Environment Protection Engineering

Vol. 10 1984 No. 3

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TREATMENT OF THE BREWING WASTEWATER

Concentration of industrial activities in Alexandria has led to disequilibrium in the ecological balance and significant deterioration in the quality of the environment. The Pyramids Brewery in Alexandria is, amongst many other industrial plants, a source of concentrated wastewater which is directly discharged to the public sewers.

The object for the study presented in this paper was to evaluate practical techniques for the treatment of this brewing wastewater. The results obtained indicate that the malting and utilities effluents may be discharged to the sewerage system. The brewing wastewater must be, however, pretreated in the physicochemical–biological combined system before the discharge, and the quality of the treated wastewater is not suitable for reuse in the plant.

1. INTRODUCTION

During the last two decades, concentration of industrial activities in Alexandria has led to disequilibrium in the ecological balance and significant deterioration in the quality of the environment. It is recognized now that long-term unplanned industrial development cannot be continued because of adverse environmental impacts, and some controls should be implemented. The Egyptian government is considering several measures for abating industrial pollution, among which are the following ones: a) direct charges on industrial effluents as an incentive to reduce pollution emissions, b) imposition of effluent standards to limit discharge of pollutants into water courses and sewerage system, and c) subsidies to promote pollution control through installation of end-of-pipe treatment facilities.

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The Pyramids Brewery in Alexandria is a source of concentrated wastewater which is directly discharged to the public seweres without treatment. The effluent can be subject to biological treatment, however, operation of on-site treatment system has been hindered by serious technical and economic problems.

The objective of the study was to evaluate practical techniques for treatment of wastewater generated from high pollution sources in the brewing industry. This objective was achieved through the performance of an experimental scale treatment system. Criteria and procedures for assessing treatment efficiency are detailed hereunder.

2. BACKGROUND

The Pyramids Brewery has a bottling capacity of 1.5 million bottles per month (1 million liters). The plant operates one 9-hours shift daily and utilizes about 200 t of malt, rice and hops per month.

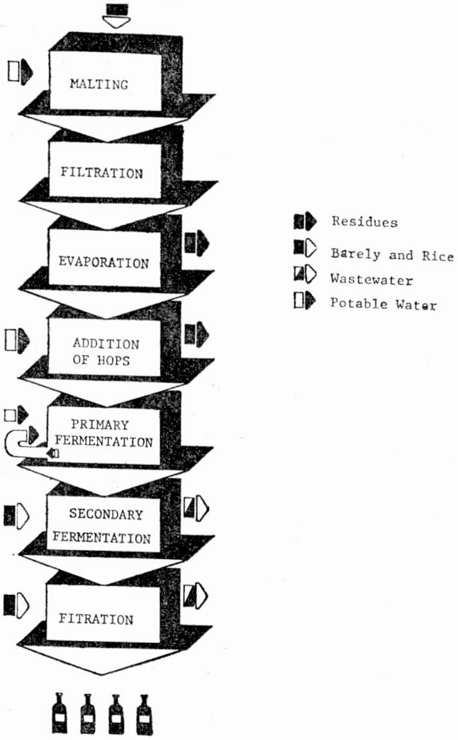

Fig. 1. Schematic diagram of processing operations at Pyramids Brewery
Rys. 1. Schemat blokowy procesu produkcji w browarze „Piramidy"

As shown in fig. 1, the brewing of beer proceeds in two stages, malting of barley and brewing the beer from malt. The malting process consists of conversion of starch contained in barley and rice into sugars through germination, using air and water to stimulate enzymatic activity. After one week the malt is filtered and the supernatant is evaporated until sugar concentration reaches 11.5%. The residue of the filtration process is sold as fodder. Wastewater generated from the malting process amounts to 30.7% of the total effluent (tab. 1) and originates from the cleaning of malting tanks and filters.

In the brewing process, hop is added (1.9 g/dm^3) to give the characteristic aroma. Primary fermentation lasting for 8 days is performed at 8–9°C using pure culture of *Sacharomyces cervisica*. The residue of the fermentation is recycled with fresh culture to be used for fermentation of the next batch. Secondary fermentatin under anaerobic conditions is performed at 1°C for three weeks. At the end of the fermentation process, globulin is added to the supernatant to aid the coagulation of suspended residue.

The supernantant is then filtered and bottled. The wastewaters of the brewing process amount to 42.8% of the total effluent and are discharged intermittantly as beer slops and wash water of the fermentation tanks and filters.

The untreated combined effluent, discharged to the municipal sewers, causes operational problems for the operation of the system and the treatment process. A preliminary investigation of effluents from the Pyramids Brewery indicated that malting and utilities effluents can be discharged directly to the municipal sewers, while brewing wastes should be pretreated before their final disposal or reuse at the plant (tab. 1).

Pollock [3] reviewed malting and brewing processes in terms of major by-products which could be used to increase the profits. They include recycling for water savings, alcohol recovery from waste beer, and drying of residues for animal feed.

In several publications the variants of biological treatment are discussed. A full-scale shaft treatment facility was installed at a brewery in Canada to meet limitations of the admissible value of BOD (300 mg/dm^3) and SS (350 mg/dm^3) (Gallo and Sanford [2]). Zahid [6] reported that bench-scale continuous flow activated sludge reactors removed more than 90% of the incoming BOD and had comparatively good settling organisms when a loading of 2 kg COD/kg MLSS/day was applied. Bulking was observed at both lower and higher loadings.

Seyfried [4] concluded that physicochemical treatment was unsatisfactory even with the addition of coagulants and other additives such as alum, lime, ferric chloride, iron, bentonite, activated charcoal, and soap. However, Charret [1] claimed that in a commercial process, AMINODAN, 70% of BOD is removed in a chemical coagulation and flotation. The process is applicable to brewery and distillery wastes.

Characteristics and flow rates
Charakterystyka i ładunek

Process		Flow m³/month	Flow %	pH(R)	Turb. NTU
Malting	$\overline{X}$	7290	30.6	6.2 –	62
	SD	3200		6.4	12
Brewing	$\overline{X}$	10210	42.9		
	SD	2810			
a) Primary fermentation	$\overline{X}$			5.2 –	136
	SD			5.7	92
b) Cleaning of tanks (2-ry fermentation)	$\overline{X}$		A	4.6 –	100
	SD			5.0	23
Bottling	$\overline{X}$	2010	8.4	11.4 –	8
	SD	818		11.8	1
Utilities	$\overline{X}$	4300	18.1	7.8 –	35
	SD	1250		8.4	7
Malting, bottling and utilities	$\overline{X}$			8.8 –	29
	SD			9.4	5
Total	$\overline{X}$	23810	100		

Estimated wastewater from secondary fermentation is 25 % of the brewing effluent.

3. EXPERIMENTAL PROGRAM AND PROCEDURES

Precoagulation experiments were conducted using six-gang floc stirrer with an adjustable paddle speed. Preliminary investigations were based on visual observations of floc formation and removal of turbidity. The following chemicals were tested for flocculation activity: alum (50–1000 mg/dm³) with Hercules anionic polymer 818 PWG (1–5 mg/dm³), ferric chloride (100–200 mg/dm³), lime (2–4 g/dm³), and ferrous sulfate (50–150 mg/dm³). Except for ferrous sulfate, all other coagulants were ineffective due to virtual absence of floc formation.

Table 1

of effluents from the Pyramids Brewery
ścieków z browaru „Piramidy"

Cl^-	$SO_4^=$	PO_4^{-3}	NO_3^-	TS	SS	VS	BOD	COD
mg/dm³								
125	95	250	15	470	44	409	520	734
15	17	30	2	27	13	89	128	198
194	433	364	133	8963	5363	6253	11250	15390
39	122	89	39	1436	892	2132	3450	4500
180	268	440	75	5445	2578	3887	2357	3560
35	88	80	27	1236	1235	984	259	367
140	60	157	13	814	28	720	430	520
24	10	22	3	17	3	136	132	241
120	73	58	12	392	136	326	234	353
42	21	7	3	73	23	89	56	113
135	85	259	17	623	58	536	366	543
22	20	68	4	136	32	234	98	217

Number of observations = 5, $\overline{X}$ = average, SD = standard deviation, (R) = range.

The continuous treatment system consists of multicompartment physicochemical unit and complete mix activated sludge unit. The physicochemical unit includes flash mixing, flocculation, classification, and filtration sections.

The feeding of sodium hydroxide for pH adjustment, ferrous sulfate and brewing waste was achieved by Master Flex multi-head pump model 7536-00. The pH of the waste was adjusted to 9–9.5 by pH controller (Coli-Parmer Model 5651-00). The activated sludge unit was fed continuously and air flow to the aeration section was monitored by YSI DO meter model 57 to maintain DO level of 2–3 mg/dm³.

In the raw waste and effluent of each treatment process turbidity (turb.), settleable solids (Set. S.), suspended solids (SS), volatile solids (VS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were the parameters monitored daily.

For assimilation of pollutants in biological systems, microorganisms utilize oxygen for growth and endogeneous respiration. Microorganisms growing in industrial effluent have different respiration activities expressed in oxygen uptake rate (mg $O_2/dm^3/h$) depending on the substrate concentration. A fixed volume of 50 cm^3 of the activated sludge was added to 15, 20, 25, 30, 35, 40, 45, and 50 cm^3 of four effluents (1 ray and 2 ray fermentation, malting and utilities). The volume of the mixture was adjusted to 100 cm^3 by addition of fresh sewage. The content of reaction vessel was stirred for 15 min at constant speed of 200 rpm and kept at 20°C. At the end of the reaction period, the dissolved oxygen reduction was continuously recorded and the oxygen uptake rate was calculated for various dilutions of the tested effluents, and plotted against their total organic carbon (TOC) content.

Analytical procedures and measurements of trace metals were in accordance with the *Standard methods for examination of water and wastewater* [5].

4. RESULTS AND DISCUSSION

Considerable variations in the quality and quantity of the brewery wastewater are attributed to batch processing and seasonal fluctuations in production rate. Peak production and increased waste emissions were noted during May through September. Table 1 presents data for flow characteristics of processing effluents. The results indicate that effluents of malting, bottling and utilities may be discharged directly to municipal sewers, while brewing effluents have high organic content in terms of BOD, COD and SS, and must be pretreated at the plant before disposal to the sewerage system.

The wastewater originated from the brewing does not contain sufficient concentrations of nutrients (ratios of BOD/N and BOD/P were 36/1 and 170/1, respectively). The deficiency of nutrients was supplemented through addition of urea and H_3PO_4. Despite the variations in characteristics of brewing effluents, efforts were made to keep an approximate balance of BOD/N/P of 100/5/1.

Foam formation was frequently observed in the aeration tank. The foam entrapped biosolids and accumulated as a crust layer, or flowed out of the unit. Locally produced anti-foaming agent (BW-15) was used to prevent foam formation.

The results of phase I experiments shown in tab. 2 indicate that precoagulation with Fe_2SO_4 is essential for reducing the concentration of solids and soluble organics in the brewing effluent. Optimum precoagulation was achieved by using a dose of 100 mg Fe_2SO_4/m^3. A slight increase in the removal efficiency by a further increase of the Fe_2SO_4 dosage does not justify the use of higher coagulant doses.

The quantities of sludge wasted daily and sludge recycling in the activated sludge unit were controlled to give the sludge age ranging from 5 to 48 days in phase II experiments. The sludge age was calculated as the ratio of the total amounts of mixed liquor suspended solids (MLSS) to the daily sludge wastage including suspended solids associated with the treated effluent. The F/M was

Table 2

Summary of the treatment performance of the brewery wastewater
Wyniki oczyszczania ścieków z browaru

Exp.		pH*	Turb. NTU	Set. S cm^3/dm^3	SS mg/dm^3	VS mg/dm^3	BOD mg/dm^3	COD mg/dm^3
Phase I. Precoagulation with Fe_2SO_4								
Raw waste	$\overline{X}$	4.3	108	42	3243	4546	4520	8365
50 mg/dm^3	E	9.6	59	43	41	34	28	31
Fe_2SO_4 100 mg/dm^3	E	9.4	76	59	64	51	36	34
150 mg/dm^3	E	9.8	78	65	69	59	39	36
Phase II. Physicochemical–biological treatment								
1. Raw waste	$\overline{X}$	4.6	122	46	2932	4635	3984	7639
A.T. = 14.3 h	E_1	9.3	74	62	63	48	30	30
	E_2	9.2	56	65	59	50	62	73
	E_T		89	87	85	74	73	81
2. Raw waste	$\overline{X}$	4.5	118	41	3428	4231	4563	7481
	E_1	9.4	76	56	68	52	31	27
A.T. = 24.4 h	E_2	29.2	67	68	73	69	76	78
	E_T		92	86	91	85	83	84
3. Raw waste	$\overline{X}$	4.6	103	51	3246	4582	4029	7136
	E_1	9.5	73	59	65	50	28	26
A.T. = 36.2 h	E_2	9.6	70	73	78	74	84	83
	E_T		92	89	92	87	88	87
4. Raw waste	$\overline{X}$	4.2	113	54	3936	4238	3921	8413
	E_1	9.7	80	65	68	46	29	28
A.T. = 49.2 h	E_2	9.5	72	69	79	75	87	86
	E_T		94	89	93	87	91	90

* – absolute value, E_1 – percentage removal after treatment with Fe_2SO_4 (100 mg/dm^3), E_2 – percentage removal after activated sludge treatment, E_T – overall percentage removal, A.T. – aeration time. Data are averages of three observations.

calculated as the ratio of BOD load to the MLSS per day. The effluent BOD concentration was the function of both the sludge age and the F/M ratio as shown in fig. 2. The BOD of the treated effluent was directly proportional to the F/M ratio. On the other hand, increase in the sludge age from 6 to 28

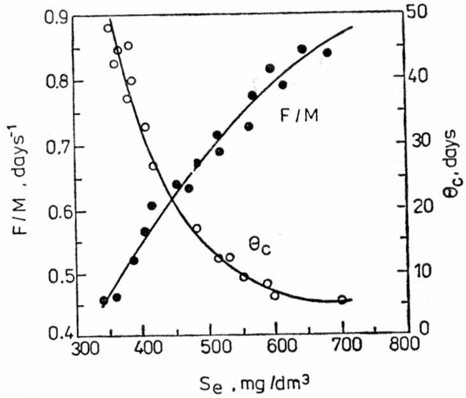

Fig. 2. Relation between effluent BOD, sludge age and F/M
Rys. 2. Zależność między BZT wycieku, wiekiem osadu i F/M

days produced significant decrease in the effluent BOD. Further increase of the sludge age to 48 days did not significantly affect the effluent BOD. The relation between the effluent BOD and both F/M and sludge age can be expressed by the following equations.

$$X = 650e^{-0.014\Theta_c}, \quad R^2 = 0.93,$$

$$X = 155e^{1.7F/M}, \quad R^2 = 0.99$$

where:

X – effluent BOD, mg/dm³,
F/M – food to microorganism ratio, days^{-1},
Θ_c – sludge age, days,
R^2 – coefficient of determinaton.

The results of tab. 2 and fig. 3 indicate a progressive improvement in the treatment performace by increasing the aeration time to 36 h. The aeration time extended to 48 h resulted in minor increases of the percentage removal of BOD and COD.

Figure 4 illustrates the relation between the oxygen uptake rate and the TOC of various mixtures of effluents and activated sludge. All the kinds of effluents are biodegradable. The results demonstrate also the favourable effect of dilution of the concentrated brewing effluents, since a decrease of the ratio of TOC of the brewing wastes to that of the activated sludge was always associated with significant increase in the oxygen uptake rate.

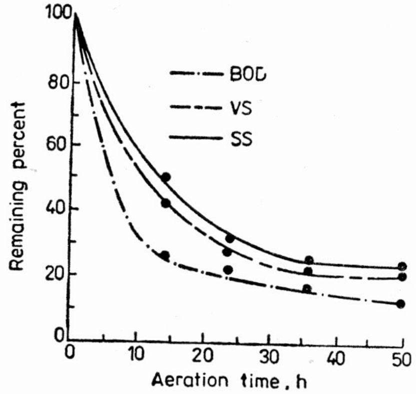

Fig. 3. Effect of aeration time on removal of pollutants
Rys. 3. Wpływ czasu napowietrzania na usuwanie zanieczyszczeń

The percentage removals of chromium, zinc, iron, manganese, copper, cadmium, lead, and nickel as functions of the sludge age are shown in fig. 5. The removals of nickel, lead and cadmium, were lower than 11 %, 17 % and 23 %, respectively. The removal of these metals was apparently independent of the

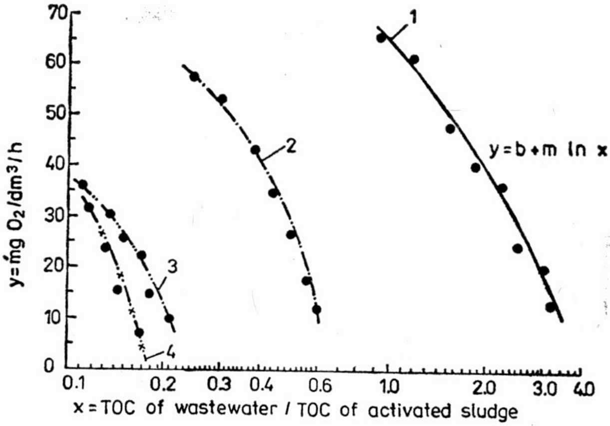

Fig. 4. Effect of TOC on oxygen uptake rate for malting and brewery processing effluents

	b	m
1 – primary fermentation	67	–43
2 – secondary fermentation	–14	–54
3 – malting effluent	–80	–57
4 – utilities effluents	–130	–75

Rys. 4. Wpływ całkowitej zawartości węgla organicznego na tempo pobierania tlenu podczas słodowania i oczyszczania ścieków browarniczych

	b	**m**
1 – fermentacja pierwotna	67	–43
2 – fermentacja wtórna	–14	–54
3 – odciek ze słodowania	–80	–57
4 – odcieki użyteczne	–130	–75

sludge age and the MLSS. It may be concluded that during the treatment these metals remained in soluble nonreactive forms. The removals of iron, manganese and copper were moderate (35–70 %). The increase in the removal percentage of iron was closely correlated to the increase in the sludge age. This is attributed to the increased adsorption of iron onto the suspended solids of the

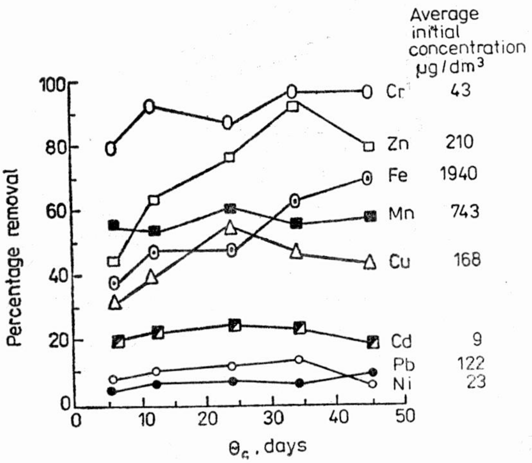

Fig. 5. Influence of sludge age Θ_c on percentage removal of trace metals in the brewery wastewater

Rys. 5. Wpływ ścieku osadu Θ_c na procent usuniętych metali śladowych w ściekach browarnianych

MLSS which increased with the sludge age. A sharp increase in the removal percentage of zinc was noticed when the sludge age increased from 6 to 36 days and was followed by inexplicable drop at the sludge age of 45 days. The removal of chromium was always higher than 80 % and generally increased with the sludge age.

5. CONCLUSIONS

1. Brewing wastes are heavily polluted and sludge discharged.

2. The waste is biodegradable, it is, however, essential to apply precoagulation with 100 mg Fe_2SO_4/dm^3 to reduce the organic load of activated sludge system.

3. For the brewing wastes it is recommended to use 36 h aeration.

4. With the increasing sludge age the percentage removal of chromium, zinc and iron increased except for the removal of manganese, copper, cadmium, lead, and nickel which were not correlated with the sludge age.

5. The results indicate that the malting and utilities effluents may by discharged to the sewerage system. The brewing effluent must be, however, pretreated by physicochemical–biological system before the discharge to public sewers.

6. The quality of the treated brewing wastewater is not suitable for reuse in the plant.

ACKNOWLEDGEMENTS

This research was funded by USEPA grant No. 3-542-4. The author would like to extend his appreciation to the Staff of the Industrial Waste Research Center, Alexandria University, for their invaluable help.

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OCZYSZCZANIE ŚCIEKÓW SŁODOWNICZYCH

Uprzemysłowienie Aleksandrii doprowadziło do naruszenia równowagi ekologicznej i wyraźnego pogorszenia warunków naturalnych w tym rejonie Egiptu. Browar „Piramidy" jest źródłem stężonych ścieków, które są odprowadzane bezpośrednio do systemu ścieków komunalnych.

Celem przedstawionych badań było znalezienie praktycznych technik oczyszczania tych ścieków. Uzyskane wyniki wskazują, że ścieki słodownicze mogą być odprowadzane bezpośrednio do kanalizacji, ścieki browarnicze natomiast muszą być uprzednio oczyszczone metodami fizykochemicznymi i biologicznymi. Jakość oczyszczonych ścieków jest niestety niewystarczająca do ponownego użycia ich w browarze.

DIE REINIGUNG DER ABWÄSSER VON EINER ÄGYPTISCHEN BRAUEREI

Als Resultat der industriellen Entwicklung Alexandriens (Ägypten) nimmt die Umweltverschmutzung in diesem Gebiet laufend zu. Die Brauerei „Pyramiden" erzeugt eine große Menge von hochkonzentrierten Abwässern, die in die städtische Kanalisation ohne Reinigung eingeleitet werden. Es wird versucht, eine optimale Wahl von Reinigungsverfahren durchzuführen.

Die Versuchsergebnisse weisen darauf hin, daß die Mälzereiabwässer in die städtische Kanalisation eingeleitet werden dürfen, während die Einleitung des Brauereiabwassers nur nach einer intensiven biologischen und chemischen Behandlung erfolgen kann.

Die Qualität der gereinigten Abwässer gestattet keine Wiederverwendung.

ОЧИСТКА СТОЧНЫХ ВОД СОЛОДОВНИ

Индустриализация Александрии привела к нарушению экологического равновесия и заметного ухудшения природных условий в этом районе Египта. Пивоваренный завод ,,Пирамиды" является источником концентрированных сточных вод, которые отводятся непосредственно в систему комунальных сточных вод.

Целью представленных исследований был поиск практических техник очистки этих сточных вод. Достигнутые результаты показывают, что сточные воды солодовни могут отводиться непосредственно в канализацию, сточные же воды пивоваренного завода должны предварительно очищаться физикохимическими и биологическими методами. Качество очищенных сточных вод, к сожалению, не достаточно для повторного их использования на пивоваренном заводе.