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Attached-Growth Cultures on Fine Media for small communities

C. Boutin*, A. Liénard* and J. Lesavre **

* Cemagref, Unité de Recherche Qualité des Eaux et Prévention des Pollutions,
3bis Quai Chauveau, CP 220, F69336-LYON Cedex 09

** Agence de l'Eau Seine-Normandie, 51 Rue Salvador Allende, F92027-NANTERRE Cedex

ABSTRACT

France counts a large number of communities with less than 2 000 inhabitants. The adjustment of wastewater treatment plants, easy to implement and to use, needed by these rural communities, enlarges the number of processes already widely used, such as waste stabilisation ponds and activated sludge. The purpose of this article is to describe the five wastewater treatment systems called "attached-growth cultures on fine media". A high and reliable quality level is obtained by supplying very small organic loads and an alternate feeding of the reactors leading to a self-regulation of the fixed biomass (these sewerage plants don't have any secondary settlement tank).

KEYWORDS

Biofilm ; domestic wastewater treatment plants ; sand filtration ; secondary treatment ; small communities.

INTRODUCTION

Until a recent past, the rural communities with less than 2 000 person-equivalent (PE) were mainly oriented to natural waste stabilisation ponds and small activated sludge plants in extended aeration. The treatment works like trickling filters and rotating biological contactors are relatively underdeveloped.

France is different of most of European countries by its low population density and huge agricultural areas. There are more than 32 000 villages with less than 2 000 inhabitants (Duchène *et al.*, 1997). The project managers were submitted to strong pressures in order to :

- develop new procedures, what has be done at the beginning of the 80's with the first infiltration-percolation on sand equipment in Port-Leucate, extrapolated from American studies (EPA, 1981),
- study the possibilities to use as collective sewerage some systems initially limited to on-site treatment (Racault *et al.*, 1990).

So these "new" techniques can be classified among attached-growth cultures on fine media. They are biological systems for wastewater treatment, for which the effective bacterial culture is developing on added or in place small sized mineral media (a few mm for gravel, to some ten's of μm for the soil in place).

GENERAL COMMON CHARACTERISTICS

The search for the best operating reliability, a high level of treatment, an easy implementation and operation joined to the media size, involves specific design and working criteria :

- very low organic loads in order to limit the development of the biomass by limiting the available food ;
- alternate working of two or three reactors in parallel, so that the oxygenation of the material interstices,

necessarily slow because operating mainly through molecular diffusion, allows to re-establish an oxygen level compatible with a new feeding phase.

A temporary inactivity of the infiltration beds increases also the control of the biomass development, which is falling in extreme food shortage conditions. So the biomass has to consume its reserves and pass to an endogenous respiration (Boutin *et al.*, 1997). Besides, dividing the reactor into several infiltration beds makes easier, to a certain extent, the necessary distribution of wastewater flows on relatively large areas (on a plant designed with 3 beds : around 150 mm per day for the buried filter in operation).

Such loads cannot be distributed uniformly on the surface if influent simply come with the current ; it is then necessary to store them temporarily and to evacuate them at a high flow during a limited period of time. This method is called batch feeding. The devices used to empty the storage basin are various (self-priming siphon, tipping bucket, pumps, electrovalves linked to level detectors).

CRITERIA OF TECHNIQUES DIFFERENTIATION

Visibility of the infiltration beds. The complexity of biological and hydraulic processes, in non-saturated media, is so that the specifications have to initially include safety factors based on a pragmatic analysis of nominal size operating units. The accessibility of the infiltration beds and the possibility to maintain the percolation area is, with the extensive nature of the process, still today, one of the safest way to control clogging phenomenon. For safety reasons, in the systems where feeding is covered by different materials (planted soil or aesthetic gravel), the surface loads are divided by two, for a media similar to one used with open air feeding.

Nature of the biomass media. Two types of filter materials are identified : added material (sand, gravel) and soil in place.

The sand (height : 70 cm), has to be non-calcic and washed river sand ; its granulometry characteristics have to be : $0.2 < d_{10} < 0.4$ mm, $U.C.* < 5$, the particles of less than 80 μ m have to be avoided. This range seems to be today an acceptable compromise between efficiency and reliability of the treatment, and local availability into an area fitting with reasonable transport costs.

When the filter medium is constituted by the soil in place, its permeability characteristics (K : permeability coefficient) will obviously enter into the dimensioning criteria by reducing appreciably the applied surface loads. It's in fact unlikely to find in place a media, appropriate for wastewater treatment, which would show a higher permeability than a chosen sand.

Primary treatment. All the attached-growth cultures on fine media methods go normally through a previous primary treatment step that insures the retention of the suspended matter after decantation (50 % efficiency on the Suspended Solids). The device mostly used is an Imhof Tank, which settling device is usually sized for an upflow velocity of 1.1 m h⁻¹ and a residence time of one hour at the peak flow. The digester has a volume of 90 l/PE and is normally emptied twice a year.

However for the communities less than or equal to 200 PE, the primary treatment can be done by a single septic tank, sized for a residence time of 3 days in one compartment. The inlet and outlet devices are designed to limit the turbulence, to prevent the sludge re-suspension and the release of floating substances. A buried filter usually follows a septic tank. In order to limit all risks of clogging due to uncontrolled release of sludge into the distribution system, a pre-filter is installed after the septic tank, ahead of the storage necessary for the batch feeding. It is not use for wastewater treatment but acts as fuse.

Special case : the reed bed filters. Among the systems based on attached-growth cultures on fine media at open air, the reed bed filters are special for several reasons :

- their implementation as a full process, requires two stages in series, the first stage is fed with only screened wastewater, but it is not necessary to regularly remove the deposits on the infiltration area. It's proven that they mineralise under the shading of the reeds and in the underground area called "rhizosphere".

* U. C. : Uniformity Coefficient = d_{60}/d_{10}

This superficial "compost" layer doesn't reduce the infiltration capacity of the system (Boutin *et al.*, 1997). In short, the five systems, which can be called attached-growth cultures on fine media, are described in table 1. The applied daily surface loads (in $\text{m}^2/\text{g BOD}_5$) are extrapolated from usual empirical values (m^2/PE).

Table 1. Attached-growth cultures on fine media.

	Visibility of the infiltration beds	Materials	Dimensioning
sand filters	yes	sand	IT + $4\text{m}^2/100 \text{ g BOD}_5$ ^(a)
buried filters	no	sand	S T or IT + $8\text{m}^2/100 \text{ g BOD}_5$ ^(a or b)
drainage trench irrigation	no	soil in place (K)	S T or IT + surface load according to K ^(b,c)
surface trench irrigation	yes	soil in place (K)	IT + surface load according to K ^(b,d)
reed bed filters	yes	gravel / sand	$[2.5\text{m}^2 (1^{\text{st}} \text{ stage}) + 1.5\text{m}^2 (2^{\text{nd}} \text{ stage})] / 100\text{g BOD}_5$ ^(a)

S T = Septic Tank I T = Imhoff Tank K = permeability coefficient in mm/h (a) split into 3 units (b) split into 2 units,
 (c) example for an average K of 50 mm/h : $27\text{m}^2 / 100 \text{ g BOD}_5$ (including 12m^2 bottom of trenches)
 (d) example for an average K of 50 mm/h : $20\text{m}^2 / 100 \text{ g BOD}_5$

Examples of dimensioning (secondary treatment only)

Sand Filtration System. For a 400 PE plant, 60 m^3 wastewater and an organic load of $20 \text{ kg of BOD}_5 \text{ d}^{-1}$:

- storage volume : 10 to 20 m^3 pending on the number of batches (3 to 6 per day) ;
- dumping system flow between 120 and $300 \text{ m}^3 \text{ h}^{-1}$;
- 3 beds each with a surface area of 200 m^2 (for example : $20 \text{ m} \times 10 \text{ m}$).

It is possible to obtain the equipartition even with a rough distribution system like a central overflow gutter aligned with the length of the bed. Nevertheless, the granulometry (and particularly d_{10}) is important to set the nominal flow of the batch dumping system. This flow must increase as d_{10} . If the implementation of such a system is not possible, it is then necessary to divide the unitary surface in order to obtain smaller surfaces, which can comply with the use of the projected dumping system.

Buried filters. For a 120 PE plant, 18 m^3 wastewater and an organic load of $6 \text{ kg of BOD}_5 \text{ d}^{-1}$:

- buried sand filters of 360 m^2 divided into two plates alternatively fed ;
- batch feeding allowing a feeding under low pressure of the network (1 m water column). The volume of the batch is about 10 times the volume of the network.
- this network has the following design criteria: nozzles diameter: 7 mm ; distance between the nozzles: 1 m ; distance between the distribution lateral pipes: 1 m

The calculations of the head loss are leading to the diameters of lateral pipes (about 40 mm) and of the manifold pipe (110 mm to 150 mm). For the network dimensioning, the calculations of the head losses result from the technological decisions: positioning and morphology of the filter, central or lateral feeding of the manifold pipe, ... (Hombourger *et al.*, 1998).

QUALITY OF THE EFFLUENT

The infiltration beds are limited in term of hydraulics. So, systems based on attached-growth cultures on fine media should be located after separative sewerage networks. When these systems are suitably designed, sized and operated, they can deliver a high-quality effluent ($\text{BOD}_5 < 25 \text{ mg l}^{-1}$; $\text{N-NH}_4^+ < 10 \text{ mg l}^{-1}$).

Correlatively, high concentrations of nitrate (N-NO_3^-) can normally be observed at each feeding period beginning, during which a nitrate leaching occurs (result of the oxidation process of the ammonia salts kept in the filters during the rest period). The reduction of the total nitrogen are this way very fluctuating. The yields, often negative at the beginning of a feeding period, increase at the end (reaching about 70 %) when the conditions are less oxidising and when the nitrification decreases. The nitrification is first affected when the working conditions are notably and permanently damaging. If at the end of the feeding period the concentrations of nitrate are still higher than those of ammonia salts (stated as elemental nitrogen), it can be concluded that the systems based on attached-growth cultures on fine media work correctly. These measures can be a good "equipment health" indicator, if they are listed into an operation notebook stating, between others, the number and alternation of batch feeding.

Concerning the phosphorus, for all the systems on added materials, the reduction is usually low. After flooding it can be quite high for a while, when the sand contains iron or aluminium, but inexorably it

decreases with the gradual saturation of the phosphate adsorption sites.

In the systems based on soil in place (non-drained) a representative sampling of the effluent's quality is not easy to obtain. Based on equipped area studies, mainly abroad (Crites *et al.*, 1998), and subject to positive assessment of a complete study of pedology, geology and hydrogeology on the concerned area, results can be better than on added materials. Nitrates and chlorides are transferred in the underground environment after the complete degradation of the organic matter. Preliminary studies are necessary for several purposes: e.g. to evaluate the pollution risks of the groundwater (according to its existing or potential use), to prevent temporary saturation conditions, to assure that the flows can be evacuated without damaging the reactor functioning, ... If the soil in place doesn't impose some hydrodynamic restrictions for the evacuation of the processed water, it is not necessary to oversize the infiltration beds for a superficial effluent.

OPERATION

For sure, the main operation constraint is to change regularly the feeding of the working reactor. It has to be done minimum every week, and preferably twice a week, when the system has 3 filters in parallel.

Then, in addition to the necessary general supervision and the surrounding maintenance, a check has to be done for the good working of the batch feeding system and the distribution of the influent when the infiltration area is at open air. The installation of a batch counter and the regular reading of the pointers help for that. The buried systems have to have, downstream the lateral pipes, some pressure tapping, which pressure load has to be periodically controlled.

The pretreatments (screening) have to be cleaned. The regular control of the sludge height accumulated in the primary treatment systems are also essential for the reliability of the treatment, especially for the buried systems. For sand filters, one has to scarify and/or to remove the layer of the superficial sediments.

For the reed bed filters fed with raw wastewater, the annual cutting of the aerial part of the reeds has to be done during winter. Have to be removed after approximately 10 years also the accumulated sediments, which have got an intense aerobic mineralization leading to a mass reduction of 65 %. The extraction, done at Gensac la Pallue in 1996 (Boutin *et al.*, 1997), has proven its feasibility. The plant came back to normal operation without replanting the reeds. New stems develop from the nodes of the rhizomes still in place.

A valuation of operating costs based on the minimum mandatory labour for each process (Boutin *et al.*, 1998) with 3 man-hours costs (regular : 15.24 Euros/hour, specialised technician : 22.87 Euros/hour, hydrocleaning : 68.60 Euros/hour), shows that, for an installation of 400 PE, the annual costs in 1996 are in between 4.57 Euros/i for drainage trench irrigation and 10.67 Euros/i for the sand filters. For a 100 PE plant, 4 multiply these costs, because maintenance time cannot be reduced and is the same for such a low-density population. These figures do not take in account the cost of sludge treatment.

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