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THE AEROBIC TREATMENT OF GREASE-CONTAINING FAST FOOD RESTAURANT WASTEWATERS

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Fast food restaurants typically produce a low volume grease-containing wastewater, generated by their daily kitchen activities, for which there is currently no acceptable treatment technology. This paper describes the performance of a novel bioreactor, the weir tank reactor, for the treatment of fast food restaurant wastewater at an organic loading rate (OLR) of 5 kg wastewater m^{-3} d^{-1}. Two different mixed microbial cultures (one designated MC1, the other an activated sludge), were used together with fast food grease residues from two different sources (Woking, Surrey, and Birmingham, West Midlands). The reactor achieved a high (84–96%) removal of FOG (fats, oils and greases) irrespective of the microbial inoculum, the source of the FOG or the alkalinity (low or high) of the water. This high performance was attributed to a combination of the effective mechanical mixing regime and the periodic removal of a portion of microbial solids from the weir tank reactor liquor, in the form of an effluent, during the weir tank reactor studies.

Keywords: fats; oils; grease; biological treatment; fast food restaurants.

INTRODUCTION

Fast food restaurants typically produce a low volume grease-containing wastewater, generated by their daily kitchen activities. In the fast food industry, wastewater treatment has traditionally been minimal, since the only necessity has been to prevent floor drain blockages caused by grease deposits blocking sewer pipes. In this respect, the industry has been well served by the simple grease trap to intercept the grease, thus preventing blockages downstream. Grease traps are often neglected or poorly operated, resulting in odour nuisances[1] and sewer pipe blockages. Even in situations where grease traps are well maintained, the grease which is retained by them will have to be removed perhaps every three weeks[2].

A second level of technology, in operation at many fast food restaurants, involves the use of biological supplements—microbial or enzyme preparations and nutrient supplements—which would either be flushed through the sink and drain system[3] or added directly to the grease trap[1]. Biological/nutrient supplements should, therefore, result in a reduction in grease accumulation in the grease trap. However, work by Viridian Bioprocessing Limited (VBL) has shown that these supplements are expensive and can take time to work[2]. Despite the existence of several diverse products and services, currently available to fast food restaurants for tackling grease-related problems, none is considered by the restaurant managers to deliver an adequate performance. Therefore, there presently exists a technology gap in this market.

This paper describes the development of a novel bioreactor which can be used as a replacement for existing technologies for the treatment of fast food restaurant wastewater, thus eliminating grease deposits in sewer pipes and subsequent sewer pipe and floor drain blockage problems.

MATERIALS AND METHODS

Bioreactor

The weir tank reactor (WTR) was originally designed by VBL (UK Patent Application Number, 9321712.3). As used in this development study, it consisted of a rectangular polypropylene cistern (Merlin C4, Tanks and Drums, Bradford, West Yorkshire), with two chambers, a weir chamber and a main chamber. A baffle was used to separate the two chambers, and this resulted in the formation of a weir, as a direct result of the action of a recirculation pump, which connected these chambers. This cascading or 'weir effect' was an essential feature of the WTR, as it provided surface aeration to the WTR liquor, whilst the recirculation pump ensured that the WTR liquor was completely mixed. The recirculation pump consisted of an externally-mounted, 'washing machine' motor (Pompe SE 30.146RN, Selni Nevers, France) at the top of a stainless steel shaft, which was the driving force for an impeller in the volute at the base of the shaft. The pump volute was immersed directly into the weir chamber liquor and, as a result, liquor was sucked up into the volute and forced, by rotation of the impeller, through an outlet projecting into the main chamber. The pump shaft penetrated the cistern lid, which was used to cover the WTR during operation, therefore allowing air to flow in and out of the WTR. A schematic vertical section through the WTR is shown in Figure 1, and the dimensions and volumes of the component parts are given in Table 1. Subsequent to this study, the reactor has been scaled up[2] and is being marketed by VBL; the largest reactor in the range is capable of handling maximum flows of 3 l s^{-1}.

Microbial Inocula

An initial screening programme of microbial cultures capable of degrading grease trap residues identified two

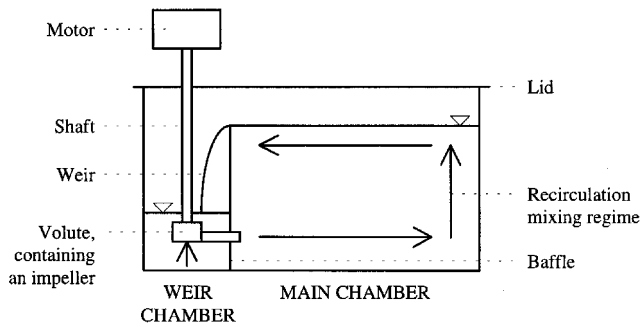

Figure 1. Schematic vertical section through the weir tank reactor.

potentially useful cultures; culture MC1 and activated sludge[4]. These were used in the WTR studies. MC1 was an unidentified consortium of Gram negative bacteria which had been isolated from grease trap residues from fast food restaurants by VBL and maintained as a stable mixed culture. The activated sludge was obtained from a local sewage treatment works, which was treating a raw wastewater containing an element of greasy material. The solids from both cultures were initially centrifuged ($g \times 2355$) for 30 seconds, and the supernatants were discarded. The solids were then resuspended to their original volumes with quarter-strength Ringer's solution. This procedure was repeated two more times, in order to remove all traces of residual carbon from the inocula.

Reactor Operation

In practice, the WTR will have to tolerate wide variations in water quality. For example, alkalinity varies considerably across the UK, and there were suggestions from work done by VBL (Internal Report QR 09/94) that this could affect performance of the WTR. Two types of water were, therefore, tested; one with a low alkalinity (WTR–1 and WTR–2), the other having a higher value (WTR–3 and WTR–4). A comparison of the essential components of all the trials is shown in Table 2.

Table 1. Dimensions of the weir tank reactor.

Component part	Dimension
Reactor	
Width	26.4 cm
Length	40.3 cm
Height	30.3 cm
Working volume	17.5 l
Weir chamber	
Width	26.4 cm
Length	10.1 cm
Height	19.2 cm
Working volume	1.5 l
Main chamber	
Width	26.4 cm
Length	30.0 cm
Height	19.2 cm
Working volume	16.0 l
Height of baffle	19.2 cm
Recirculation pump	
Inlet diameter	2.1 cm
Outlet diameter	2.4 cm

Table 2. Comparison of the essential components of the four trials.

Trial	Inoculum	Alkalinity	Fast food residue
WTR–1	MC1	Low	Woking
WTR–2	Activated sludge	Low	Woking
WTR–3	MC1	High	Birmingham
WTR–4	Activated sludge	High	Birmingham

The WTR was essentially operated on a fill-and-draw basis and so, in this respect, there were similarities in operation to that of a sequencing batch reactor, except that instead of attempting to retain all the microbial solids, a portion was periodically removed from the WTR liquor, in the form of an effluent. Each trial was initially operated as a batch process for 3–4 days during the start-up period, in order to encourage acclimatization of each microbial inoculum to the fast food restaurant wastewater. The WTR was supplied manually with wastewater and nutrients on weekdays and operated as a batch process over weekends. In each trial, the total run time was 33 days. This was deemed to be a sufficiently long period to demonstrate the feasability of the process and to provide data upon which a pilot scale reactor could be built. The composition of the influent is shown in Table 3.

The fast food restaurant grease trap residues, supplied by a major fast food restaurant chain, were initially melted at 80°C for 3 hours, and the upper hydrophobic grease layer, subsequently referred to as 'fast food restaurant residue', was removed for use in the WTR studies. Initially, this was obtained from Woking (WTR–1 and WTR–2), but later samples were, for convenience, obtained from Birmingham. Since they were from the same restaurant chain, few if any differences in the grease composition, were expected. Preliminary work had showed that these residues were deficient in nitrogen and phosphorus. In a commercial situation, cheap sources of these nutrients were required and, in this case, a mixture of three fertilizers was used so as to give a COD:N:P balance of about 100:10:1 (Table 3). The sodium carbonate concentration, used for WTR–1 and WTR–2, was that observed by VBL to be effective, in conjunction with the local, hard tap water, in suppressing mixed-liquor pH changes during the treatment process using culture MC1 (VBL personal communication). A higher sodium carbonate concentration was used for WTR–3 and WTR–4, in order to suppress the mixed-liquor pH changes subsequently observed during WTR–1 and WTR–2, which used Birmingham mains water (a soft water). The addition of feed to the WTR liquor required the temporary inactivation of the recirculation pump, followed by settling of the liquor for 10 minutes. Liquor was manually siphoned from the bottom of the WTR. Wastewater, nutrients and tap water were then added to the WTR liquor, and the recirculation pump was reactivated.

No heating mechanisms were supplied to the mixed-liquor. In this study, sufficient heat was generated from the operation of the recirculation pump to maintain a mixed-liquor temperature of approximately 30 ± 2°C. However, further work would be required during scale-up studies to determine whether heating was likely to be necessary. The operational parameters are shown in Table 4. The requirement for an influent wastewater concentration of 2% (w/v) and a 4 day hydraulic retention time (HRT) resulted in a

Table 3. Composition of the influent used in the trials.

Component	Concentration
Fast food restaurant residue: start-up	0.86% (w/v)
: operation	2.00% (w/v)
Nitrogen fertilizer (Cropsure, Essex)	0.22 g/g grease
Compound B505(Sheppy Fertilisers and Seeds, Isle of Sheppy)	0.02 g/g grease
Triple superphosphate (Sheppy Fertilisers and Seeds, Isle of Sheppy)	0.03 g/g grease
Sodium carbonate: low alkalinity	0.02 g/g grease
: high alkalinity	0.18 g/g grease

high organic loading rate (OLR), of 5 kg wastewater m^{-3} d^{-1} being used.

Sampling and Analyses

Samples (10 ml) of the mixed-liquor and effluent were taken regularly during each trial and analysed for fats, oils and grease (FOG), total suspended solids (TSS) and fatty acids. In addition, mixed-liquor pH and redox potential values were monitored. All parameters relating to the mixed-liquor were measured just prior to the settlement phase of the manual feeding regime.

FOG and TSS concentrations were measured using the methods described by Wakelin and Forster[4]. Gas chromatography was used to measure the fatty acid composition of the influent wastewaters, and the mixed-liquor and effluent FOG samples. Trimethylsulphonium hydroxide (TMSH) was used to form the fatty acid methyl esters which were the form required for GC separation. This is an esterification process which can be carried out at room temperature and, although it has been successfully applied to sample preparation in the analysis of fats and oils in food chemistry[5,6], it has not been evaluated or reported for wastewater samples. Methyl-*tert*-butyl ether was added to the FOG sample (50 mg), in a sample vial, to obtain a 20 mg ml^{-1} FOG concentration. Once the sample had dissolved in the ether, a portion (50 μl) was transferred to a smaller volume (1 ml) chromatography vial. TMSH (100 μl) was then added. The resultant solution (1 μl) was injected into the chromatograph.

The GC94 gas chromatograph (Ai Cambridge Ltd., Cambridge) contained a DB–225 capillary column (30 m length $\times$0.325 mm ID widebore, and 0.25 mm film thickness, J & W Scientific, Folsom, California, USA) and was connected to an IBM-compatible PC, which had been installed with a chromatography data analysis system (Summit, version 0.20, Comus, Kingston upon Hull). The operating conditions of the gas chromatograph are shown in Table 5. The system was calibrated with a standard mixture of fatty acid methyl esters, which had been derivatized with TMSH. The fatty acid profile of a series of fatty acid methyl esters in the range C3:0 to C22:0, after derivatization with TMSH, is shown in Figure 2. Trace quantities of FOG components, <0.5% (w/w) FOG, were not detected by gas chromatography. The fatty acid proportion and concentration data, provided by gas chromatography, were accurate to $\pm$ 5% ($n = 50$).

The pH was measured using a standard dual glass electrode, and the redox potential was measured using a platinum-pin redox electrode.The alkalinity of the tap water used in making up the reactor feed was determined using the standard titration method[7].

Table 4. Operational parameters used in the WTR trials.

Operational parameter		Value
Reactor		
	Inoculum size	10% (v/v)
	Hydraulic retention time	4 days
	Organic loading rate	5 kg m^{-3} d^{-1}
	Trial duration	33 days
Recirculation pump		
	Flow	1.1 l s^{-1}
	Impellor speed	2800 rpm

RESULTS AND DISCUSSION

A number of parameters were calculated in order to evaluate the performance of a particular bioreactor study. Bioreactor FOG removal and microbial FOG removal values were determined during each bioreactor study, and the FOG mass balance and overall yield coefficient values were determined at the end of each bioreactor study.

Bioreactor FOG removal (%) refers to the proportion of influent wastewater removed by the WTR during the bioreactor study.

Microbial FOG removal refers to the proportion of cumulative influent wastewater removed by the mixed-liquor micro-organisms during the bioreactor study:

$$\text{Microbial FOG removal (\%)} = \left[\frac{\sum(S_o v) - S_r V - \sum(S_e v)}{\sum(S_o v)}\right] \times 100 \quad (1)$$

Table 5. Operating conditions for the separation of fatty acid methyl esters by GC.

Control parameters	Control value
Number of ramps	3
Starting temperature	40°C
Ramp rate 1	20°C min^{-1}
Temperature 2	180°C
Ramp rate 2	2°C min^{-1}
Temperature 3	200°C
Ramp rate 3	3°C min^{-1}
Temperature 4	220°C
Total run time	35 min
Air flow rate	308 ml min^{-1}
Hydrogen flow rate	60 ml min^{-1}
Helium (carrier gas) flow rate	1.4 ml min^{-1}
Make-up gas (flow through detector)	50 ml min^{-1}
Injection port temperature	250°C
Detector temperature	260°C

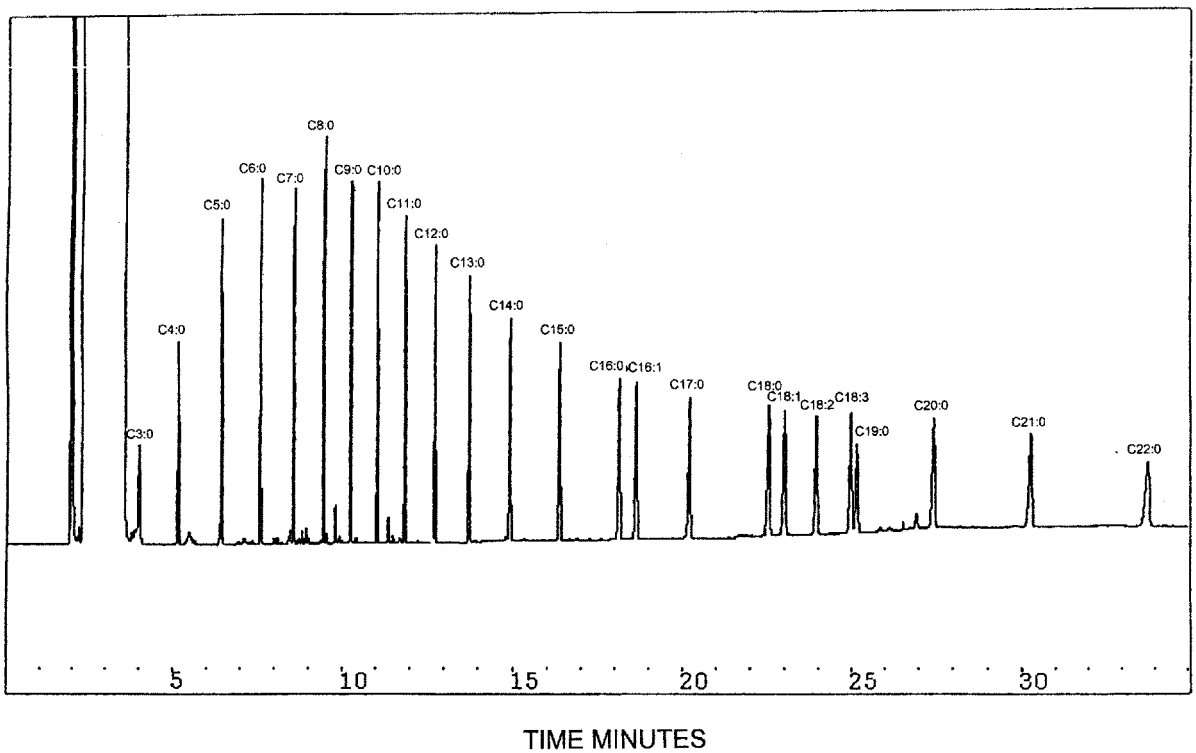

Figure 2. Gas chromatographic separation of fatty acid methyl esters derivatized with TMSH.

By doing a mass balance at the end of the reactor study (i.e., day 33), the accumulation of FOG could be determined. The yield coefficient is also an important parameter, since it quantifies the biomass production in terms of the substrate removed (equation (2)). As such, it is an important design parameter which is used to cost the sludge handling and disposal processes.

Overall yield coefficient

$$= \frac{(X_r V - X_o V) + \sum (X_e v)}{\sum (S_o v) - S_r V - \sum (S_e v)} \qquad (2)$$

The mean variability of replicate proportions of the individual components of the different sources of fast food restaurant wastewater, as determined by gas chromatography, was observed to be $\pm$ 5% ($n = 10$ for each wastewater) for the Woking and Birmingham sources. The mean variability of replicate bioreactor and microbial FOG removal values, and mixed-liquor and effluent TSS concentrations, was determined to be $\pm$ 2% ($n = 5$), whilst the mean variability of replicate mixed-liquor and effluent fatty acid concentrations, as determined by gas chromatography, was observed to be $\pm$ 5% ($n = 5$).

The fatty acid composition of the raw Woking and Birmingham fast food restaurant residues is shown in Figure 3 and confirms that the two materials were very similar, being essentially a mixture of C-16 and C-18 acids with a significant quantity of unidentifiable material. This would be expected from a major fast food restaurant chain whose restaurants would prepare the same menu items under the same cooking conditions in similar proportions, as well as using similar washing and cleaning regimes.

Two of the trials, WTR–1 and WTR–2, produced a two-phase mixed-liquor, containing small agglomerations or 'balls' of grease with a diameter of approximately 1 mm, whereas a frothy, single-phase mixed-liquor was observed during WTR–3 and WTR–4. However, a single-phase effluent was discharged from the WTR during all the trials. The only other operational problem which was noted was an apparent increase in the mixed-liquor working volume, a few hours after the addition of wastewater and nutrients to

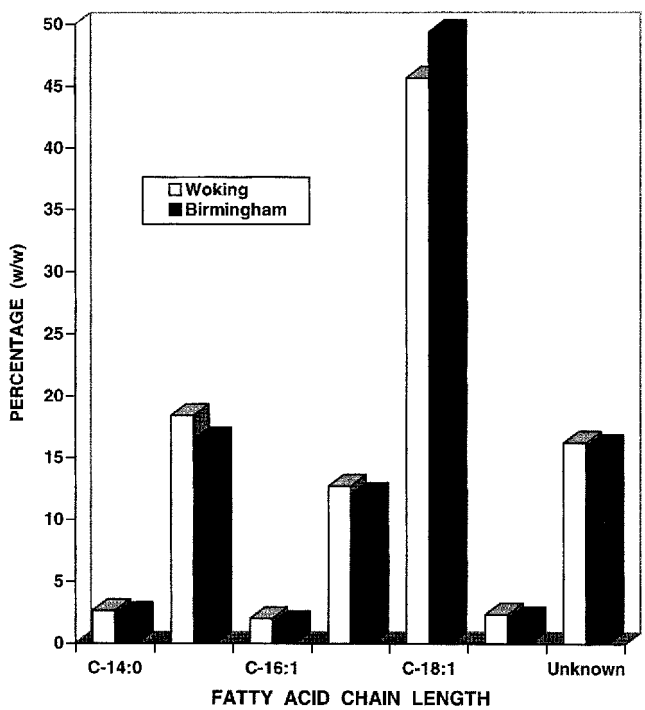

Figure 3. Comparison of the fatty acid composition of the two fast food restaurant residues.

Table 6. Performance data for the weir tank reactor trials showing the mean values and the standard deviations.

Parameter	WTR–1	WTR–2	WTR–3	WTR–4
FOG added, g	2075	1988	2075	2075
Fog accumulation, %	7.4	9.4	1.4	1.4
Yield, g g^{-1}	0.42	0.46	0.55	0.48
pH	1.9± 0.2	2.2± 0.3	7.7± 0.3	7.9± 0.4
ORP, mV	+ 345± 32	+ 322± 49	−91± 85	−65± 89
Temperature, °C	31± 2	29± 3	30± 2	32± 2

the WTR liquor (WTR–3 and WTR–4), with the result that the height of the weir drop was significantly reduced. This varied slightly during both trials.

The overall performance of the WTR (Table 6 and Figures 4–6) was exceptional in all the studies, irrespective of the microbial inoculum, the source of fast food restaurant wastewater or the alkalinity of the water. The bioreactor FOG removal values (Figure 4) were generally better than 90%, with WTR–4 showing slightly the better stability. The mean values varied between 91.4 ± 6.4%, for WTR–3, and 95.9 ± 2.4%, for WTR–4, which indicated that only a very low proportion of the grease residues in the influent was discharged, in the form of an effluent, from the WTR.

The microbial FOG removal values (Figure 5) also showed that WTR–4 had the greater stability. The data also show that the other trials did not stabilize for about 15 days and that their plateau values were lower than that achieved in WTR–4. The mean values varied between 84.7 ± 4.4%, for WTR–2, and 93.0 ± 2.6%, for WTR–4. Taken in conjunction with the bioreactor FOG removal values, this indicated that both culture MC1 and activated sludge could provide effective treatment. This notion was further enhanced by the FOG mass balance data, which showed a low FOG accumulation in all the trials.

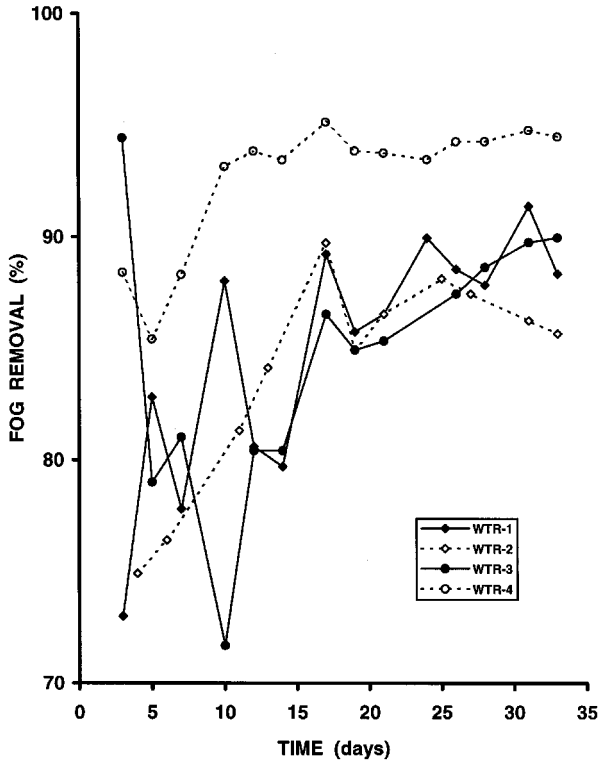

Figure 5. Microbial FOG removal.

The concentrations of fatty acid in the mixed-liquor and effluent (Table 7) did not indicate the formation of shorter chain length fatty acids or breakdown products, which

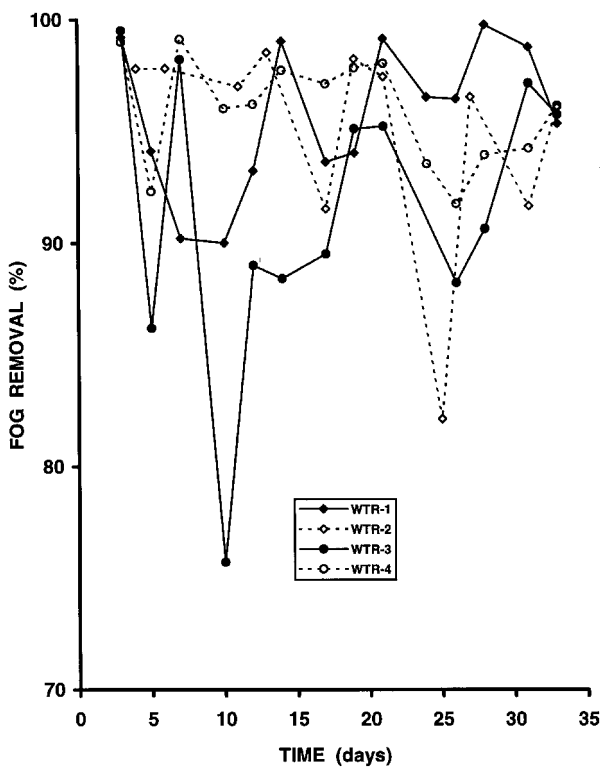

Figure 4. Bioreactor FOG removal.

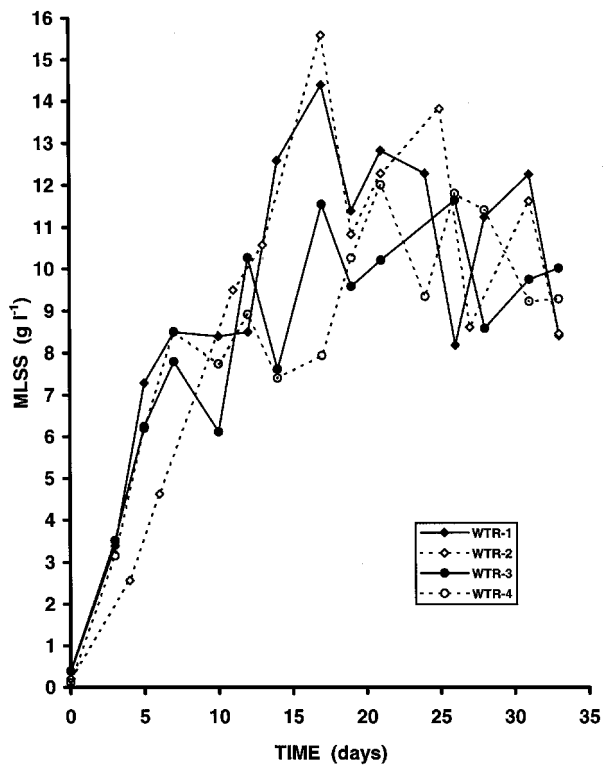

Figure 6. Variations in the mixed-liquour suspended solids (MLSS).

Table 7. Mean fatty acid concentrations (gl^{-1})in the mixed liquors and the effluents showing the standard deviations and the number of analyses (*n*).

Fatty acid	WTR–1	WTR–2	WTR-3	WTR–4
MLSS				
C 14:0	–	0.12 ± 0.02 $n = 5$	0.11 ± 0.01 $n = 4$	–
C 16:0	0.97 ± 0.35 $n = 14$	1.38 ± 0.49 $n = 11$	0.60 ± 0.28 $n = 12$	0.29 ± 0.13 $n = 14$
C 18:0	1.42 ± 0.50 $n = 14$	1.67 ± 0.64 $n = 11$	0.74 ± 0.33 $n = 13$	0.61 ± 0.25 $n = 14$
C 18:1	1.61 ± 0.78 $n = 14$	1.82 ± 0.74 $n = 11$	1.15 ± 0.78 $n = 13$	0.41 ± 0.17 $n = 14$
C 18:2	0.11 ± 0.01 $n = 2$	0.11 ± 0.01 $n = 3$	–	–
Effluent				
C 16:0	0.24 ± 0.12 $n = 9$	0.24 ± 0.24 $n = 9$	0.33 ± 0.19 $n = 11$	0.18 ± 0.04 $n = 6$
C 18: 0	0.34 ± 0.23 $n = 10$	0.36 ± 0.39 $n = 9$	0.49 ± 0.24 $n = 10$	0.23 ± 0.11 $n = 13$
C 18:1	0.37 ± 0.17 $n = 9$	0.27 ± 0.16 $n = 11$	0.61 ± 0.47 $n = 12$	0.26 ± 0.14 $n = 11$

suggested that the fatty acids, removed from the mixed-liquor, were completely metabolized by culture MC1 and activated sludge in all the trials.

The use of the recirculation pump provided a highly effective mixing regime for the WTR liquor and, therefore, ensured the maximum possible surface area for contact between the micro-organisms and wastewater, for wastewater hydrolysis, removal and subsequent metabolic reactions. The variations in the mixed-liquor solids' (MLSS) concentrations (Figure 6) also show that there was a period of about 10-12 days before the reactors achieved a steady state. Mean values varied between 8.7 ± 2.4 g l^{-1}, for WTR–3, and 10.0 ± 2.9 g l^{-1}, for WTR–1 (Table 6). The results indicated that there was a similar amount of growth of culture MC1 and activated sludge during all bioreactor studies, resulting from the hydrolysis, removal and subsequent metabolism of wastewater. This was reflected by the similar overall yield coefficient values, which varied between 0.4 g g^{-1}, for WTR–1, and 0.5 g g^{-1}, for WTR–3 (Table 6).

Mean effluent suspended solids' concentrations varied between 6.3 ± 4.2 g l^{-1}, for WTR–1, and 8.2 ± 3.4 g l^{-1}, for WTR–3, which indicated that the effluent contained high, but variable, TSS concentrations during all the studies. The periodic removal of a portion of microbial solids from the WTR liquor, in the form of an effluent, during the bioreactor studies ensured optimum conditions in the mixed-liquor for effective microbial wastewater hydrolysis, removal, metabolism and subsequent growth, and was an important factor behind the success of the weir tank reactor studies.

There were significant differences between the mean mixed-liquor and effluent solids' concentrations for WTR–1 and WTR–2, and this was attributed to variable settleability of the biological solids during these bioreactor studies. This was in agreement with earlier work[8,9] which reported that FOG can affect activated sludge settleability. The wastewater appeared to have little effect on the settleability of the microbial solids during WTR–3 and WTR–4, where similar mean mixed-liquor and effluent solids' concentrations were observed. This could be attributed to the high alkalinity mains water used for WTR–3 and WTR–4, which could have 'held' the wastewater-coated solids in suspension during the settlement phase of the manual feeding regime.

Acidic mean mixed-liquor pH values, of 1.9 ± 0.2, for WTR–1, and 2.2 ± 0.3, for WTR–2, were observed for the low alkalinity studies. During the high alkalinity studies the mixed-liquor pH values were on the alkaline side of neutrality; 7.7 ± 0.3, for WTR–3, and 7.9 ± 0.4, for WTR–4. The reduced buffering capacity of the low alkalinity mains water available in Birmingham was thought to be responsible for these pH differences. The two-phase mixed-liquor, containing small balls of grease, which was observed during WTR–1 and WTR–2, was thought to be a consequence of the low mixed-liquor pH. The enhanced buffering capacity of mains water with a higher added alkalinity was capable of resisting pH changes in the mixed-liquor and subsequently resulted in the formation of a single-phase mixed-liquor. These results have considerable significance in the operation of a WTR system and it could be worth contemplating whether some form of alkalinity control, such as is used in anaerobic digesters[10], might be a useful route for process optimization.

High mean mixed-liquor redox potential values, of $+345 \pm 32$ mV, for WTR–1, and $+322 \pm 49$ mV, for WTR–2, were observed for the low alkalinity mains water bioreactor studies, which indicated that the mixed-liquor contained sufficient oxygen for microbial wastewater metabolism. Significantly lower mean mixed-liquor redox potential values— -91 ± 85 mV for WTR–3, and -65 ± 89 mV for WTR–4—were observed for the high alkalinity bioreactor studies, which indicated that the mixed-liquor was deficient in oxygen. It is probable that this was associated with the reduction in the height of the weir drop which occurred a few hours after the addition of wastewater and nutrients to the WTR liquor, during WTR–3 and WTR–4. This would certainly have caused a reduction in the transfer of oxygen into the mixed-liquor and, therefore, in the dissolved oxygen concentration.

Although not of any critical significance in this current study, the differences in the weir drop could have an appreciable effect under other circumstances. It is, therefore, worth identifying the possible causes for this phenomenon:

- Wastewater triglycerides and free fatty acids would react readily with an alkali, such as sodium carbonate, and this would result in the formation of soluble fatty acid salts or 'soaps'[11]. Vigorous agitation of such a solution could result in the apparent increase in the mixed-liquor working volume, due to entrained air, and the subsequent reduction in the weir drop. This would also explain the single-phase mixed-liquor observed during WTR–3 and WTR-4.
- Another possible explanation for the reduced weir effect could be attributed to differences in the chemical composition of the two fast food restaurant residues, with one containing more cleaning reagents/detergents, which would also cause air to be entrained in the mixed-liquors.

Obviously, further research is required to determine the precise reason for the apparent increase in the mixed-liquor working volume and the associated effect on the weir.

The mean mixed-liquor temperature was relatively constant for all bioreactor studies and varied between 29 ± 3°C, for WTR–2, and 32 ± 2°C, for WTR–4, despite

the absence of a thermostatically-controlled heater in the mixed-liquor. A considerable amount of heat was generated by operation of the recirculation pump, and this was subsequently transferred to the mixed-liquor. How effectively this would happen with a commercial version of the WTR is unknown and the impact of temperature on performance will have to be assessed.

Viewed overall, the results would support the view that mixed microbial cultures were robust and effective for the treatment of fast food restaurant wastewater from different sources. Therefore, it would not be necessary to develop specific cultures for each fast food restaurant.

CONCLUSIONS

The single most important requirement in the development of a suitable bioreactor for the treatment of fast food restaurant wastewater would primarily have to be the production of a single-phase effluent, in order to prevent blockage problems. All the WTR studies achieved this particular requirement.

The discharge of an acidic WTR effluent, as observed during WTR–1 and WTR–2, would not be recommended on the basis that such liquors could be detrimental to the sewerage system.

The WTR studies suggested that a mixed culture such as activated sludge would be a suitable microbial inoculum for a full-scale version of the WTR.

A high alkalinity would be required in the presence of a low alkalinity mains water supply. The only operational problem which could be experienced by the use of activated sludge and a high alkalinity mains water supply, would be that of an apparent increase in the mixed-liquor working volume, resulting in a significant reduction in the height of the weir drop and a subsequent reduction of oxygen transfer. Some element of automatic control might be beneficial.

NOMENCLATURE

S_0	influent wastewater concentration, g l^{-1}
S_r	mixed-liquor FOG concentration, g l^{-1}
S_e	effluent FOG concentration, g l^{-1}
X_0	mixed-liquor TSS concentration, after inoculation, on day 0 of the bioreactor study, g l^{-1}
X_r	mixed-liquor TSS concentration, g l^{-1}
X_e	effluent TSS concentration, g l^{-1}
v	influent/effluent volume, l
V	WTR mixed-liquor volume, l
n	length of the bioreactor study, days

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