŁNY

Omówiono biologiczne oczyszczanie stężonych ścieków (10–35 g/dm³ ChZT i 10–20 g/dm³ BZT), powstających podczas prania wełny z użyciem mydła i sody kaustycznej. Przedstawiono kinetykę utleniania ścieków surowych i poddanych wstępnemu oczyszczaniu w warunkach anaerobowych w komorze fermentacyjnej i komorze napowietrzania. Określono wartości stałych kinetycznych potrzebnych do projektowania instalacji oczyszczania ścieków. Wykazano, że kombinacja metody anaerobowej z aerobową pozwala uniknąć ograniczeń każdej z nich i pełniej wykorzystać ich zalety, co w konsekwencji podnosi efektywność całego procesu. Wybór biologicznej metody oczyszczania oparto na wynikach badań i analizie ekonomicznej różnorodnych schematów oczyszczania ścieków pochodzących z prania wełny.

BIOLOGISCHE REINIGUNG VON HOCHKONZENTRIERTEN WOLLEWASCHWÄSSER

In Wollewäschereien, wo der zu waschenden Wolle Seife und Ätznatron zugesetzt werden, entstehen hochkonzentrierte Abwässer mit einem CSB von 10–35 g/dm³ und einem BSB_5 von 10–20 gO_2/dm^3. Beschrieben wird die Oxydationskinetik dieser Abwässer in einem Fermenter und im Belüftungsbecken, wo sowohl rohe wie anaerob vorbehandelte Abwässer gereinigt wurden. Die für einen Entwurf benötigten Werte der kinetischen Konstanten konnten festgelegt werden. Es wird aufgezeigt, daß beim Einsatz der anaeroben und anschliessend der aeroben Verfahren, beide Methoden besser genutzt werden können unter gleichzeitigem Ausschluß von Engpässen der beiden Methoden. Die Wahl der biologischen Abwasserreinigung stützte sich auf eingehenden Untersuchungen und auf der Kosten-Nutzen-Analyse verschiedener Reinigungsverfahren.

БИОЛОГИЧЕСКАЯ ОЧИСТКА КОНЦЕНТРИРОВАННЫХ СТОЧНЫХ ВОД, ПРОИСХОДЯЩИХ ОТ СТИРКИ ШЕРСТИ

Обсуждена биологическая очистка концентрированных сточных вод (10–35 г/дм³ ХПК и 10–20 г/дм³ БПК), образующихся во время стирки шерсти с использованием мыла и каустической соды. Представлена кинетика окисления сырых сточных вод и подвергнутых предварительной очистке в анаэробных условиях в бродильной камере и в аэротенке. Определены значения кинетических постоянных, нужных для проектирования установки для очистки сточных вод. Доказано, что комбинация анаэробного метода с аэробным позволяет избежать ограничения каждого из них и более полно использовать их преимущества, что в результате повышает эффективность всего процесса. Выбор биологического метода очистки основан на результатах исследований и на экономическом анализе разнообразных схем очистки сточных вод, происходящих от стирки шерсти.