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C. Boutin*
A.Liénard*
J. Lesavre**

WASTEWATER TREATMENT PLANTS FOR SMALL COMMUNITIES: FIVE ATTACHED-GROWTH CULTURES ON FINE MEDIA

* Cemagref, Unité de Recherche Qualité des Eaux et Prévention des Pollutions, CP 220, 3bis Quai Chauveau, 69336-LYON Cedex 09 - France

** Agence de l'Eau Seine-Normandie, 51 Rue Salvador Allende, 92027-NANTERRE Cedex - France

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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. The purpose of this article is to describe 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). The effluent's quality reaches 90 mg.L⁻¹ COD. The nitrification is almost complete (KN-N <10 mg.L⁻¹). Nitrate contents are variable depending on feeding cycles and can be important.

KEYWORDS

Attached biofilm ; wastewater treatment plants ; sand filtration; small communities.

INTRODUCTION

Until a recent past, the French rural communities with less than 2 000 people-equivalent (PE) were mainly oriented to natural waste stabilization ponds (WSP) and small activated sludge plants in extended aeration (AS). One of the great interests of WSP is to be possibly maintained by a staff who didn't receive any special training. On the other hand, the quality of the effluent determined by the expected filtered COD concentration is only 125 mg.L⁻¹. AS has a greater efficiency and produces an effluent with a good quality level. But in order to reach such targets, it is necessary that a skilled staff operates rigorously. The project managers were submitted to strong pressures in order to develop new processes which combine the performances of AS and the easy operation of WSP. They suggest to:

- develop infiltration percolation on sand (so called Sand Filters).
- study the possibilities use as collective sewerage 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 (Boutin *et al.*, 1998). The purifying processes are based on aerobic bacteria fixed on an inert media which development is self-regulated. This bacterial development is controlled by a low input of organic load. That is equivalent to limit the quantity of available food. Furthermore, in order to reduce biological clogging risks and secondly to limit discharges of suspended solids, non-feeding or rest periods further a self-regulation of the biofilm. This temporary inactivity increases the control of the biomass development, which has to consume its reserves and pass to an endogenous respiration. As the granular interstices have no sufficient size (a few mm) to allow a natural ventilation, the aerobic conditions upholding is mostly done by gas molecules diffusion between ambient air and infiltration bed. So specific design and working criteria are: i) very low organic loads, ii) alternate working of two or three reactors in parallel. Hydraulic loads cannot be distributed uniformly if influents 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".

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CRITERIA OF DIFFERENCIATION

Five processes have these common characteristics: Sand Filters (SF), Buried Filters (BF), Drainage Trench Irrigation (DTI), Ridge Irrigation (RI) and Reed Bed Filters (RBF).

Nature of the biomass media: 2 types of materials are used: added material (sand, gravel) and soil in place. The sand used for SF and BF (height: 70 cm) has to be non-calcic and washed river sand. Concerning its granulometry characteristics, the best compromise seems to be today: $0.25 < d_{10} < 0.4$ mm (Liénard *et al.*, 2000). RBF use gravel at first stage and sand (with previously defined quality) at second stage. The infiltration beds which dimensioning criteria follow are water-tightened and drained in order to control the effluent's quality. They can be "not drained" in some specific conditions. If the soil doesn't impose some hydrodynamic restrictions (defined by preliminary exploration), it is not necessary to oversize them. When the filter medium is constituted by the soil in place, its permeability characteristics (K : permeability coefficient) will obviously enter into the dimensioning criteria. After a qualitative exploration of the soil and the subsoil thanks to several soil profiles (Crites *et al.*, 1998), some permeability tests will be made. In case of DTI, the wastewater daily flow allowable per wetted soil area at the bottom of the trench (see abacus on fig. 1) is quantified when K is known (Gril, 1982). Equivalent hydraulic loads have been found in a similar experience in Quebec for soils which permeability is included between 6 and 50 mm.h^{-1} (Société québécoise d'assainissement des eaux, 1991). The same abacus is used for RI and it leads to define the wetted area in which ridges (30 to 50 cm deep) are dug judiciously along the contour-lines.

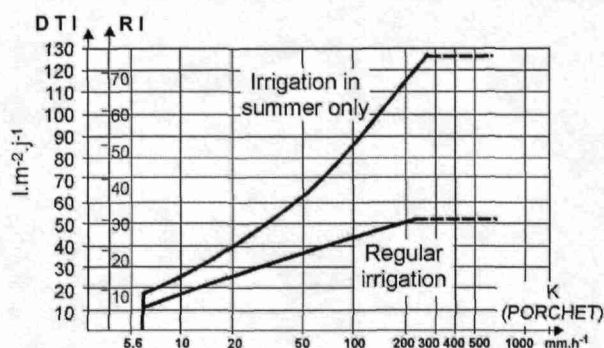
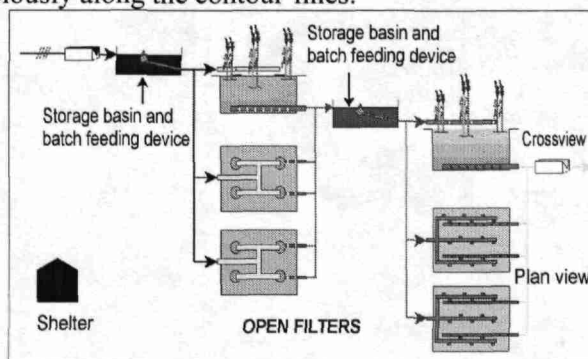


Figure 1. Allowable hydraulic load according K .



Schema 1. Reed Bed Filters (RBF)

Visibility of the infiltration area. Two cases are met:

- i) the wastewater dispersion area is visible and is voluntarily kept at open air,
- ii) it is not visible and it is voluntarily covered with a planted soil or preferably by an aesthetic gravel. Corresponding plants were initially set up for on-site treatment and are being developed in general for communities with a few tens of houses.

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 ways to control clogging phenomenon. For safety reasons, in systems where the feeding area is covered, the applied surface loads are divided by two, for a media similar to the one used with open air feeding.

MAIN DESIGN CRITERIA

Schemas 1, 2, 3, 4 and 5 show 5 processes drafts. Among the systems based on attached-growth cultures on fine media at open air, the RBF are special for several reasons:

- i) their implementation requires two stages in series (see schema 1),
- ii) 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 the deposits mineralise in the "rhizosphere". This superficial "compost" layer doesn't reduce the infiltration capacity.

In short, the dimensioning of the five systems are described in table 1. The applied daily surface loads in $\text{g BOD}_5.\text{m}^{-2}.\text{d}^{-1}$ are extrapolated from empirical values generally used in France (m^2/PE).

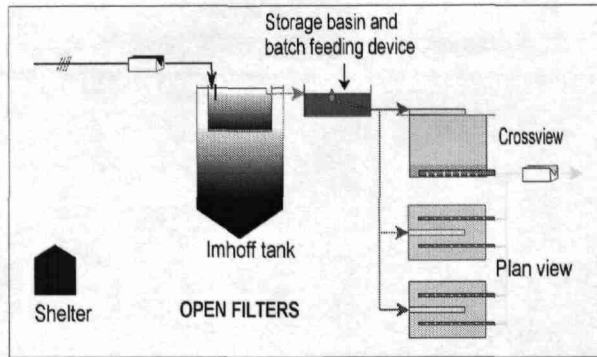
operated, they can deliver a high-quality effluent, which can be quantified in case of drained processes: $BOD_5 < 25 \text{ mg.L}^{-1}$, $COD < 90 \text{ mg.L}^{-1}$, $SS < 30 \text{ mg.L}^{-1}$, $NH_4^+-N < 10 \text{ mg.L}^{-1}$ (Guilloteau *et al.*, 1993). Correlatively, high concentrations of nitrate can normally be observed at the beginning of each feeding period, 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 is 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. Concerning phosphorus, for all the systems on added materials, the reduction is usually low. It can be quite high for a while, when the sand contains iron or aluminium but 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, 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. BOD_5 removal reaches 98 % (Crites *et al.*, 1998). 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 functioning of the filters.

CONCLUSIONS

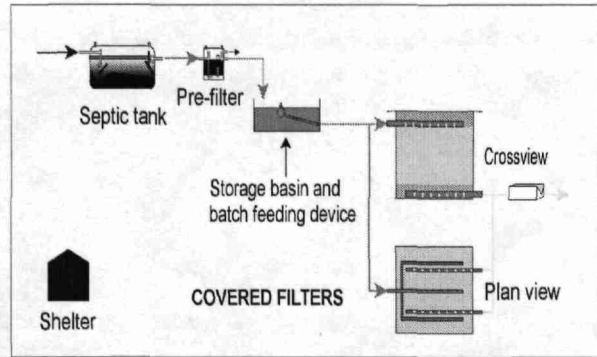
The attached-growth cultures on fine media wastewater treatment plants are defined by a very low level of applied loads ($< 40 \text{ g of } BOD_5.m^{-2}.j^{-1}$) and are split in a few alternately fed units (2 or 3). These two requirements allow a control of the development of the active biomass and avoid mass clogging. The five processes differ by the nature of the biomass base material (added media or soil in place) and the possible visibility of the infiltration area. The plants where the infiltration area is either regularly scratched (SF) or pierced by the reed stems (RBF) allow more important surfacic loads. These techniques are leading to a quality effluent ($COD < 90 \text{ mg.L}^{-1}$). Nitrogen is almost completely nitrified and the follow up of the nitrate contents gives a good indication of the filter oxygenation. Attached-growth cultures on fine media are completing the choice of techniques for collective sewerage (even though some were previously only used for on-site treatment) for a range between 50 to 2 000 PE. In spite of a still imperfect knowledge of the complex mechanisms happening in these non-saturated media, and in spite of onsite implementation not completely mastered, they show some advantages (effluent quality, easy maintenance,...) already attractive for many small communities.

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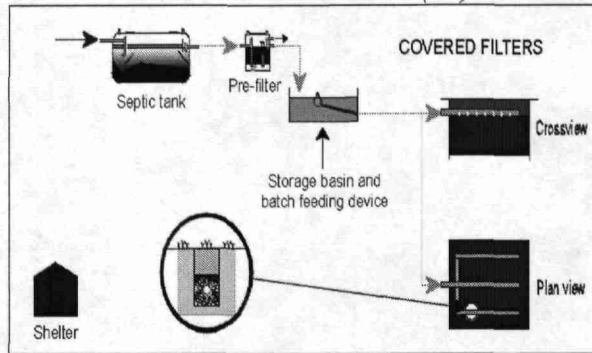
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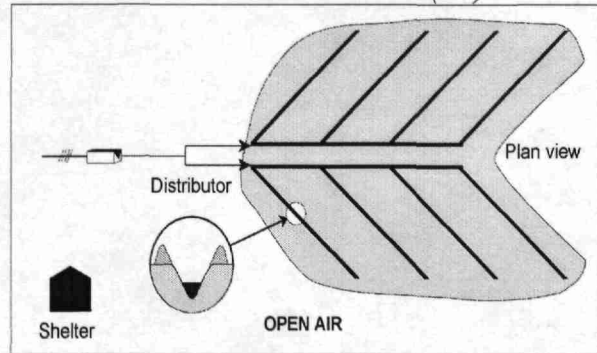
Schema 2. Sand Filters (SF)



Schema 3. Buried Filters (BF)



Schema 4. Drainage Trench Irrigation (DTI)



Schema 5. Ridge Irrigation (RI)

Table 1. Main design criteria of attached-growth cultures on fine media systems.

	Infiltration area's visibility	Materials	Dimensioning
SF	Yes	Sand	pre-treatment + $25 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (a)
BF	No	Sand	pre-treatment + $12.5 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (a or b)
DTI	No	Soil in place (K)	pre-treatment + surface load according to K (b,c)
RI	Yes	Soil in place (K)	pre-treatment + surface load according to K (b,d)
RBF	Yes	Gravel/sand	$40 \text{ g BOD}_5 / [1 \text{ m}^2 (1^{\text{st}} \text{ stage}) + 0.6 \text{ m}^2 (2^{\text{nd}} \text{ stage})] \cdot \text{d}^{-1(a)}$

(a) split into 3 units ; (b) split into 2 units ; (c) example for an average K of 50 mm/h : $3.7 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (including 0.44 m² bottom of trenches) ; (d) example for an average K of 50 mm/h : $5 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$

The daily applied load for french BF is on the high side of the following range: $2.5\text{-}10 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ used for similar processes called "intermittent sand filters" mentioned by Crites (1998). The differentiation between SF and BF is seldom utilised. That leads to accept no precise ($5 \text{ to } 20 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$) applied load rates for an "open or buried filter bed" (Van Buuren *et al.*, 1999). We can also consider that the lower limit of this range rather concerns BF and the upper limit concerns SF. RI can be compared to "Land treatment slow rate process" for which applied loads are generally less than $1.1 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (Crites *et al.*, 1998). The applied loads for RBF, also called "vertical flow constructed wetlands" are equivalent to those generally used in Europe, with an upper limit fixed at $75 \text{ g BOD}_5 \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (Vymazal *et al.*, 1998). BF, DTI and RI work for effluents coming from communities whose size usually do not exceed 400 PE. Due to their covered infiltration area, BF and DTI have a good integration into the landscape. But, the difficult control of an optimised distribution limits the size of the plants. The size of RI, similar to a simple irrigation of settled wastewater at open air is also limited for obvious aesthetic reasons. SF and RBF can process wastewater coming from a larger range of population (a few tens of inhabitants and more than 2 000 PE).

EFFLUENT QUALITY

The hydraulic capacity of such filters is limited and/or not clearly established. So, these systems should be connected after separate sewerage networks. When they are suitably designed, sized and