Combined biological and physico-chemical treatment of baker's yeast wastewater

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Abstract The UASB reactor (35 °C) was quite efficient for removal of bulk COD (52–74%) from the raw and diluted cultivation medium from the first separation process of baker's yeasts (the average organic loading rates varied in the range 3.7–16 g COD/l/d). The aerobic-anoxic biofilter (19–23 °C) can be used for removal of remaining BOD and ammonia from anaerobic effluents; however, it had insufficient COD to fulfil the denitrification requirements. To balance COD/N ratio, some bypass of raw wastewater (~10%) should be added to the biofilter feed. The application of iron (III)-, aluminium- or calcium-induced coagulation for post-treatment of aerobic effluents can fulfil the limits for discharge to sewerage (even for colour mainly exerted by hardly biodegradable melanoidins), however, the required amounts of coagulants were relatively high.

Keywords Aerobic-anoxic biofilter; baker's yeast wastewater; coagulation; melanoidins; UASB reactor

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Introduction

Baker's yeast industry is abundant in Russia: such factories exist in almost all Russian provinces and altogether they produced 56 mln m^3 wastewater per year. These wastewaters are high strength (till 80 g COD/l), strongly nitrogenous (till 1.5 g/l total N), sulphate-rich (up to 10 g/l), phosphorous variable (sometimes P-deficient), recalcitrant for biodegradation and highly coloured (melanoidins etc.) (Kalyuzhnyi *et al.*, 2003). Currently many yeast factories are faced with heavy trade-effluent charges because a majority of local municipal sewage treatment plants are now insisting on on-site pre-treatment of such streams before discharge into their sewerage. The objective of this paper was to develop a laboratory technology for treatment of baker's yeast wastewater to meet the typical limits for discharge of treated wastewater into municipal sewerage. The most troublesome limits in this case are the following (mg/l, except colour): COD – 800; SO_4^{2-} – 500; total N – 100; N-NH_3 – 50; P-PO_4^{3-} – 3.5; colour – optical density $<$ 0.1 at dominant wavelength)). As a first treatment step, the UASB reactor operating at 35 °C was applied for the elimination of the major part of COD and concomitant sulphate reduction. In a subsequent step, the biofilter operating in alternative aerobic-anoxic regime at 19–23 °C was used for the removal of remaining BOD and nitrogen. Finally, coagulation with Fe, Al and Ca was tested to fulfil the limits on COD, total nitrogen, PO_4^{3-} and colour.

Materials and methods

Wastewater. Since the major (~30% of total volume wastewater produced) and the strongest stream from yeast factories (Kalyuzhnyi *et al.*, 2003), is the cultivation medium obtained after the first separation of yeasts (CM-1S), this wastewater taken from Moscow baker's yeast factory was used in this study. Some characteristics of the CM-1S during the period of sampling from November 2002 to March 2003 are given in Table 1.

Table 1 Range of variation of some characteristics of the CM-1S (average values from 5 samplings are given in brackets)

COD_{tot}, g/l	**COD_{SS}, g/l**	**COD_{col}, g/l**	**COD_{sol}, g/l**	**pH**
17.9–31.1 (22.5)	0.95–2.93 (1.07)	0.82–1.91 (1.46)	15.0–26.6 (19.0)	4.01–5.68 (5.14)
Total N, mg/l	**N-NH_3, mg/l**	**Total P, mg/l**	**P-PO_4, mg/l**	**SO_4, mg/l**
993–1,651 (1,179)	186–450 (278)	12–78 (32)	2–32 (9)	682–3,028 (1,828)
Phenolic compounds, mg/l	**Dominant wavelength, nm**	**Colour purity, %**	**Colour luminance, %**	**OD_{580}**
713–1,167 (875)	580	45.7–52.8 (48.6)	40.6–50.2 (46.6)	0.76–1.17 (0.95)

Laboratory reactors. Details of UASB reactor and aerobic-anoxic biofilter used here we described previously (Gladchenko *et al.*, 2004). The UASB reactor was kept in the thermostat (35 ± 1 °C) and was seeded with granular sludge (66.5 g VSS, specific aceticlastic activity – 0.3 g COD/g VSS/day) from the full-scale EGSB reactor treating brewery wastewater (Efes-Moscow). The biofilter operated at 19–23 °C with attached nitrifying-denitrifying biomass formed during the previous research (Gladchenko *et al.*, 2004) was directly used for treatment of anaerobic effluents in this study.

Coagulation assays. They were performed with 200 ml of biofilter effluent in a laboratory glass under continuous stirring and pH control. Addition of coagulant ($FeCl_3 \cdot 6H_2O$, $AlCl_3$ or CaO) was carried out under 200 rpm, then stirring intensity was reduced to 40 rpm to complete a flocculation process during which pH was maintained at 7.2–7.5 for Fe and Al as well as at 8.0–8.5 for Ca.

Analyses. Sampling of treated wastewater for analysis was usually started after 3 hydraulic retention times (HRT) after change of working regime to ensure the reactors were operating in quasi-steady-state conditions. All analyses were performed by *Standard Methods* (1995) or as described previously (Gladchenko *et al.*, 2004). Statistical analysis of data was done using Microsoft Excel.

Results and discussion

UASB reactor performance

In the preliminary experiments, it was found that the raw CM-1Ss were quite biodegradable in anaerobic conditions (> 80% on COD basis). Some results of the UASB treatment of the raw and diluted CM-1S under quasi-steady-state operation are shown in Figure 1. It can be seen that a stepwise increase of organic loading rate (OLR) from 3.7 to 10.3 g COD/l/d during treatment of the raw CM-1S almost did not influence the total COD removal (Figure 1a), which was in the range of 60–67%. However, further increase of OLR to 16 g COD/l/d during treatment of the diluted CM-1S led to a drop of the total COD removal to 52% (Figure 1b). These results are in accordance with literature data on anaerobic treatment of baker's yeast wastewater (Van Der Merwe and Britz, 1993; Van Der Merwe-Botha and Britz, 1997; Inanc *et al.*, 1999; Radrigan *et al.*, 2002; Kalyuzhnyi *et al.*, 2003). Only traces of VFA were detected in the effluents (data not shown). However, such an exhaustion of easily biodegradable COD in the anaerobic effluents might create COD deficiency problems for subsequent biological nitrogen removal. In spite of acidic influent pH fed, the effluent pH was around 8.0 as a result of VFA consumption and mineralisation of nitrogenous species to ammonia (Figure 2). The specific methane production was around or higher than the theoretically expected values taking into account the observed COD removal and concomitant sulphate reduction (Figure 2). The observed higher methane production can be attributed to the presence of betaine in the

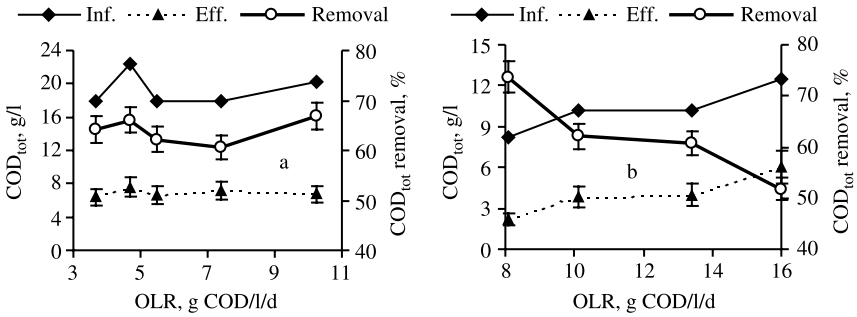

Figure 1 Influent and effluent total COD concentrations and total COD removal versus OLR under quasi-steady-state operation of UASB reactor treating the raw (a) and diluted (b) CM-1S

influents, which is not measured in the COD analysis (Radrigan *et al.*, 2002). The concentrations of phosphate increased (data not shown) in the effluents due to mineralisation of phosphoric species. However, a gradual development of biological sulphate reduction led to an almost complete disappearance of sulphate in the UASB reactor (Figure 3). The latter is almost quantitatively recovered as soluble sulphide (Figure 3). The observed sulphide concentrations seem to be non-inhibitory for anaerobic sludge, which was a concern for some other studies (Lo and Liao, 1990; Lo *et al.*, 1990). Colour removal was generally insignificant during this stage.

Performance of alternative aerobic-anoxic biofilter

The effluents from UASB treatment of raw CM-1S were diluted (~ in 2 times by tap water) before being fed to the biofilter in order to simulate a possible scenario at the yeast factory, when only the most high strength stream may be treated anaerobically, then the anaerobic effluent is mixed with the other less concentrated factory wastewaters. The results are presented in Table 2.

It is seen that after tuning of durations of aerobic and anoxic phases during run 1 (Table 2), the average total COD and ammonia removals accounted for 68% and 94%, respectively. However, the effluent nitrate concentrations were relatively high (207 mg N/l, on average) that was related to a COD deficiency to have a stable denitrification – some part of incoming COD (~1.15 g/l, Table 2, run 1) was non-biodegradable.

To balance COD/N ratio, some bypass of raw CM-1S (10–11%) was added to the biofilter feed during runs 2–3. This led to a substantial decrease of nitrate but some increase of ammonia in aerobic effluents (Table 2, runs 2–3). It seems that it is hardly possible to reach a lower level of ammonia in the effluent due to an immanent drawback of this

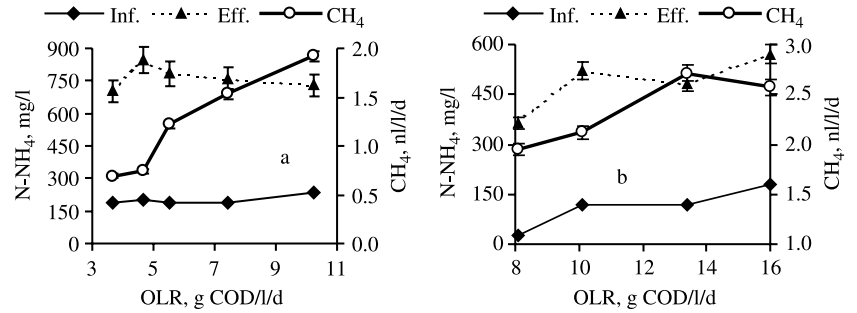

Figure 2 Influent and effluent ammonia concentrations and specific methane production versus OLR under quasi-steady-state operation of UASB reactor treating the raw (a) and diluted (b) CM-1S

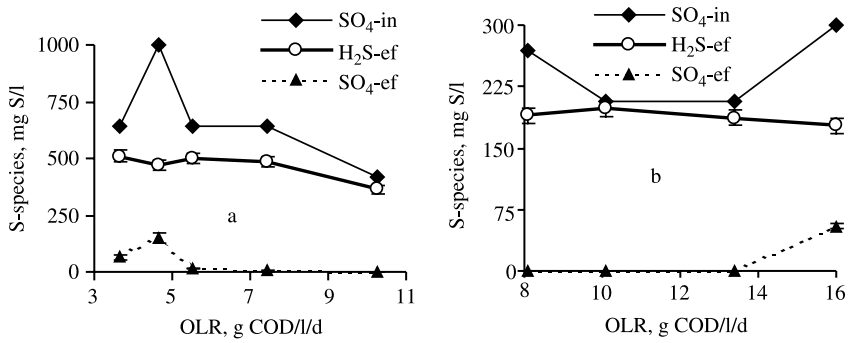

Figure 3 Influent and effluent sulphate as well as effluent sulphide concentrations versus OLR under quasi-steady-state operation of UASB reactor treating the raw (a) and diluted (b) CM-1S

relatively simple biofilter construction where wastewater filling and effluent withdrawal were performed simultaneously in a CSTR regime. The better performance can be expected under disruption of filling and withdrawal phases in the biofilter as in sequencing batch biofilm reactor (SBBR) constructions. Though during runs 2–3 the total

Table 2 Operational parameters and efficiency of the biofilter treating diluted in 2 times anaerobic effluents from UASB treatment of raw CM-1S (mean ± standard deviation)

Parameter/run	1	2[a]	3[b]
Temperature, °C	20.4 ± 2.0	22.6 ± 0.7	22.4 ± 0.8
Aeration phase, min	25	35	40
Mixing after aeration, min	14	9	4
Feeding phase, min	3	3	2
Mixing after feeding, min	18	13	14
HRT, days	3.11 ± 0.07	3.12 ± 0.04	4.35 ± 0.44
Sampling period, days	9	13	10
OLR, g COD_{tot}/l/d	1.16 ± 0.16	1.52 ± 0.03	1.73 ± 0.03
Influent COD_{tot}, g/l	3.59 ± 0.48	4.7 ± 0.05	7.9 ± 0.04
Effluent COD_{tot}, g/l	1.15 ± 0.17	1.49 ± 0.10	2.30 ± 0.02
Total COD removal, %	68.1 ± 1.7	68.3 ± 2.0	71.0 ± 0.2
Influent pH	8.14 ± 0.18	7.54 ± 0.06	7.39 ± 0.07
Effluent pH	7.83 ± 0.1	8.52 ± 0.04	7.63 ± 0.12
Influent N_{tot}, mg/l	474 ± 10	353 ± 3	636 ± 11
Effluent N_{tot}, mg/l	290 ± 7	121 ± 2	140 ± 5
Total N removal, %	38.8 ± 3.5	65.7 ± 0.8	78.0 ± 1.0
Influent N-NH_3, mg/l	416 ± 21	299 ± 2	558 ± 3
Effluent N-NH_3, mg/l	25 ± 5	61 ± 4	64 ± 5
N-NH_3 removal, %	94.0 ± 0.9	79.7 ± 1.4	88.5 ± 1.0
Effluent N-NO_3, mg/l	207 ± 31	8 ± 1	12 ± 2
Effluent N-NO_2, mg/l	Traces	Traces	Traces
[#]Denitrification efficiency, %	47.1 ± 6.5	96.6 ± 1.5	86.4 ± 1.1
Effluent N_{inorg}, mg/l	232 ± 35	69 ± 4	76 ± 6
Effluent N_{org}, mg/l	58 ± 4	52 ± 1	65 ± 1
Influent P-PO_4, mg/l	3.2 ± 0.8	6.4 ± 0.2	7.7 ± 0.1
Effluent P-PO_4, mg/l	3.1 ± 1.2	1.7 ± 0.3	4.1 ± 0.8
Influent phenols, mg/l	456 ± 39	333 ± 3	869 ± 12
Effluent phenols, mg/l	222 ± 21	105 ± 10	322 ± 20
Phenols, removal, %	51.1 ± 5.6	68.4 ± 2.9	62.9 ± 2.1
Influent SO_4, mg/l	17 ± 15	130 ± 7	164 ± 3
Effluent SO_4, mg/l	246 ± 35	285 ± 45	453 ± 41
Influent OD_{580}	0.381 ± 0.012	0.23	0.532 ± 0.001
Effluent OD_{580}	0.325 ± 0.005	0.21 ± 0.01	0.41 ± 0.01
OD_{580} removal, %	11.2 ± 0.9	7.9 ± 0.1	22.5 ± 1.2

[a]10% of CM-1S were added to anaerobic effluent to balance COD/N ratio for denitrification
[b]11% of raw CM-1S were added to balance COD/N ratio for denitrification
[#]Calculated as: $\{1 - ([N - NO_3]_{ef} + [N - NO_2]_{ef})/([N - NH_3]_{in} - [N - NH_3]_{ef})\} * 100$

Table 3 Performance of coagulation step

Parameter/coagulant	Fe			Al			Ca		
Acting Me conc., mg/l	0	193	275	0	195	375	0	1,463	1,790
COD_{tot}, mg/l	1,810	1,050	800	1,810	1,040	800	1,810	1,620	1,490
Phenols, mg/l	122	68	60	122	79	67	122	58	49
P-PO_4, mg/l	1.79	<0.1	<0.1	1.79	0.14	<0.1	1.79	<0.1	<0.1
Total N, mg/l	121	75	66	121	90	78	121	ND	61
N-NH_3, mg/l	61	50	49	61	60	50	61	56	50
OD_{580}	0.219	0.108	0.07	0.219	0.138	0.1	0.219	0.062	0.052
Sludge, % vol*	–	46.4	49.6	–	90.7	92.1	–	98.8	32.2
SVI, ml/g TSS*	–	418	316	–	501	342	–	402	118
Sludge VSS/TSS, %	–	46.3	41.6	–	51.2	54.0	–	54.6	38.9

*After 30 min of settling
ND – not determined

inorganic nitrogen concentrations were around 70 mg N/l (Table 2), the aerobic effluents also contained significant concentrations (52–65 mg N/l) of organic nitrogen (seems to be hardly biodegradable) resulting in total nitrogen concentrations above 120 mg N/l, i.e., higher than the discharge limit to the sewer (100 mg N/l). The total COD concentrations during runs 2–3 were close to the biodegradability limit of yeast wastewater but higher (Table 2) than discharge limit to sewer (800 mg/l). Due to oxidation of sulphide present in the anaerobic effluents, sulphate concentrations were below the discharge limit (500 mg/l), however, it was due to elementary sulphur pre-settling before biofilter treatment. Since such pre-settling may be difficult to implement in full-scale conditions, sulphate can be a concern for biologically treated baker's yeast wastewater. The phosphate concentrations (Table 2, runs 2–3) in the aerobic-anoxic effluents were close to the discharge limit (3.5 mg P/l). In spite of 63% removal of phenolic compounds during the aerobic-anoxic stage, colour removal accounted for only 8–23% (Table 2, runs 2–3). Thus, the visible colour is mainly associated with the other than phenolic compounds (e.g., persistent to biodegradation melanoidins according to our own (Gladchenko *et al.*, 2004) and literature data (Francisca Kalavathi *et al.*, 2001)).

Performance of coagulation step

Some results for treatment of aerobic-anoxic effluents are presented in Table 3. It is seen that all targeted parameters (total COD, total N, phosphate, ammonia and colour) decreased with increasing acting metal concentrations and the discharge limits are already achievable under concentrations of 275, 375 and 1,790 mg/l for Fe, Al and Ca (for the latter, except COD limit), respectively. The colour of wastewater underwent dramatic changes from deep brown to pastel yellow after coagulation under these coagulant concentrations. These results are superior (with regard to coagulant added) to those reported in the literature for only anaerobically treated baker's yeast wastewater (Mutlu *et al.*, 2002). It is likely that the additional removal of COD (and partly colour) which occurred on an aerobic-anoxic step led to significant economy in coagulant addition. The sludge formed was relatively voluminous and had ~50% VSS content (Table 3). The addition of polyelectrolyte (Praestol 650 BC, Stockhausen) in concentrations 10 mg/l can enhance coagulation and decrease the volume of the sludge formed (data not shown). Since the concentration of applied polyelectrolyte was low, it is not expected that problems will be encountered with disposal of such sludge on municipal landfills.

Conclusions

The UASB reactor was quite efficient for removal of bulk COD (52–74%) from the raw and diluted cultivation medium obtained after the first separation of yeasts.

The aerobic-anoxic biofilter can be used for removal of remaining BOD and ammonia from anaerobic effluents; however, it suffered from COD-deficiency to fulfil denitrification requirements. To balance COD/N ratio, some bypass of raw wastewater should be added to the biofilter feed.

The application of coagulation for post-treatment of aerobic-anoxic effluents can fulfil the discharge limits to the sewer (even for colour exerted by hardly biodegradable melanoidins), however, the required amount of inorganic coagulants was relatively high.

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