Use of recycling through medium size granular filters to treat small food processing industry effluents

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Abstract Currently there are no suitable wastewater treatment systems for effluents from small food processing industries (dairy, cheese, wine production). Such raw sewages are characterized by high organic matter concentrations (about 10 g COD L^{-1}) and relatively low daily volumes (about 2 m^3). An adaptation of attached-growth cultures on fine media processes, known to be easy and inexpensive to use, could fit both the technical and economical context of those industries. Coarser filter particle size distributions than those normally used allow a better aeration and reduce clogging risk. The transit time of the effluent through the porous filter materials is shortened and requires recycling to increase the contact time between the biomass and the substrate. A pilot plant was built to compare the efficiency of two kinds of filter materials, gravel (2–5 mm) and pozzolana (3–7 mm). Two measurement campaigns were undertaken on a full-scale unit dealing with cheese dairy effluents. Both pilot-scale and full-scale plants show high COD removal rates (>95%). Pilot-scale experiments show that accumulation of organic matter leads to the clogging of the recycling filter. To prevent early clogging, a better definition of feeding cycles is needed.

Keywords Attached-growth culture; food processing industry; gravel; pozzolana; recycling

Introduction

Small Food Processing Industries (SFPI) produce specific effluents which are mainly characterized by high Organic Matter (OM) concentrations (about 10 g COD L^{-1}) and relatively low daily volumes. Their connection to the local sewerage network is not always possible due to the important load they induce in rural areas. A goat rearing of 50 heads induces the same load as 50 people, mainly due to the presence of whey, which COD concentration is about 70 g L^{-1}. Treatment systems based on suspended cultures (aerated lagoons, activated sludge) are not economically suitable for this sector of activity. Such processes have high operating costs and generate large quantities of excess sludge which is costly to dispose of. An adaptation of attached-growth cultures on fine media processes to treat effluents from SFPI is an attractive alternative to suspended cultures processes.

Attached-growth cultures on fine media processes, and especially Sand Filters (SF), are considered to be simple treatment systems which operate with minimal human intervention. As such, they are appropriate for rural areas, where low maintenance and reliability are essential. In SF, wastewater is introduced at the top of the bed and flows through the unsaturated porous media. The sand provides the physical support for sorption and biofilm growth. Good effluent quality is obtained (≈ 90 mg COD L^{-1}), nitrification is almost complete (TKN<10 mg L^{-1}) and no sludge production is theoretically expected. Typically in France, the filters are fed for 3 days and then made to rest for 7 days. Thus, several filters work alternatively, usually three. The aim of the rest periods is to regulate biofilm growth by endogenous respiration and thereby avoid bed clogging. Rest periods also allow oxygen stock restoration inside the porous media. Batch feeding allows the influent to be homogeneously applied all over the bed surface. It means that influents are temporarily stored and then evacuated during a limited period of time (Boutin *et al.*, 2000).

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In France, such processes are now widely used for domestic wastewater treatment. The use of SF to treat highly concentrated effluents (about 10 g COD L^{-1}) necessitates large surfaces. Thus, achieving an even distribution of influent over the bed is difficult. Furthermore, SF are more likely to clog. Adaptation of the system is thus required to treat SFPI effluents. The use of coarser material instead of sand leads to a better ventilation of the filter and decreases clogging risks. In a SF, the flow speed is usually low compared to the assimilation speed (Schmitt, 1989). With a coarser material, flow speed is increased; so, in order to increase the contact time between substrate and biomass, recycling of the effluent is necessary.

A pilot plant consisting of a set of trial columns was built. Pilot-scale experimentation took place from March 1999 to August 2001. Gravel Recirculating Filter (RF) and pozzolana RF were tried. Performances regarding the removal of COD were monitored since the main objective of the process, given the relatively low nitrogen content of the influent, is organic matter removal.

Since 1996, the Pradel experimental caprin farm in France treats its effluents using the process described above. It is the only French wastewater management system of its kind which deals with small cheese dairy effluents, including whey. Two in-situ measurement campaigns were performed in September 1999 and June 2000. The aim of this paper is to present the main data obtained from both pilot and full-scale plants.

Material and methods

Pilot plant

Description of the pilot-scale system. The pilot consists of a set of columns placed in a covered room. The columns are made of transparent PVC tubes having an inside diameter of 360 mm (0.1 m^2) and a height of 1.20 m. The columns are wrapped with black paper in order to prevent algal growth. Each column is filled with 60 cm of gravel or pozzolana. A geogrid is placed at the bottom of the bed to avoid material losses. As shown on Figure 1, a feeding tank (F) and a recycling tank (R) are attached to each column. A gear pump controls the flow from tank F to the RF. Water is evenly distributed at the top of the bed by a spraying nozzle. The output effluent is collected by tank R. Every 4 hours, a peristaltic pump recycles effluent towards tank F just before the next feeding. The influent is therefore passed 6 times on the filter over a 24 hours period before being disposed of and replaced by raw influent.

Support material characteristics. The characteristics of the two materials used in the experiment are given in Table 1. The characteristics of the sand typically used in SF are also given (Liénard *et al.*, 2000). The gravel is sieved to 2–5 mm. The pozzolana, sieved to 3–7 mm, is provided by a quarry situated near Pradel farm. It is characterized by an alveolar and slagged texture. The specific area (*As)* of the bed material is estimated assuming the particles to be spherical. This calculation method underestimates the pozzolana *As* because of its alveolar texture. Both gravel and pozzolana provide less surface for the biofilm to grow than sand and substrate recirculation is therefore required.

Operation. The laboratory experiments were carried out in two periods. The first period took place over 33 weeks from March to October 1999. Two columns were operated, one filled with pozzolana (P1) and the other with gravel (G1). The beds were fed for 3 days and then made to rest for 4 days (3f/4r). The second period took place from April 2000 to August 2001; at this time, the beds were fed for 7 days and then made to rest for 7 days (7f/7r). A new column of pozzolana (P2) was operated in addition to P1 and G1.

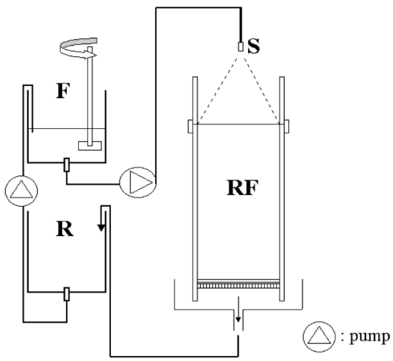

Figure 1 Diagram of column with F and R tanks. F: feeding tank; RF: recirculating filter (gravel or pozzolana); R: recycling tank; S: spraying nozzle

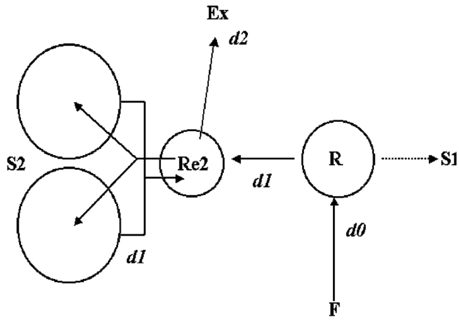

Figure 2 Diagram of Pradel farm plant. *di*: day i; Ex: exit; F: farm; R: reception tank; Re: recycling tank; S_i: station sub-unit

Table 1 Characteristics of the bed materials used in the experiments

	Sand	Gravel 2–5 mm	Pozzolana 3–7 mm
d10* (mm)	0.25< d10<0.40	2.07	1.51
d60* (mm)	<1.00	2.92	3.80
CU(ad)= d60/d10	3.00<CU<6.00	1.41	2.52
Specific gravity	2,500	2,600	2130
Bulk density (kg m^{-3})	1,620	1,380	980
Porosity (ad)	0.36	0.42	0.54
*A*s (m^{-1})	6,800	1,030	1110

* dx: sieve mesh allowing x% in mass of the material grains to go through

Table 2 Mean concentrations of influent for pilot plant experiment and at Pradel farm (standard deviation (STDV) in parentheses)

	COD (raw)	COD (filtered)	Suspended Solids (SS)
Pilot influent	9,300 mg L^{-1} (695)	8,400 mg L^{-1} (837)	350 mg L^{-1} (132)
number of values	79	46	46
Pradel (1999) influent	8,300 mg L^{-1} (2,710)	6,800 mg L^{-1} (2,030)	1360 mg L^{-1} (1080)
number of values	7	7	7
Pradel (2000) influent	9,400 mg L^{-1} (2,430)	7,600 mg L^{-1} (3,540)	910 mg L^{-1} (230)
number of values	7	3	6

Applied loads. The influent was prepared daily from milk and whey powder in the F tank. Appropriate amounts of powder were dissolved in tap water. Mean concentrations of synthetic influent are given in Table 2. The influent volumes depend on the loading rate cycle sequence. With 3f/4r operation, 7 litres per day were prepared and the load during one feeding day was 650 g COD d^{-1} m^{-2}. The average loading rate was 280 g COD d^{-1} m^{-2}. With 7f/7r operation, in order to maintain the same average load, 6 litres were prepared per feeding day. Special influent was prepared for the P2 column (40% less COD concentration) such that the average loading rate was 170 g COD d^{-1} m^{-2}.

Start-up. In order to shorten the start-up period, first operation day influent, in 1999, was prepared using wastewater from a domestic activated sludge tank.

Analyses. COD analyses were made according to AFNOR method NF T90-101 which is equivalent to the normalised method ISO6060. Suspended solids (SS) measurements were carried out by filtration on glass fibre membranes according to EN872 method.

Mass variation. The columns, together with their tanks F and R, are equipped with electronic balances (manufactured by Thermonobel). The balance measurements are collected through "data acquisition modules" connected to a PC via a RS-485 plug. The accuracy for the column mass monitoring is about 10 g.

Tracer experiments. The hydraulic properties of the different RF were evaluated using NaCl as tracer. Filters are fed with clear water until the steady state condition is reached, then salt is introduced (10 g in 100 mL). Conductivity is recorded at the filter outlet. The tracer experiments were performed for clean and used support materials.

Pradel experimental farm

The Pradel experimental farm owns a goat herd of 120 heads. The milk production is about 120,000 litres per year, most of it is used to make cheese. Influent consists of a mixture of washing parlour water (210 to 240 L d^{-1}), water from the cheese dairy (2.8 L per L of milk) and whey (0.75 L per L of milk).

The treatment plant consists of two sub-units S1 and S2, each made of several filters; they work alternatively one week each. S1 is the older sub-unit built in 1996 with 3 rectangular beds, 8 m^2 each. S2 consists of two circular beds of 15 m^2 each (Figure 2). Wastewater is distributed at the top of the bed by a garden sprinkler. Each bed comprises a 80 cm pozzolana layer with aeration pipes inside; the same pozzolana material was used in the pilot-scale experiments. At the bottom of the bed, a geogrid prevents material losses.

Wastewater produced at the farm (F) on "d" day is collected in the reception tank (R). On "d+1" day morning, it is pumped towards recycling tank (Re) of one of the sub-units. Then effluent circulates 4 times through the filters. At each feeding, wastewater returns to the recycling tank. The recycling tank is emptied out to the environment (Ex) at "d+2" day, just before receiving new effluent produced on "d+1" day.

Two campaigns of measurements were undertaken to investigate S2 sub-unit efficiency. Organic and hydraulic loads introduced in the filters (Table 2) were monitored to evaluate the removal efficiency of the process.

Results and discussion

Pilot scale study

Operation at 3f/4r. COD and SS concentrations of the treated effluent are given in Table 3. The average values do not take into account the start-up period which was 4 weeks for the G1 column and 1 week for the P1 column. Because of influent high initial COD concentration values and in spite of high removal rates (not less than 96%), the treated effluent COD concentrations remain relatively high (> 500 mg COD L^{-1} for the gravel). Significant differences exist between pozzolana and gravel removal efficiencies. SS production lowers effluent quality for both material types; SS originated from sloughed off biofilm. Pozzolana alveolar texture provides better adhesion conditions for biofilm growth with less sloughing off (Show and Tay, 1999; Annachhatre and Bhamidimarri, 1992). This may explain the faster start-up for the pozzolana filter (1 week against 4) and its less important SS production. Differences found in hydraulic properties of material types may also contribute to the better performance of the pozzolana filter (Figure 3). Tracer experiments performed on clean material show longer retention time for pozzolana (387 s against 251 s for gravel bed). However, these differences progressively disappear, as shown in Figure 4, when the materials become colonised by the biofilm, the retention time become less different between the two medias: 315 s for gravel and 370 s for pozzolana. In providing physical support for biofilm growth, pozzolana loses its original texture characteristics. Likewise, in colonised media, the biofilm volume slowly exchanges tracer with the flow-through zone

Table 3 Treated effluent concentrations for the first experiment period (in parentheses STDV)

	Applied loads	COD (raw)	COD filtered	SS	Load removal rate (%)
Gravel (G1)	280 g COD d^{-1} m^{-2}	533 mg L^{-1} (496)	142 mg L^{-1} (73)	376 mg L^{-1} (374)	96%
number of values		54	51	63	54
Pozzolana (P1)	280 g COD d^{-1} m^{-2}	299 mg L^{-1} (204)	83 mg L^{-1} (46)	210 mg L^{-1} (205)	98%
number of values		63	62	67	63

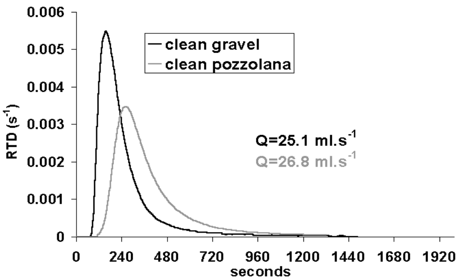

Figure 3 Comparison of residence time distribution into the two material types (clean material)

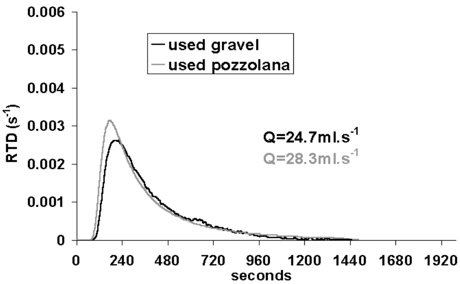

Figure 4 Comparison of residence time distribution into the two material types (used material)

and behaves like a stagnant zone, which significantly increases tailing (Séguret *et al.*, 2000). By creating a retarded exchange zone, the biofilm increases retention time in the gravel bed. The same process occurs in the pozzolana and balances the loss of alveolar texture.

Operation at 7f/7r. COD and SS concentrations of the treated effluent are given in Table 4. The average values do not take into account the start-up period which lasted 1 week for both G1 and P1 columns. The observation of the same start-up period lasting is due to the fact that the columns have been re-operated after a 168 days break. The biomass has not completely disappeared and the re-colonisation took place more quickly and almost at the same level of development. For both periods, 1 g of SS corresponds to 1.2 g of COD ((raw COD – filtered COD) SS^{-1}).

During the second experiment period, no significant difference was found between the qualities of treated effluent percolated through gravel or pozzolana beds. Gravel bed performance has improved to reach pozzolana performance level which remains as in the first experiment. The levelling of the difference between the two material types is mainly due to the fact that during 7f/7r operation period, gravel bed SS sloughing off is balanced by the better yield of the following operation days. First day of operation is always affected by high SS slough off probably due to the weakening effect of the rest period. Nevertheless,

Table 4 Treated effluent concentrations for the second experiment period (in parentheses STDV)

	Applied loads	COD (raw)	COD (filtered)	SS	Load removal rate (%)
Gravel (G1)	280 g COD d^{-1} m^{-2}	287 mg L^{-1} (304)	125 mg L^{-1} (70)	164 mg L^{-1} (248)	97%
number of values		114	26	44	114
Pozzolana (P1)	280 g COD d^{-1} m^{-2}	275 mg L^{-1} (194)	150 mg L^{-1} (69)	141 mg L^{-1} (116)	98%
number of values		105	26	26	105
Pozzolana (P2)	170 g COD d^{-1} m^{-2}	69 mg L^{-1} (36)	–	–	99%
number of values		150	–	–	150

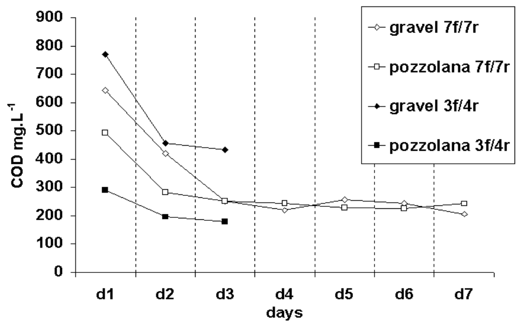

Figure 5 Average COD concentrations (raw) in the treated effluents for both periods

during the last 5 days of an operation week, gravel bed reaches high performance (Figure 5).

Fed with a lower load, P2 column shows very high COD removal rate (average COD concentration of about 70 mg L^{-1}), significantly higher than P1. This shows that applied loads on G1 and P1 exceed system capacities.

Clogging. During second experiment period, both P1 and G1 columns clog, respectively after 18 and 21 operation cycles. Pozzolana and gravel filters were operated during 427 and 469 days respectively over the whole experiment. The variation of the columns long term mass indicates that rest periods are insufficient to allow sustainable treatment of highly concentrated influent. According to Figure 6, the bed masses increase linearly throughout the operation. Filters seem to accumulate stable OM which causes the filling of material pore spaces and lead to clogging. Such an accumulation was observed by Tanner *et al.* (1998) working on gravel-bed horizontal flow constructed wetlands treating farm dairy wastewater. Most (>90%) of the OM accumulated in the constructed wetland over a 5-year period is composed of stable (recalcitrant) OM fraction (Nguyen, 2000). This was attributed to the refractory nature of OM inputs from wetland plant litter (lignocellulose and humic compounds) and the applied dairy wastewaters. In our case, most of the load is applied under dissolved form, thus stable OM fraction results from microbial activities.

The mass balance between biomass production and decomposition was not reached. Even the P2 column which operated with lower loads (170 g COD d^{-1} m^{-2}) showed similar mass increase.

To try to explain such a phenomenon, Figure 7 shows the mass balance of 100 g of COD introduced in a column. One fraction is stocked in the bed, another is decomposed and mineralised and another is rejected with the effluent. COD inputs and outputs are estimated by

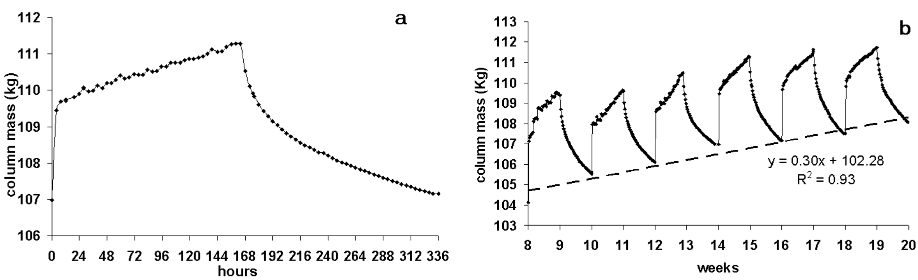

Figure 6 Column mass variations; 6a: P1 column mass variation during 1 operation cycle (7f/7r); 6b: P1 column mass variation during second operation period

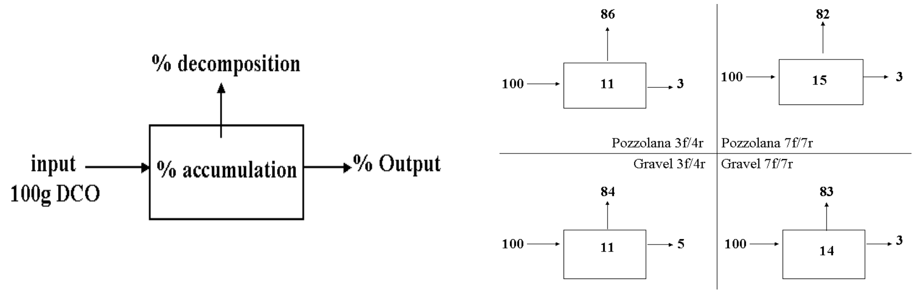

Figure 7 Organic matter balance between inlet and outlet in the RF

considering effective loads, applied and discharged. OM accumulation is obtained by mass variation of the column. To estimate COD accumulation, OM is taken to have 90% humidity (estimation based on material analysis (STDV = 4% $n = 32$)) and, as previously seen, 1 g of SS corresponds to 1.2 g of COD. Decomposition is calculated by difference between input and output, including accumulation.

The G1 bed performance improvement observed during 7f/7r operation appears to be the result of a larger accumulation of OM in the filter (14% vs. 11% during 3f/4r operation). P1 column stores a larger amount of OM, but filter performances are not improved because of a less efficient decomposition (82% vs. 86% during 3f/4r operation). Operation at lower loads does not provide better decomposition rates, accumulation in P2 column is in the same range than in columns operated at higher loads. Further studies of OM accumulation are undertaken to specify this first global approach.

The pollutant load transformation in biomass seems to be accomplished and allows the high COD removal efficiency of the process. However, the effectiveness of endogenous respiration is insufficient to preserve steady conditions. Actually the process generates sludge in significant amounts. To ensure a longer filter life time, it seems more efficient to increase rest periods while distributing the same load on a shorter feeding period.

Operation at full-scale

S2 sub-unit is under operation since summer 1999. The results obtained during the summer 2000 campaign are given in Table 5. According to Table 5, COD removal rates are in the same range as pilot removal rates (98%). However, it must be noticed that such loads (about 330 g COD m^{-2} d^{-1}) would obviously tend to clog if they remain at such a level all year round. In fact, these figures represent the peak of pollution load, which vary with the day-milk production under the influence of the dropping.

At Pradel farm, the monitoring established that the total load induced by the mixing of washing parlour, dairy effluents and whey is about 60 g of COD L^{-1} of milk produced. So, in addition to geographic and climatic considerations, the design of coming plants must be

Table 5 One week measurement campaign results from Pradel farm (STDV in parentheses)

Days	Treated volumes (L)	Inlet raw COD (mg L^{-1})	Outlet raw COD (mg L^{-1})	Outlet volumes (L)	Load removal rate
d1	3,320	12,950	210	3400	98%
d2	3,190	7,000	200	2370	98%
d3	2,980	6,860	170	2520	98%
d4	2,410	8,180	200	1870	98%
d5	1,950	12,880	350	1480	98%
d6	690	14,230	580	550	97%
d7	1,310	16,050	290	1096	98%
mean	2,090 (880)	11,160 (3,750)	287 (142)	1900 (960)	98% (1)

done on a compromise taking into account the production peak, the season when it occurs and its duration to ensure that the treatment capacities of a plant will not be undersized.

Conclusion

The use of a coarser material (gravel or pozzolana) and the recycling of the influent seems to be an effective way to adapt attached growth cultures on fine media processes for the treatment of highly concentrated effluents. Pilot-scale experiments and full-scale monitoring confirm that removal rate of more than 95% in COD can be achieved while treating high concentration effluent (about 10 g COD L^{-1}).

Such processes, requiring relatively low maintenance, fit well with economical and technical context of small food processing industries.

Nevertheless, in the experimented conditions the use of coarser filter material does not prevent clogging. During pilot-scale experiments, both pozzolana and gravel RF clogged (after respectively 427 and 469 operation days). A fraction of the incoming COD (more than 10%) is stored in the RF without being decomposed, even at the end of a rest period which is equal or longer than the feeding period. Feeding cycle characteristics seem to be one of the key factor which controls this OM accumulation.

Further studies on feeding cycles should determine the best working conditions allowing a sustainable treatment. A better understanding of biomass regression phenomena is also needed.

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