

Evaluation of a laboratory-scale biological process for the treatment of edible oil effluent[#]

SP Mkhize, BW Atkinson and F Bux*

Centre for Water and Wastewater Research, Technikon Natal, PO Box 953, Durban, 4000, South Africa

Abstract

The discharge of poor quality effluents by the edible oil refining industry in South Africa is posing a serious threat to water sources and wastewater treatment installations alike. The main objective of this study was to assess the efficiency of a laboratory-scale activated sludge treatment process in producing a final effluent conforming to regulatory standards with regards to COD and phosphate loads. The study was conducted in three principal stages: waste characterisation; treatability studies and laboratory-scale investigations. After analysing various raw effluent parameters, treatability studies were conducted using an anaerobic/aerobic sequencing batch reactor (SBR). The results showed 75% influent COD (S_o) reduction and more than 90% removal of oils and suspended solids. Based on the results from waste characterisation and treatability studies, a continuous laboratory-scale nutrient removal system was designed. The reactor was operated on a fed-batch basis for 15 d resulting in 70% S_o and 4% phosphate reduction. Poor phosphorus (P) removal was attributed to a small anaerobic sludge mass fraction. The system was then operated continuously with structural changes to the reactor. A COD and phosphate reduction of 44% and a 36%, respectively, was achieved at an organic loading rate of 0.5 kgCOD/kgMLSS·d⁻¹.

Introduction

There are 16 operational edible oil processing plants in South Africa which produce approximately 3×10^5 t of vegetable oil annually, concomitantly consuming nearly 2×10^6 m³ of water. Potentially potable water entering these processing plants is either discharged to sewers or vaporised in cooling circuits (WRC, 1989). Quantity and physico-chemical characteristics of the effluents produced vary considerably for different refineries. Characteristic of the specific effluent is the high quantity of fats, oils and grease (FOG), sulphates and phosphates resulting in both high inorganic as well as organic loading of the respective wastewater treatment works.

Crude oils, particularly soybean oil, contain significant quantities of organic phosphorus in the form of phosphatides. These compounds are removed to a large extent from the oil phase in the refining process. If refinery wash waters and soap stock are acidified, P is then translocated to the water phase (Boyer, 1996). The process of edible oil refining includes neutralisation of free fatty acids, removal of gummy materials and colour and deodorising. Generally, the first three stages of refining are carried out in the same reactor as a batch process that produces a soap stock from which fatty acids are recovered by means of acid splitting. Acid splitting is carried out through addition of sulphuric acid to the soap stock which causes free fatty acids to be separated from the medium. The resulting effluent is highly acidic, with an average pH of 1.7 and average sulphate content of 4 000 mg/l (Eroglu et al., 1990; Boyer, 1996). Previous studies have shown that fatty materials within waste streams from food industries are readily biodegradable and it therefore follows that these effluents are amenable to biological treatment (Eroglu et al., 1990).

South African oil industries generally use two methods for effluent treatment: physical separation of oil and grease using dissolved air floatation (DAF) and pH control (WRC, 1997). Even after application of these methods, the remaining emulsified grease tends to clog the sewer pipes and pumps and the high COD and phosphate concentrations create shock loading problems for receiving wastewater treatment plants (Eroglu et al., 1990).

The main aim of this study was to design a laboratory-scale biological treatment process (for possible integration as an on-site remediation process) that would produce an edible oil effluent with an acceptable COD and phosphate content, in terms of regulatory standards, prior to discharge to municipal sewer systems.

Methods and materials

Wastewater characterisation

Composite wastewater samples from an edible oil refining industry situated in Pietermaritzburg (South Africa) were collected, prepared and analysed (*Standard Methods*, 1985) for parameters considered necessary for waste characterisation and system design (Table 1).

Laboratory-scale investigations

Laboratory-scale investigations were conducted in three phases. Phase 1 consisted of a semi-continuous (fed-batch) operation; during Phase 2, the system was operated on a continuous basis at high organic and phosphorus loading rates. The system was operated in a similar fashion during Phase 3 but at relatively lower organic and phosphorus loads. Based on waste characterisation studies, a 2-stage activated sludge system (alternating anaerobic/aerobic reactors) was selected to accomplish treatment. An anoxic zone was omitted from the design due to the low nitrogen content of the effluent. Operating capacities of the various zones were as follows: 1 000 m³ for the anaerobic reactor; 4 000 m³ for the aerobic reactor; and 1 800 m³ for the clarifier.

During Phase 1 of the study, the anaerobic and aerobic reactors

Revised paper. Originally presented at the WISA Conf., 28 May - 1 Jun 2000, Sun City, South Africa.

* To whom all correspondence should be addressed.

☎(031)204-2346; fax (031)204-2714; e-mail: faizalb@umfoloji.ntechn.ac.za
Received 15 May 2000; accepted in revised form 4 September 2000.

TABLE 1
Characteristics of edible oil refining wastewater for periods evaluated (values represent range and mean of three samples per month)

Parameter (mg/l except pH)	June		July		August		September		October	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
pH	4.95-5.89	5.55	8.76-10.6	9.8	5.71-6.99	6.5	7.1-8.05	7.7	7.61-9.93	8.6
COD	7 590-7 680	7 630	7 550-8 710	8 160	1 025-1 270	1 155	7 240-7 590	7 400	11 700-11 810	11 763
PO ₄ ³⁻ (-P)	500-590	550	910-1140	1 020	1 640-1 680	1 660	4 320-4 510	4 400	2 110-2 180	2 140
TKN (-N)	6.08-7.96	6.93	3.21-6.26	4.78	6.54-7.19	6.82	6.98-8.67	7.65	4.36-5.81	4.98
NH ₄ ⁺ (-N)	0.98-1.51	1.25	0.41-0.76	0.6	1.39-2.62	2.0	1.09-1.21	1.15	2.09-3.6	2.69
SO ₄ ²⁻	4 980-5 910	5 550	5 280-5 830	5 600	3 410-3 530	3 470	5 690-5 980	5 800	1 170-1 400	1 260
Lipids	248.8-266.5	255.6	102.8-120.8	111.1	324.8-352.1	339.9	581.4-630.8	627.8	297.2-319.3	308.2
TSS	239.2-281.1	265.2	379.3-387.8	383	97.7-134.1	111.5	255.6-274.2	265.2	309.2-340.2	322.3
Alkalinity	487-542	520	465-492	480	1670-1760	1 720	616-649	630	742-778	766

were operated at working volumes of 340 ml and 4 000 ml, respectively. Final MLSS was adjusted to 4 300 mg/l and maintained between 4 000 and 4 300 mg/l through hydraulic control. The system was fed diluted vegetable oil wastewater with an average COD of 3 850 mg/l, orthophosphate concentration of 2 155 mg/l and TKN of < 7 mg/l. The reactor was operated semi-continuously for 15 d at a hydraulic retention time (HRT) of 24 h, food: micro-organism (F:M) ratio of 1.0 kgCOD/kgMLSS·d⁻¹ and sludge age (R_s) of 30 d to simulate extended aeration processes.

Prior to Phase 2 of the study, fresh seed mixed liquor was collected and used to inoculate the system. The anaerobic reactor and secondary settling tank volumes were maximised to 1 000 ml (working volume) and 450 ml, respectively, in order to improve system performance in terms of phosphorus reduction. An increased anaerobic reactor volume would effectively increase contact time for fermentation of readily biodegradable COD (RBCOD) to volatile fatty acids (VFA) which are sequestered by the poly-phosphate-accumulating organisms (PAOs). Reducing the size of the secondary clarifier would prevent the onset of anaerobiosis and subsequent secondary phosphorus release.

During Phase 2, influent flow rate (Q_i) was maintained at 5 l/d; clarified sludge was recycled (s-recycle) at a rate of 3Q_i. The F:M ratio was also increased to 1.5 kgCOD/kgMLSS·d⁻¹. Influent had a relatively low phosphorus concentration, ranging from 430 mg/l to 450 mg/l PO₄³⁻-P. HRT was maintained at 24 h and R_s was reduced to 15 d. The reactor was operated at ambient temperature (ca. 25°C ± 5°C) and pH maintained at 7.0 (± 0.2) using dilute (1 M) hydrochloric acid.

Phase 3 of the study was initiated using the same operating parameters as in Phase 2, except that F:M ratios were decreased to 0.5 kgCOD/kgMLSS·d⁻¹. Influent was supplemented with 0.01 M sodium acetate tri-hydrate (1.75 g/l) to increase the anaerobic VFA concentration.

Results and discussion

Wastewater characterisation studies of composite samples indicated that wastewaters from the edible oil refining industry contain both high organic and P loads. The nitrogen content (as TKN) of the vegetable oil effluent was found to be below 10 mgN/l. The effluent would therefore either require nitrogen supplementation or treatment using a 2-stage nutrient removal process incorporating carbon and P removal. Boyer (1996) reported that vegetable oil

effluent could be effectively treated in full-scale wastewater treatment installations when it is diluted with domestic liquid wastes. Characterisation results of the raw oil wastewater samples during the present study are given in Table 1.

System performance during Phase 1 of the study showed 70% S_i removal but negligible removal of P (4.4%) (Figs. 1 and 2). Although it appears as if percentage phosphate removal was minimal, in real terms the system was actually removing ca. 102 mg PO₄³⁻-P/l, a result which may have possibly been elevated due to the phosphate analytical method error. The reduced P uptake capacity of the system was attributed to the insufficient anaerobic sludge mass fraction of 0.08. It is likely that synthesis of short chain fatty acids from the fermentation of influent RBCOD was incomplete and the full acetate complement was not realised (Ekama et al., 1984). The size of the settling tank also contributed to poor phosphate removal due to prevailing anaerobic conditions as a result of extended sludge retention times.

Once the anaerobic reactor volume was increased to a ratio of 0.2 (with respect to total system volume) and the settling tank volume was decreased, a slight improvement in phosphate removal was recorded, increasing to 8% during Phase 2 (Fig. 2). The gradual decline in COD removal was attributed to the high operational F:M ratio (1.5 kgCOD/kg MLSS·d⁻¹). Results after decreasing the organic loading rate (at constant P/COD ratios between Phases 2 and 3) showed an improvement in terms of P removal (Fig. 2). However, improved phosphate removal was coupled to a decline in COD removal (Fig. 1). This was attributed to increased dominance of PAOs over the non-PAOs in the activated sludge biota. Non-PAOs metabolise both readily and slowly biodegradable substrate in the presence of terminal electron acceptors whereas PAOs will take up and store readily biodegradable organics in the anaerobic zone (acetate supplementation to the influent). It is hypothesised that the PAOs were unable to efficiently utilise the initial biodegradable COD fractions within the influent wastewater.

Conclusions

Vegetable oil effluents can be successfully treated using biological methods as a form of pre-treatment. Although S_i values were considerably reduced during the present study, the effluent would require further polishing to ensure regulatory discharge standards are successfully adhered to. The waste requires dilution prior to

Figure 1
 S_{ii} and S_{ie}
 concentrations
 during Phases
 1 to 3 for
 laboratory-scale
 investigations

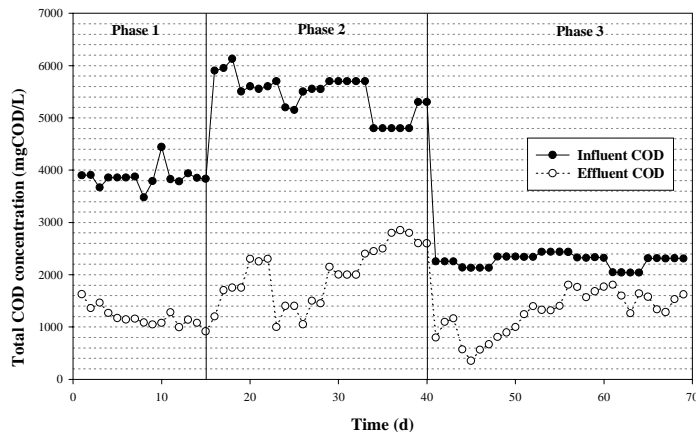
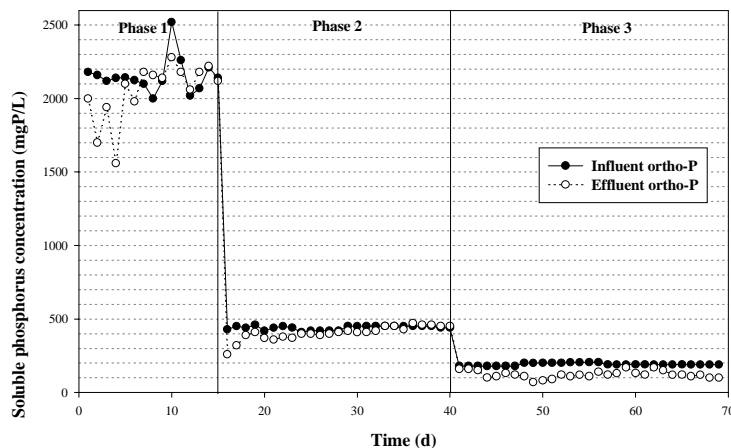


Figure 2
 Soluble influent and
 effluent
 orthophosphate
 concentrations
 during Phases 1 to
 3 for laboratory-
 scale investigations



treatment using domestic effluents to ensure that wastewater characteristics are more favourable to the application of biological remediation techniques, i.e. altering TKN/COD ratio and increasing RBCOD/ S_{ii} ratios. Effluent parameters are strongly dependent on the quality of crude oil and the refining method (physical or caustic) employed for the particular oil type. Additional P removal using chemical methods may be required prior to discharge to prevent shock loading of receiving wastewater treatment works. Current research is directed towards process optimisation to enhance biological remediation of edible oil effluents, including supplementation of the influent wastewater with nitrogen to improve C:N:P ratios.

Acknowledgements

The authors gratefully acknowledge the financial assistance of the Water Research Commission (Pretoria, South Africa) as well as the National Research Foundation (Pretoria, South Africa).

References

- BOYER MJ (1996) Environmental impact and waste management. In: *Bailey's Industrial Oil and Fat Products*. Vol. 4 (5th edn), John Wiley & Sons, New York. 631-655.
- EKAMA GA, MARAIS GvR and SIEBRITZ IP (1984) Biological excess phosphorus removal. In: HNS Wiechers, GA Ekama, GFP Gerber, GFP Keay, W Malan, GvR Marais, DW Osborn, AR Pitman, DJJ

- Potgieter and WA Pretorius (eds.). *Theory, Design and Operation of Nutrient Removal Activated Sludge Processes*, Water Research Commission, South Africa. 7.1-7.32.
- EROGLU V, OZTURK I, SAN HA and DEMIR I (1990) Comparative evaluation of treatment alternatives for wastewaters from an edible oil refining industry. *Water Sci. Technol.* **22** (9) 225-234.
- STANDARD METHODS (1985) *Standard Methods for the Examination of Water and Wastewater* (16th edn.) American Public Health Association, Washington DC, USA.
- WATER RESEARCH COMMISSION (WRC) (1989) *Water and Wastewater Management in the Edible Oil Industry*. Report No. TT 40/89, Water Research Commission, Pretoria, South Africa.
- WATER RESEARCH COMMISSION (WRC) (1997) *Operating Manual for Biological Nutrient Removal Wastewater Treatment Works*. Report No. TT 83/97, Water Research Commission, Pretoria, South Africa.
-