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EXPERIMENTAL PLANTS FOR VERY SMALL COMMUNITIES: CHOICE AND DESIGN CRITERIA FOR FIVE DIFFERENT PROCESSES

C. Boutin*, A. Liénard*, J. L. Ramain** and L. Beyeler**

** CEntre national du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts (CEMAGREF), Division Qualité des Eaux, 3bis, Quai Chauveau, CP 220, 69336 Lyon Cedex 09, France*
*** Conseil Général de Haute Loire (Haute Loire County Council), Service Départemental de l'Eau, 10, Rue Jules Valès, 43000 Le Puy, France*

ABSTRACT

Waste stabilization ponds and land treatment seepage, which are generally used for very small communities, are being used less frequently due to their specificity and their lack of suitability in certain cases (ground characteristics, available space, fragile receiving bodies, etc.)

This article gives the choice criteria for the proposed new series for 5 communities sized between 50 and 400 p.e. (person equivalents), together with a detailed description of the facilities :

- septic tank + covered infiltration bed
- horizontal settling-digestion tank + covered infiltration bed
- settling-digestion tank (Imhof tank) + trickling filter + infiltration bed
- pond + covered infiltration bed
- reed bed filters

in addition to the design of the infiltration beds and discussion of the investment costs.

All the series had to achieve the following effluent quality levels :

- COD = 90 mg/l, BOD_5 = 30 mg/l, TSS = 30 mg/l, N-NK = 40 mg/l

For the time being, the difficulties encountered are of a technical nature and concern the infiltration beds' feeder devices which do not produce a flat water jet that gives even spreading.

KEYWORDS

Association of processes; costs; design criteria; infiltration-percolation beds; reed bed filters; septic tank; small communities; wastewater treatment.

INTRODUCTION

For a long time, the CEMAGREF has taken a great interest in wastewater treatment systems for small communities in rural areas that are of a "rustic" and simple type. It has made major contributions to the development of wastewater stabilization ponds. In France the most common wastewater treatment series for very small communities (about 100 p.e.) are :

- seepage
- wastewater stabilization ponds (WSP's).

Land treatment of wastewater uses the local soil's capacity for treatment. Feasibility studies based on an appraisal of topological and hydrological soil conditions investigate the general nature of the site. It is also necessary to measure soil permeability. It is the conclusions of these prior site surveys that therefore determine whether or not it is possible to use this technique.

WSP's are not entirely satisfactory for very small communities. Very small communities' wastewater is indeed particularly characterised by its very small quantity (Pujol *et al.*, 1990). If, in addition, the facilities have been oversized (even by as little as several tens of p.e.), and if the connection rate remains low in the first few years, the pond will only be filled to a very low level and the community will soon be confronted with malfunctioning problems (increasing concentration due to lack of effluent). This situation will become even worse if the prior design studies concerning the tightness ($K<10^{-8}$ m/s) have not been correctly carried out. In the case of a violent rain storm, since most systems are of combined type, the ponds will be subject to such a hydraulic overload that a "flushing" effect will occur, leading them to discharge an effluent of high organic content. The Conseil Général (County Council) of Haute Loire, a French department with a low population density is aware of the limits of WSP's and is involved in a programme to experiment with various types of wastewater series for very small communities.

The aim of this paper is:

- to explain the choice criteria for each plant
- to describe the 5 experimental plants
- to give the values used in design
- and to give the initial results collected from monitoring that has been carried out.

CHOICE CRITERIA FOR EACH SERIES

The sizes are small, greater than 50 p.e., but not exceeding 400 p.e (Table 1). Site 3 is subject to a slight seasonal tourist effect which leads to an increase in population by a factor of approximately 2 in the summer period. Small sized communities do not have specific staff at their disposal to operate their intended wastewater treatment plants. It is thus advisable to install "rustic" series (Ministère de l'Agriculture, 1986) in other words, plant which can be operated by staff (without any particular training) and which has low operating costs.

TABLE 1. Size of the Communities

SITES	1	2	3	4	5
Population in p.e.					
. Permanent	50	110	70	270	60
. Seasonal	--	40	50	50	20
. Maximum	50	150	120	320	80
. Used in the project	50	150	120	400	100

All effluent is basically of household type. The effluent quality to be treated is only likely to be changed by a few discharges from agricultural activities. The sewerage systems are mostly of combined type (sites 3, 4 and 5) or of pseudo-separate type (site 2). Only one installation is fed by a truly separate system (site 1). The effluent quality of the intended wastewater treatment plant is defined, as far as possible, in terms of the recipient type (Table 2).

In two of the cases, the recipient requires a relatively thorough treatment to be performed, removing organic matter to concentrations ≤ 90 and 30 mg/l respectively for COD and BOD_5 (Circulaire interministérielle, 1980). This level cannot be achieved by a conventional 3 pond lagooning series. If possible, it is thus advisable to install a new type of plant. For the other sites, the constraints relating to the chosen location (Table 3) also preclude the use of a lagooning treatment technique due to shortage of space (sites 3 and 5) in conjunction with undulating topography (site 1).

TABLE 2. Recipient Characteristics

SITES	1	2	3	4	5
Type	intermittent stream	small stream	ditch dry valley	river	small stream
Ranking Classification (STRAHLER, 1952)	0	1	---	3	2
Comments	---	water quality objectives (class 1A)	---	minimum flow 0.5 m^3/s	---
Quality of the effluent to reach	---	COD=90 mg/l BOD_5=30 mg/l	---	COD=90 mg/l BOD5=30 mg/l NK=40 mg/l	---

TABLE 3. Inherent Constraints of the Sites

SITES	1	2	3	4	5
Available space	little	little	very little	average	little
Altitude	700 m	1,200 m	850 m	730 m	530 m
Gradient	high	low	high	low	low
Under-soil type	granite	clay and boulder	granite	loamy alluvium	clay

In this particular French department, the climate can be very harsh at higher altitudes. Snow and intense freezing conditions are not uncommon in winter.

DESCRIPTION OF THE FACILITIES

The above-mentioned limits point towards compact types of series (Agences de l'Eau, 1993), based on processes involving attached growth biological systems on fine media, hereafter called "infiltration beds" (IB's). The principle is to percolate wastewater vertically through several beds containing a gravel medium, then the effluent is collected. Aerobic conditions for decomposition of organic matter are maintained by sequencing the alimentation (a feed period followed by a rest period). Batch feeding favours air renewal and gives a better spread of the influent.

The 5 plants, all of different design, all include at least one IB treatment stage; they can be open-air, covered with top-soil or have reeds (*Phragmites communis*) planted on them. Combining this stage with various technologies allows original series (Schierup *et al.*, 1990) to be proposed, enlarging the range of processes adapted to small communities.

The first three sites have relatively similar physical constraints (shortage of available space, high altitude, granite or heterogeneous type soil).

Plant 1 comprises a septic tank and a covered IB .

Plant 2 is of similar design to 1. A horizontal settling-digestion tank replaces the septic tank: this choice is influenced by the population size and will enable the two primary treatment stages to be compared later on. The design of the horizontal settling-digestion tank means that it probably behaves much as a septic tank since the settling and digestion zones are not separated.

Plant 3 comprises a settling-digestion tank, a low rate trickling filter and an IB with an open-air feed. On this site, the naturally very steep gradient enabled a trickling filter to be installed without it creating an eyesore.

In this case, the IB, which receives an effluent that is already well treated, is deliberately left exposed to the weather. In fact it is open-air in order to determine the real consequences of a harsh climate on such an IB system, at least in terms of operating considerations.

Plant 4 comprises a pond and a covered IB system. The space available and the type of under-soil enabled a natural clay-lined lagoon to be constructed. In view of the altitude, the IB's are covered with top-soil.

Plant 5, located at the lowest altitude of the five, is a two-stage filter of reed bed type, for which the feed is entirely open to the air (Lienard *et al.*, 1990, in press).

Table 4 below, gives a summary of the series' design and gives the bases for theoretical design. For vertical settling-digestion tanks, the use of usual values leads to oversizing of the settling zone and thus to an increase in the detention time. In this layout, the effluent is likely to become septic.

TABLE 4 The Proposed Series

SITES	1	2	3	4	5
First treatment stage	septic tank	horizontal settling-digestion tank	vertical settling-digestion tank	1 pond	IB with reeds
Theoretical bases for design	tank volume $= 4m^3 + 0.75V$ daily average	total volume > 200l/p.e.	settling (at peak flow rate) Rising V ≤ $1.5\ m^3/m^2h$ Detention T ≥ 1 h digestion Effective V=150 l/p.e.	$5\ m^2$/p.e.	effective surface area = $1\ m^2$ planted/ 80g COD
examples of ground space requirements					
For 50 p.e.*	$V = 9.6\ m^3$	$V = 10\ m^3$	---	$A = 250\ m^2$	$A = 50m^2$
For 150 p.e.*	$V = 21\ m^3$	$V = 30\ m^3$	$A = 9.1 m^2$ H = 2.8 m $V = 25.5\ m^3$	$A = 750\ m^2$	$A = 150\ m^2$
Following stage(s)	covered IB	covered IB	low rate Trickling Filter (TF) + IB	covered IB	planted sand filter,
Bases for design	$3\ m^2$/p.e.	$3\ m^2$/p.e.	TF=180g BOD_5/m^3 media. $IB=0.20\ m^3/m^2$	$1\ m^2$/p.e.	$150l/m^2$
examples of ground space requirements					
For 150 p.e.*	$S=450\ m^2$	$S=450\ m^2$	TF h=3m R=1.5 m IF $S=115\ m^2$	$S=750\ m^2$	$S=150m^2$

* In rural area 1p.e. = 150 l day^{-1} and 75 - 80 g COD day^{-1} (PUJOL *et al.*, 1990)

Using the results acquired (Guilloteau *et al.*, in press) concerning infiltration-percolation beds, it is reasonable to think that the effluents from these five series should in theory at least comply with the following quality:

- COD ≤ 90 mg/l
- BOD_5 ≤ 30 mg/l
- TSS ≤ 30 mg/l

In addition, the Kjeldahl nitrogen level should remain below the 40 mg/l limit (Circulaire interministérielle, 1980). This limit value could be lower if the initial concentration of the effluent is relatively low. Plant 5 is likely to give a better quality level due to the design of the second stage (intermittently immersed).

TABLE 5. Investment Costs (1991–1992 prices) (excluding the sewerage system)

SITES	UNITS	1	2	3	4	5
Budgeted cost	FF exc. tax	120,000	250,000	180,000	500,000	200,000
Real cost	FF exc. tax	102,000	198,000	286,000	610,000	200,000
Cost/p.e.	FF exc. tax /p.e.	2,040	1,320	2,385	1,525	2,000
Community size	p.e.	50	150	120	400	100

The series requiring the greatest investment (Table 5) is also the most complicated one since it includes a trickling filter. This data underlines the disparity of the values encountered, values which can vary by a factor of two, basically dependent on the inherent constraints of the site. Within the population range chosen (50 to 400 p.e.) the average investment cost of these series offering an expected quality mentioned above can however be estimated at approximately 1,860 FF exc. tax, per p.e. This relatively low cost is largely due to availability of filtering materials used in IB's. The frequent use of pouzzolana is particular to the Haute Loire region, a volcanic region.

DESIGN OF INFILTRATION BEDS

An IB generally comprises 3 zones (Fig. 1). A feeder and water spreading zone (Table 6), an "active" zone (Table 7) which often has a medium of finer granulometry than the previous stage followed by a collector zone for the treated effluent (Table 8).

TABLE 6. Feeder Zone (Ø = diameter in mm)

SITES	1	2	3	4	5
Covering	top-soil h=70cm	top-soil h=70cm	open-air	open-air	open-air, reed bed
Batch feeding . device	tipping bucket	bell-type siphon, replaced by a tipping bucket	tank + oscillating arm	tank + valves	siphon
. unit volume	100 l	120 l	200 l	6 m^3	1.5 m^3
Distribution	gravity 2 underdrains /filter Ø 60	gravity 6 underdrains Ø 80	pressurised 3 outlets Ø 315	pressurised 2 outlets Ø 315	gravity 2 outlets
Dispersing materials	pouzzolana* Ø 30-60 h=30 cm	pouzzolana* Ø 30-60 h=30 cm	---	top-soil h=10-20 cm	gravel Ø 2-5 h=5 cm

TABLE 7. Active Zone (Ø = diameter in mm)

SITES	1	2	3	4	5
Number of beds	2	1	1	2	4
Surface area	2x73.5m^2	450m^2	82m^2	2x200m^2	4x37.5m
Length	21m	30m	13.1m	20m	7.5m
Width	7m	15m	6.2m	10m	5m
Material	pouzzolana* Ø 3-6	pouzzolana* Ø 3-6	pouzzolana* Ø 10-40	pouzzolana*/sand Ø 3-6	sand Ø 0-4
Height	1m	1m	0.65m	1m	0.6m

TABLE 8. Effluent Collection Zone (∅ = diameter in mm)

SITES	1	2	3	4	5
Material	--------------------	pouzzolana* ∅30-60	or 40-100	------------	gravel ∅30-60
Height	0.25-0.30m	0.3m	0.35m	0.3m	0.1m
Drains	yes	yes	no	yes	yes
. function	drainage	aeration	---	aeration	drainage
. number	5	7	---	2/ bed	1/ bed
. position	1/2 length	total length	---	total length	across length
. diameter	∅ 60	∅ 60	---	∅ 100	∅ 100

* The use of pouzzolana is particular to this volcanic region.

The following comments apply to the preceding tables.

- Design of the IB's is dependent on their position in the treatment series. When treating a raw effluent or one that has simply undergone a settling process, the basis for design depends on the organic content to be treated. The value used is 1-3m^2/p.e., or in other words 1-3 m^2 of effective surface area treats 80 g of COD.

For additional treatment the design is based on hydraulic considerations and the value of 150-200 l/m^2 is taken.

- The height of the active zone varies from 60 cm to 1 m

- The material is commonly of a granulometry of between 3 and 6 mm. Use of a coarser material (10-40 mm), and its use in additional treatment, can only be justified by specific local constraints (site 3). In order to complete the study, it will certainly be necessary to change this over-coarse material.

- The deepest zone, of high granulometry (∅ 30-60 or 40-100) often performs a dual function: drainage and aeration of the active zone (enhanced by installation of drains linked to vents open to the air.

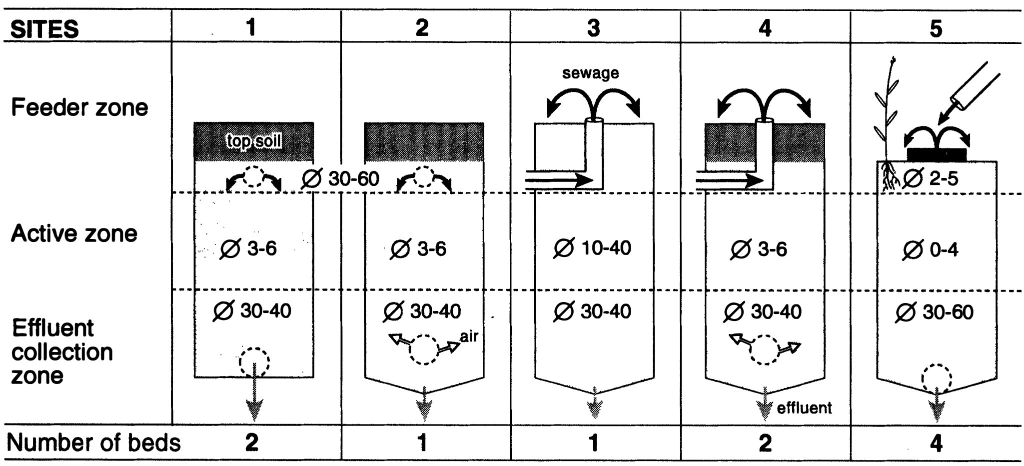

Fig. 1. Schematic cross sections of IB's.

ALTERNATE FEEDING OF INFILTRATION BEDS

Wherever they are situated in the treatment series, IB's are alternately dosed and rested in order to maintain the aerobic conditions for decomposition of organic matter (Liénard *et al.*, 1990). The methods used to achieve this objective are:

- either to multiply the number of independent beds,
- or to individually control the operation of drains or outlets on single beds.

Table 9 below shows for each facility, the theoretical maximum height of water for each batch.

TABLE 9. Theoretical Height of Water for Each Batch

SITES	1	2	3	4	5
Unit batch volume	0.1 m^3	0.12 m^3	0.2 m^3	6 m^3	1.5 m^3
Minimum unit surface area	73.5 m^2	7.5 m^2	27.3 m^2	200 m^2	37.5 m^2
Theoretical height of water	1.36 mm	1.6 mm	7.3mm	30 mm	40 mm

These figures highlight the major design difficulty encountered on IB's: the optimal use of the available surface area. Indeed, in 3 out of 5 cases, the height of water jet is a lot less than the maximum granulometry of the material. Under these conditions, only a very small portion of the available surface area is actually wetted on each batch. For sites 4 and 5, the unit batch volume, assuming that it is inlet in a very short time (one minute) seems to only just account for the initial permeability of the material used. Using this first approach it would seem that a minimum height of 50 mm could be used. The difficulty is thus to have unit volumes sufficiently large and unit surface areas sufficiently small without overly increasing investment costs.

MONITORING

Only sites 2 and 3 were monitored last summer. Site 2 functioned in conditions close to design values. During the period over which measurements were taken, the effluent quality was as expected (see table 2).

TABLE 10. Change in Nitrogen Composition (in mg/l)

	wastewater	effluent				
	N-Nk	N-Nk	$N\text{-}NH_4^+$	$N\text{-}NO_2^-$	$N\text{-}NO_3^-$	N-NT
Site 2	83	12.8	11.0	1.5	26.7	41.0
Site 3	100	5.4	5.0	1.5	32.5	39.4

The IB of site 3, operating as a complementary (tertiary) treatment, operated under conditions of significant hydraulic underload (less than 50% of its capacity). With this reservation, the effluent quality also reached the standards.

In terms of nitrogen (Table 10), the results obtained for site 2 are those usually encountered with attached growth biological systems. The high performance level on site 3 is due to successive passage through the deep trickling filter and the IB which gives good nutrient oxidation. Initiation of the recorded denitrification is not controlled and it can thus not be enhanced.

Both plants discharge an effluent whose Kjeldahl nitrogen content is less than the initially fixed 40 mg/l value. The next level (N-Nk $\leq$ 10mg/l) could be achieved if IB's are used as an additional treatment process. Further studies will enable this hypothesis to be backed up.

In both cases, phosphorus is mineralized but not absorbed by the "pouzzolana" material. Removal of this substance is thus very poor (20%).

DISCUSSION

The use of infiltration beds (IB's), for which the treatment process is based on aerobic attached growth biological films on a fine medium, would seem to be likely to develop in France for small communities, due to their reduced requirement for ground-space and their "rustic" criteria which are usually attributed to waste stabilization ponds.

IB's can be associated with various primary treatment processes (septic tanks or settling-digestion tanks) or associated with the finishing stage of lagoons and with other rustic processes. Whether covered, open-air or as reed beds, they should very soon see an increase in their use as wastewater treatment plants for all small communities.

Due to the action of mechanical filtration combined with bacterial degradation, the initial results are encouraging in terms of the removal of organic matter, as characterised by the parameters COD, BOD_5 and TSS. The effluent concentrations for these parameters should achieve the following levels: 90 mg/l, 30 mg/l and 30 mg/l respectively.

Removal of nitrogen is normal and exceptional removal must not be expected without a specific and controlled denitrification stage.

The greatest difficulty encountered with IB's today lies in the correct installation of the batch feeder in order to obtain optimal spreading. The appropriate devices (for example : siphon or tipping bucket) must always be "rustic". A balance must be sought between the batch volume and the minimum surface area, without causing the investment costs to rise too high.

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