Aerobic biological treatment of grease from urban wastewater treatment plants

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Abstract Biological grease treatment is rapidly expanding in France, with about sixty plants recorded in 1998. They are designed at a volumetric loading of 2.5 kg COD/m^3 of reactor per day. Several sites have been selected for their representativity and studied.

Prior to detailed monitoring over a long period, preliminary investigations provided some information on the operation of these reactors. They showed that most of them are not optimized (low removal efficiency), but have limited operational constraints given their low load. This study enabled us to assess the quantity actually skimmed from the surface of the aerated grease separator in relation to the lipids in raw sewage, and to define the precautions to be taken for sampling and analysis of grease, before any data interpretation.

A detailed measurement series was then implemented. It shows the considerable value of this process for the reduction of lipids and highlights the main operational parameters in order to obtain high performance while keeping low operating constraints.

Keywords Aerobic treatment; grease separator; lipids; performance; design

Introduction

The preliminary treatment of urban wastewater generates different by-products, including greasy waste (also named F.O.G., for fats oils and grease). Presently most of it is disposed of landfills. However it will no longer be accepted in storage centres for solid wastes, according to the new regulations which will be enforced in 2002: indeed, grease cannot be considered as a final waste given its biodegradability, its low dry matter and high organic matter content.

Several treatment techniques have been and/or are being developed. The aerobic biological treatment of F.O.G., a quite recent but most developed process, is however still poorly known by the professionals.

The grease found in raw sewage is essentially of animal or vegetal origin. This lipid waste consists mainly of triglycerides (triesters) composed of fatty acids with chains of varying length (Thonard *et al.*, 1997). When entering the treatment plant, the grease is being hydrolysed. It is thus composed of a mix of free fatty acids and triglycerides, whose proportions vary according to the sites (Kallel *et al.*, 1990).

The main physical and chemical characteristics of the lipids are their insolubility, which increases with the number of carbon atoms, their low density (below 1), their hydrophobic nature, and, for most fatty acids, their solidification at the temperatures most frequently observed for the influent (Bridoux, 1992).

Hydrolysis and solubilization of the F.O.G. are important steps prior to any biological assimilation. This is performed:

- naturally, by exo-cellular enzymes called lipases, secreted by the biomass present in the medium, and/or,
- chemically, by the saponification reaction (formation of fatty acid salts) which occurs in

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a basic medium and results in the formation of foaming agents (Kallel *et al*., 1994).

Grease causes various difficulties in the management of wastewater treatment plants. The main problems encountered are the following:

1. For particulate greases:
   – clogging of pipeworks and of the attached-growth support media, and fouling of the level detectors in the pumping tanks,
   – foul odours related to their high fermentascibility,
   – the development of filamentous micro-organisms resulting from the favorable environment (floating matter, and a substrate rich in fatty acids) (Soddel and Seviour, 1990). This can affect the decantability of the sludge and/or cause biological foaming, with severe operational problems (Lemmer and Baumann, 1988; Duchène,1993).
2. For soluble greases: reduction of the oxygen transfer coefficient in the medium
3. For the grease absorbed on the floc: decrease of the dry matter content of the sludge during dewatering.

The aim of this paper is to examine the grease treatment more closely, especially the process design and the operational parameters, its limitations, and to establish some recommendations to facilitate its implementation.

Material and methods

Treatment facilities

The studied facilities for aerobic grease treatment were built by Degremont (Biomaster® process), Stereau (Lipocycle® process), and OTV (Biolix® process). They are combined with activated sludge plants with design capacities ranging from 80,000 to 150,000 PE.

They include a single treatment tank with the design characteristics proposed by the constructors, as shown in Table 1.

Except plant no 1, the tanks are preceded by a storage-equalization tank and were all tested on the basis of 1 to 3 daily input cycles. They are equipped with fine or medium bubble aeration systems, with specific design power ranging from 110 to 350 $W.m^{-3}$. Facilities for the dilution of the F.O.G. to be treated are systematically installed, whereas the devices required for the addition of nutrient are found in one case only. Two of the facilities are also equipped with a continuously operating mixer (15 and 30 $W.m^{-3}$).

Study conditions

The facilities were studied in 1997 and 1998 over continuous periods of 10 to 20 days, once the necessary arrangements had been made to come close to the design loads. To compensate for the underloading observed during preliminary investigations, F.O.G. from other urban WWTP was added and the operational volume of the treatment tanks was reduced. To facilitate the biological activity and the maintenance of the required biomass, the dilution rate was modified and a facility for the addition of nutrients was adjusted or installed.

Table 1 Design characteristics of the aerobic grease treatment tanks studied

Plant no		1	2	3
Volume	(m^3)	200	600	210
Vol. loading	(kg $COD.m^{-3}.d^{-1}$)	2.5	2.5	2.5
F/M	(kg COD.kg $MLVSS^{-1}.d^{-1}$)	0.22–0.33	0.21–0.31	0.25
MLVSS	($kg.m^{-3}$)	7.8–11	8–12	10
HRT	(d)	20	15–20	12–20

Sampling

The representativity of the samples of the greasy waste and of the mixed liquor of the aerobic treatment tanks was impaired by the heterogeneity, the insolubility, and the hydrophobicity of the grease. In addition the preliminary investigations had shown that it might clog the automatic sampling devices.

Sampling was thus performed manually by a series of grab samples, so as to obtain an initial 70 l composite sample proportional to the volume. After the removal of the coarsest particles, followed by vigorous mechanical agitation (13,500 rpm), several 2 l samples were collected in wide-necked glass bottles (APHA, 1985), including one acidified to a pH of 2 for preservation. For the analyses not performed on the spot, the samples were stored at 4°C immediately after collection.

Analyses

The COD, SS, DS, VSS, NH_4^+-N, TP, PO_4^{3-}-P parameters were quantified according to standardized methods (AFNOR, 1997). For the analysis of the TSS of certain greasy waste, classic drying at 105°C for 24 hours sometimes had to be replaced by drying to a constant weight at 60°C, due to the presence of some more volatile lipids (in particular, in aged residues or greases from industrial activities). COD and various analyses of fats were performed on the acidified sample, the others on the raw samples. Since the BOD_5 was not suitable (particulate, hydrophobic product), the biodegradable part was estimated by the COD.

Test samples on which the analysis of the F.O.G. were performed were taken by weighing, and not by volume. But given the small amounts of the test samples and the heterogeneity of F.O.G., the results obtained were still erratic. The measurement of the COD was thus modified for this study by increasing the pH to 13 by addition of soda (5 ml of NaOH, 37% in 40 g of homogenized F.O.G.), enabling the formation of more soluble fatty acid salts.

The lipids were quantified by IR spectrophotometry using carbon tetrachloride (CCl_4) as a solvent. Prior tests on several dozen samples of raw wastewater, mixed liquors and F.O.G. had in fact shown:

- an extraction efficiency approximately 10% lower than that of chloroform ($CH\,Cl_3$) or of a mixture of chloroform and methanol for the most stable emulsions, but approximately 10% higher than that of n–hexane, both being classic solvents in gravimetric quantification methods of fats,
- that all the fatty acids, especially those with short chains and possible volatile fractions, are taken into account (on 15 samples, IR spectrophotometry gave 21% more than gravimetric quantification with the same solvent CCl_4),
- a lower detection limit, around 0.2 mg L^{-1} of lipids,
- and a distinction of the hydrocarbons from all the extracted matter.

Results and discussion

The greasy waste skimmed off

The average F.O.G. collected from the surface of the aerated grease separator revealed an extremely similar composition from one site to another, with the mean, min and max values shown in Table 2.

These results, combined with an accurate characterization of the WWTP influent and the effluent of the grease extractor, enabled us to estimate the mean performance of the extractors (Table 3) (Duchène, 1980; Bridoux *et al.*, 1994).

The lipids trapped are found:

- floating on the surface for removal by the scraper to the collection chute. It is this fraction which impacts on the design of the biological grease reactors,

Table 2 Analytical results of a mean F.O.G. skimmed from wastewater treatment plants

	COD $g.L^{-1}$	Lipids $g.L^{-1}$	COD / lipids	Lipids / VSS	COD Lipids $/COD_T$	KN $mg.L^{-1}$	TP $mg.L^{-1}$	COD / N / P	DS $g.L^{-1}$	VSS $g.L^{-1}$
	181	69	2.76	0.88	0.88	1079	455	100/0.6/0.2	88	76.5 (90% of DS)
Min-max	162–196	61–74	–	–	–	840–1260	390–557	–	74–108	66–88

Table 3 Mean removal efficiency of the grease extractors

	COD	Lipids	SS
Removal efficiency	9%	15 to 20%	15 to 20%

- at the bottom of the separator by adsorption on the trapped suspended solids, composed of easily settleable sand and organic matter.

The breakdown between these two removal modes calls for particular care. Our measurements showed a surface collection efficiency about 20% of the total lipids removed by the separator. However there are not enough data to draw any final ratio, given the type of input lipids (free fatty acids, triesters, fatty acid salts) and other parameters (upflow velocity, quantity of SS trapped).

The percentage of pollution collected from the grease extractor for later treatment represents 2% of the raw sewage COD (Table 4). For design, constructing companies take 5%. This difference can be explained by the various removal modes and performances obtained with the grease separators, as summarized in Table 4.

Although the part trapped on the surface of the extractor is very small compared to the load in COD brought in by the lipids of the wastewater, the installation of such separators is always advisable, not to say essential. In the absence of a grease separation system, the grease floating on the treatment tanks would result in operational problems (risk of biological foaming, then bulking, visual pollution), that can only be avoided by the installation of very high stirring power in the tanks, which is not economical.

The concentrations in lipids obtained on a population equivalent basis give on average the following ratios:

- As a component of raw sewage: 15 to 20 g of lipids/PE.day.
- For a biological grease treatment, the following values can be taken:
  - 2 g of lipids/PE.day, i.e. 0.7 kg of lipids / PE.year, and
  - about 10 to 11 litres of F.O.G. per PE.year (average concentration of 65 g of lipids.L^{-1}).

Biological grease treatment

The aerobic biological treatment of grease requires a specific reactor (Maillet, 1997; Grulois *et al*., 1997) equipped with air diffusion systems for oxygen input . Given the high concentration of the greasy waste to be treated, the absence of recycling is a characteristic of this process. The sludge age is therefore equivalent to the hydraulic residence time.

Table 4 Percentage of the influent COD collected for biological treatment

Removal efficiency of the grease extractor	Fraction collected on the surface	Global grease removal efficiency
5 to15% of the COD of the wastewater	20% to 50% of the trapped COD	2 to 4% of the influent COD

The sludge age depends on the required food to micro-organisms ratio (F/M ratio), resulting in high residence times. The sludge produced is removed every day to the sludge disposal unit or to the aeration tank. This latter option offers two advantages:

- stabilization of the sludge if the receiving aeration tank is of the extended aeration type (F/M $\leq$ 0.1 kg BOD.kg^{-1} MLVSS.d^{-1}),
- continuation of grease treatment in the case of a F.O.G. treatment reactor with limited biodegradation efficiency.

The greasy waste placed in the specific aerobic treatment reactor will continue to undergo biological hydrolysis thanks to the lipases produced in the system, and chemical hydrolysis by saponification, given the pH of the medium (generally between 7.5 and 8). This is an essential stage for the assimilation of the free fatty acids. The disorders which can occur at this level are mainly related to improper management of the facility. They may be physical (extensive foaming) or biological, through a lack of nutrients, resulting in an absence of assimilation and, indirectly, in an acidification of the system with a negative impact on saponification and lipase activity.

Operational parameters

The main operational parameters are shown in Table 5.

The VSS′ values correspond to the total volatile matter from which the part of adsorbed lipids has been substracted. This operational parameter is closer to reality because of the high adsorbed fraction measured in these reactors.

Upstream of the biological reactor, various equipment or specific facilities can be added to complement the treatment, depending on the constructors. The F.O.G. can be stored (where feeding is of the batch type). It can undergo an initial physical treatment, by screening or even maceration, to facilitate pumping, or a chemical treatment by the addition of a base for hydrolysis by saponification. Depending on the pH obtained, the solubility of the product is improved, and the lipids are found in the form of more easily assimilable fatty acids.

Performance

The results obtained in the optimized installations, and especially with an input of nutrients to enable assimilation and the maintenance of a pH compatible with treatment, are shown in Table 6 (Royer, 1994).

Table 5 Reactor operational parameters

F.O.G. reactors	1	2	3
F/M (kg of COD/kg of MLVSS.day)	0.05	0.26	0.26
F/M' (kg of COD/kg of MLVVS'.day)	0.07	0.42	0.35
Vol. loading rate (kg of COD / m^3 of reactor.day)	0.35	2.34	3.48
MLVSS (g.L^{-1})	7.1	9	13.4
COD of the greasy waste including dilution water (g.L^{-1})	–	40	50

Table 6 Yield of the reactors and other data

F.O.G. reactors	1	2	3
Lipid removal efficiency from the total sludge (%)	89	79	84
Reactor temperature (°C)	19	42	30
Oxygen input	satisfactory	satisfactory	satisfactory
Addition of nutrients	No	Yes (limited)	Yes (in excess)
Assimilation rate (kg of COD eliminated/kg of MLVSS'.day)	0.05	0.30	0.31
Lipids adsorbed in relation to MLVSS (%)	29	39	22
Lipids adsorbed in relation of MLVSS' (%)	29	63	32

The level of absorbed lipids, in a stabilized system and in the absence of any limiting factor, provides information on the residence time required for complete assimilation of the substrate, which is much lower than the design residence times. Our measurements show a mean residence time for assimilation about 2 to 3 days.

The efficiency of the treatment is conventionally judged by taking account of the quantity of lipids or COD in relation to the amount of biomass (estimated by MLVSS). The main factors which explain the variation in removal efficiency are the F/M ratio, the nutrient balance and the input of oxygen.

The quantity of biomass produced measured at the facilities is shown in Table 7.

It can be observed that for equivalent F/M ratios and assimilation rates (sites 2 and 3), site 2 produces a much smaller quantity of sludge (30% less than reactor 3), which can be explained by a much higher temperature encouraging the self-oxidation of the biomass.

Two operational parameters resulting from our results would therefore be: a F/M′ of 0.3 kg of COD/kg of MLVSS′.day, and a production of sludge around 0.3 kg of MLVSS′/kg of COD removed.

Design and operational data

Given the results obtained during the monitoring of the different types of aerobic F.O.G. treatment reactors, a facility capable of ensuring a satisfactory treatment of these residues before discharge into the WWTP aeration tank consists of an aeration tank designed for a volumetric loading around 2.5 kg.COD/m^3 of reactor per day, with a MLVSS concentration around 10 $g.L^{-1}$. This tank must be equipped with a controlled aeration system, and an extraction pump or an overflow. It must have a high freeboard (well over 1 m to cope with the possible production of foam). Furthermore, it may be equipped with a mixer. A controllable source of dilution water is required, preferably with pre-treated water bringing in assimilable nutrients, but distribution water or treated wastewater are also possible. Moreover, a storage structure and nutrient input equipment to complement the greasy waste should be provided.

An equalization tank can be added if the plant also receives batch inputs of external liquid greasy waste dumped in by trucks. In this case a strong agitation and a suitable pump are required. Finally a fine screen, or, even better, a dilaceration stage will help to prevent operational problems caused by coarse solids.

The first part of our study showed a widespread lack of knowledge about the operation of this type of facilities by the operators, and an underloading (not always recognized) of most of the aerobic grease treatment systems. This can be explained to a large extent by the difficulties of sampling and analysis.

The major problem, reported by operators in 40% of the plants, is the development of foam. However this inconvenience should not occur in facilities operating according to the design basis studied. Foaming is in fact often caused by a blocking of the biological activity, due to the absence of nutrients or to an excessively low pH, resulting in a high lipid concentration in the reactor. On-going studies into the foaming mechanism will make it possible to identify the factors triggering foaming and to set the upper F/M limits.

Table 7 Production of sludge

F.O.G. reactors	1	2	3
P_B (kg of MLVSS' / kg of COD eliminated)	0.10	0.19	0.3
Sludge age (days)	> 100	17	12
Nutrients	Absent	Limited	In excess
Temperature (°C)	19	42	30
Fraction of lipids absorbed but not assimilated (%)	29	39	22

In 20% of cases, operators are essentially concerned about the problems of “rags and tow”, resulting in the clogging of pipes and pumps and in failures in various sensors.

Finally, 20% of the operators reported problems with the diffusion of oxygen, to be related more to the facility or quality of the equipment, associated with the high flow rates used in respect of the high volumetric loading rate of these plants. Such failures raise the issue of the use of fine bubble aeration devices in these reactors. This issue will be examined in the near future.

The operational constraints of properly designed aerobic biological grease treatment reactors should be limited in the long term, and only concern the management of dilution, the addition of nutrients (COD/NH_4^+-N/PO_4^{3-}-P of 100/2.7/1) and the analytical monitoring.

The characterization, sampling and analysis of greasy waste are all extremely delicate operations. Their quantification remains essential during the commissioning, for the proper start-up of the system. In day to day operation, the flows brought in by F.O.G. and the various resultant parameters could be estimated by the sludge production.

Conclusion

The greasy waste collected from the surface of the aerated grease separators represents only a very small part of the lipids brought into the wastewater treatment plant (about 10%). This fraction obtained by flotation is often solid and difficult to assimilate as such. It therefore requires prior treatment to enable a complete biological degradation. A physical and chemical modification of these lipids takes place in the treatment reactor. This transformation always occurred, irrespective of the level of treatment, and is essentially due to the dilution of the product, to the chemical hydrolysis related to saponification and to the biological hydrolysis due to the enzymes present in the medium. The lipids become consequently more easily available (higher soluble fraction) and therefore more rapidly assimilable by the biomass.

On the basis of these observations, complete biological treatment can be tackled by 2 distinct approaches:

- an essentially physical treatment, based solely on absorption, the assimilation mechanism occuring in the WWTP aeration tank (in this case, there is no need to add N and P, which are often in excess in the aeration tank);
- complete treatment in a specific biological reactor, where the addition of nutrients and a sufficient input of oxygen are essential.

The study of 3 previously optimized biological aerobic F.O.G. treatment facilities has shown the considerable value of this process, but also the main mechanisms involved, their limitations and their ranking to facilitate their operation and avoid failures.

The removal efficiencies obtained for the lipids are about 80% to 85% with loads applied around 0.25 kg of COD/kg MLVSS.day. At such values, the addition of nutrients is essential, otherwise the following problems may occur:

- an absence of treatment,
- an increase of the lipids in the reactor, which could cause foaming and high operational constraints, and
- a risk of acidification of the medium, which would block the biological activity.

Additional studies are currently under way, to have a closer look into the mechanisms of biological treatments of F.O.G. (adsorption, hydrolysis, assimilation), the characteristics of oxygen transfer in these concentrated media, and the conditions triggering the development of foam. The results of these investigations should make it possible to obtain a better optimization of these systems, or even a modification of the process.

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