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Catherine Boutin, A. Lienard

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CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT : THE FRENCH EXPERIENCE

Catherine Boutin *and Alain Liénard *

* Cemagref, Water Quality Research Unit
3bis, Quai Chauveau, CP 220, F69336-LYON Cedex 09, FRANCE.
catherine.boutin@cemagref.fr

1. INTRODUCTION

Concerning wastewater treatment, France has a very special position in Europe: the 60 millions inhabitants, according to the census of 1999, are spread over 36 600 administrative districts. France has compared with the neighbour countries, a low population density (100 inhabitants per km²). Even though an important part of the population is living in some important urban areas, 25 % of the population is spread over 31 900 administrative districts of less than 2 000 inhabitants.

This situation explains the importance part of on-site treatment (11 millions inhabitants, 5 millions plants) and the high number of low capacity treatment plants. In France, about 80 % of the 15 000 wastewater treatment plants have a capacity lower than 2 000 Person Equivalent (PE).

Above 1000 PE, the treatment process is mainly based on activated sludge. Below, more rustic processes are being used: Waste Stabilisation Ponds (WSP), Intermittent Sand Filters (ISF), and Reed Bed Filters (RBF).

“Rustic” and rather simple wastewater treatment systems for such small communities in rural areas have been a major interest of Cemagref for a long time.

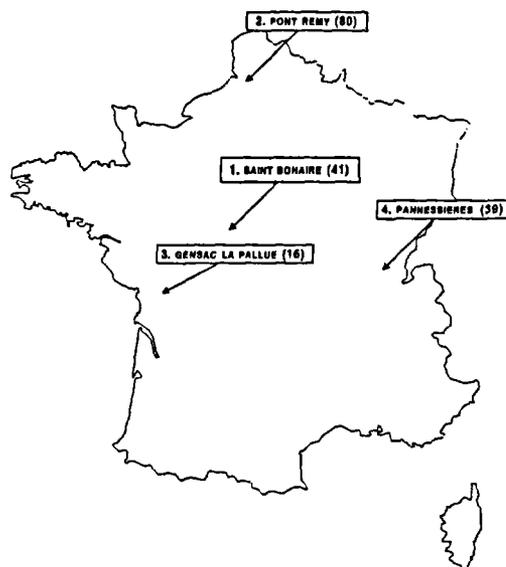
2. BRIEF HISTORY

Cemagref has largely contributed to the development of the technique of treating wastewater in WSP, which have considerably developed in the 1980's. To a certain extent, one of the first widely spread technical papers related with the design of a “WSP French type” (3 ponds in series with a specific area of 10 m².PE⁻¹ [the 1st one with a depth of 1 to 1.2 m is of microphytes type and a specific area of 5 m².PE⁻¹]) had encouraged the planting of macrophytes in the 2nd and mainly in the 3rd basin (Ministère de l'Environnement *et al.*, 1979). To enable the growing of the different rooted aquatic plants (*Typha*, *Scirpus*, *Juncus*, *Phragmites*,...) in these basins, it was recommended that their water column has to be reduced to about 0.3 m. In 1987 (Boutin *et al.*, 1987), the

development of the planted ponds has been estimated to represent 17 % of the number of WSP, mainly built in the North East of France and representing a total area of 147 ha. Only a few of them (35 ha) were completely covered with emergent hydrophytes and could have been compared to Surface Flow Wetland systems.

A national survey done in 1992, with the aid of local services and water agencies, revealed that based on 280 questionnaire data sheets describing 178 WSP, the proportions were quite similar to the previous survey in 1987. In 80 % of the cases, plants studied were with microphytes only. In 20 % of the cases, the last pond was entirely or partially planted with macrophytes (Racault *et al.*, 1995). Very few studies have been conducted in France to evaluate the benefits of planting the whole or only a part of WSP. But a lot of communities reported the difficulty of cutting the aerial part of the macrophytes and to remove it from the water every year in winter to avoid the degradation of the withered vegetation in the water. Therefore, in France, the planting of macrophytes in WSP has not yet been recommended.

Because the surface required for WSP is large and can be a limiting factor together with the necessary tightness of the underlying soil, it has been also important to look for alternatives to WSP.



- 1 - 2 small plants directly designed by K.Seidel (5 treatment stages) in a boarding school (around 30PE each).
- 2 - Experimental plant (also 5 stages) designed by Cemagref for 500 PE in a housing site (abandoned when the whole community was connected to a sewerage network).
- 3 - 8 vertical flow reed-bed filters, for 1600 PE, designed by Cemagref, acting as a 1st stage treatment upstream of 3 under dimensioned WSP (5 m²/p.e.).
- 4 - Plant with 5 stages for 500 PE., designed by local services after a technical visit to Dr. Seidel in Germany.

Figure- Location of plants, more or less designed on a « Seidel basis », built between 1978 and 1990

Since the 1980's, Cemagref has undertaken research in the field of attached growth biological treatment systems on fine media planted with macrophytes as a whole. These investigations took place first on 2 small wastewater treatment plants at a boarding school (see 1, Fig.1), constructed in 1978 and 1982 under the direct advice of Dr. K. Seidel. The encouraging results (Boutin, 1987) obtained, mainly on the 2 first Vertical Flow stages, fed with raw wastewater without clogging, largely contributed to continue the investigations on other experimental plants (Liénard, 1987, Liénard *et al.*, 1990a) and mainly in the one built to extend the capacity of an existing WSP (see 3, Fig.1), through the installation of a first stage of RBF upstream of the ponds (Liénard *et al.*, 1993).

This shows that the use of constructed wetlands systems was relatively poor at that time.

SINT (Société d'Ingénierie Nature et Technique) is a private design and building company which has been created in 1991, with Cemagref's expert back up being provided under contract to develop the Reed Bed Filters.

In 1996, 14 domestic sewage treatment plants, directly designed by SINT, were in operation in France for the treatment of domestic wastewater. They have all been completed since 1992. RBF were most frequently developed for small sewerage systems; the sizes of 10 of these plants range between 100 and 250 PE. Their average size is slightly more than 320 PE, although two facilities have been designed for 1 000 PE. Most of these plants are fed by combined sewerage systems (Liénard *et al.*, 1998).

To day in 2003, the use of such described Reed Bed Filters (raw wastewater treated by 2 stages of vertical flow RBF in series) is very common in France. Most of them are constructed by SINT. It should be possible to count more than 200 plants.

In the middle of February 2003, a national survey (section 3) concerning the use of macrophytes in wastewater treatment was sent to each French administrative department. 1.5 months later, the rate of answers reaches around 35 % (33 French departments compared to the 95): It's possible to exactly enumerate 172 wastewater treatment plants using macrophytes and located on 25 French departments. SINT has designed and/or constructed more of 70% of them.

3. SPECIALIST GROUP IN FRANCE

In France, all the techniques using plants are considered as ecological, rustic, and easily integrated in a rural landscape. So, they are very worthy and their development is really growing.

A French specialist Group was created in May 2001 with the aim of “**promoting the best use of the different processes using macrophytes for waste water treatment**”. So, this group wants:

- i) to have better knowledge in the different processes,
- ii) their limits,
- iii) their design and
- iv) their building conditions

The partners are:

- i) departmental structures for technical aid in the water domain (so called SATESE),
- ii) some universities, engineer schools and a current courses centre,
- iii) some builders,
- iv) Cemagref and
- v) Water Agencies.

This technical group works on two main subjects:

- 1- Conception of a technical guide about recommendations on building red beds filters (both lines: vertical and horizontal flow) for domestic wastewater treatment. Its issue should take place by the end of 2003.
- 2- Establishment of a national data basis. A national technical survey, just at the beginning, will feed it with descriptive data. Before the end of this year, SATESE have in charge to collect quantitative and qualitative data from about 50 wastewater treatment plants, located all over the country and choose from their technical interest. Those measures will take place two times, in summer and in winter. A statistic analysis should help to estimate the influence on several parameters (organic and hydraulic loads, network types, wastewater concentrations, climate, ageing,..) on the outlet quality.

4. REED BED FILTERS'S configuration for raw domestic wastewater

4.1. General configuration of the beds

A typical plant consists of 2 stages of filters: a primary stage of type A filters, followed by a secondary stage of type B filters (Fig.2). Most of the time each stage is divided into 3 units operating independently, but some plants have been designed with 4 units. For very small plants ≤ 100 PE, to reduce the investment cost per capita, it can be possible to design only with 2 units per stage.



Each primary stage unit receives the full organic load during the feeding phase which lasts a number of days (3 to 4 days) prior to being rested for twice this time (around 6 to 8 days) in the case of 3 units per stage, which seems to be the best configuration.

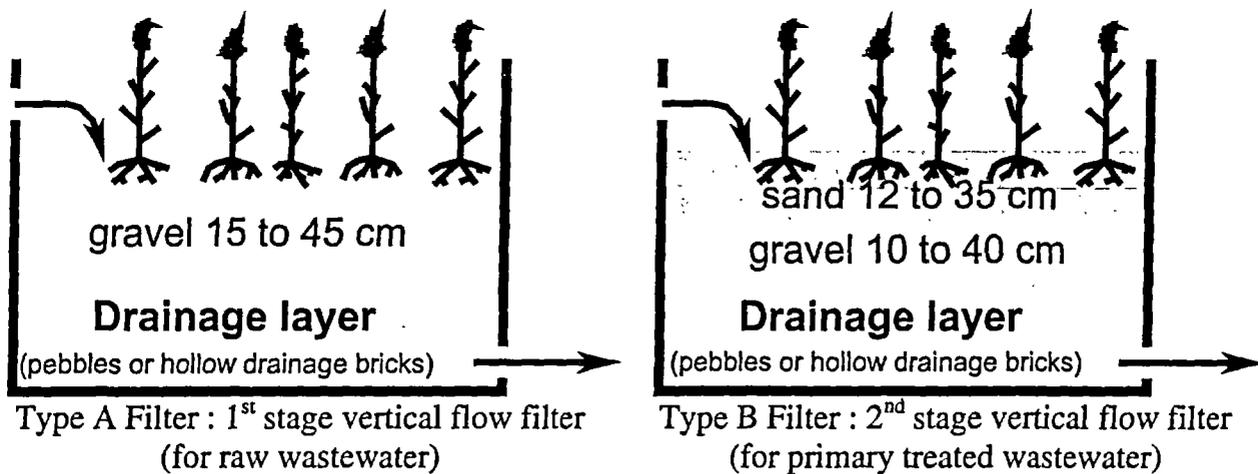


Figure- 2

A typical RBF = A filters (1st stage) followed by B filters (2nd stage)

4.1.1. Batch and alternate feeding

Wastewater is supplied to the filters in hydraulic batches by means of a storage and a high capacity feeding system (pumps, self-priming siphon, etc.). This ensures optimum distribution of wastewater (as well as that of the suspended solids in the first stage) over the whole available infiltration area and improves oxygen renewal between each batch feed.

The feeding system allows for a better distribution of sludge on the filter surface. The sludge accumulation and the withdrawal period depend on the freeboard, which is normally designed to at least 40 cm.

Just after the pumps or the siphon, there are gates to feed one of the filters of the 1st stage.

These alternating phases of feed and rest are fundamental to control the growth of the attached biomass on the filter material (sand, gravel or rhizomes), to maintain aerobic conditions within the filter bed and to mineralise the organic deposits resulting from the TSS contained in the raw sewage retained at the surface of the primary stage filters (Liénard *et al.*, 1990b).

The effluent is then sent to the secondary stage composed of finer filter material, where it is subjected to further treatment and, in particular, the nitrification of nitrogen compounds.

4.1.2. Pre-treatment

A typical RBF plant designed for the treatment of raw domestic sewage (which has been demonstrated to be feasible without clogging problems and which induces only the handling of small amounts of sludge as compost on the top layer of the 1st stage filters every 10-12 years), comprises at least a bar screen retaining large-size particles (≥ 2 cm). Sometimes, for the plants fed by gravity, and especially with combined sewerage systems, 2 bar screen may be installed. The 1st one has a width between the bars of about 4 cm and the 2nd is 2 cm wide.

When a pumping unit feeds the plant, screening is done by a screening basket.

4.2. Design

The dimensioning of RBF is not yet calculated according to sophisticated models but is based on empirical experience. The first stage filters which receive the larger part of the pollution and particularly the suspended solids must have the larger area.

A first stage comprising a total area of 1.2 - 1.3 m² per PE, divided into 3 identical, alternately fed units of 0.4 - 0.45 m² per PE (i.e. a global organic load of the order of 100 g COD m⁻².d⁻¹) allows significant removals to be achieved in relation to carbon waste and suspended solids (> 80 % of COD, > 85 % of TSS), as well as a beginning of nitrogen oxidation (Boutin *et al.*, 1997, 2000b).

Nevertheless, attention must be paid to flows of mineral suspended solids, which could enter the plant with surface run-off water.

For separate sewerage systems, warmer climates and seasonal peak loads during the summer the required surface of the 1st stage filters can most likely be lower (about 1.0 m² per PE).

Considering the second stage, it should be possible to reduce its area. In fact, the effluent feed to the B filters contains low concentrations of TSS (see Table 3) and cannot contribute to the build-up of a clogging surface layer. In spite of an adapted distribution network, different to the one of the 1st stage filters, we still have to evaluate



the area, which is necessary to achieve the performances taking mainly in account the hydraulic loads really applied. The minimal area of the 2nd stage is 1m² per PE and its sizing depends predominantly on the hydraulic loads applied and its good distribution.

4.3. Planting the reeds

Very often the young reeds come from seedlings provided by a specialised horticulturist. The density of planting is generally one plant every 50 cm in each direction.

The propagation is good one year after planting especially on the 1st stage filters and doesn't seem affected by the planting time if it is carried out between March and October.

5. SOME RESULTS

5.1. Rousillon plant

This plant is a typical French RBF and is located in a very touristic area in the Provence region. The treated load changes between summer and winter. The summer population reaches 2 015 inhabitants, the winter population is only 465 inhabitants. The weight mean used for the design was estimated to 1 250 PE. The nominal organic load varies between 56 kg COD.d⁻¹ in winter and 150 kg COD.d⁻¹ in summer. The total area of the filters is 1 550 m² (1st stage:3*350 m² +2nd stage: 2*250m²).

The results, measured from 7 daily values and some quick samples are obtained between 1998 and 2001 (table 1). The removals are calculated from the average of the inlet and the average of the outlet concentrations.

Table- 1
Average evolution of concentrations and yields in Rousillon plant

		COD	BOD ₅	SS	NK-N	NH ₄ ⁺ -N	TP
Concentrations in mg.L ⁻¹	Inlet (7)*	792	405	341	71	41	13
	Outlet 1 st stage (1)*	129	21	35	55	30	10
	Outlet 2 nd stage (12)*	42	6	6	5	2	7
Removal in %	1 st stage	90	99 6	83	45	86	29
	2 nd stage	69	71 1	84	86	93	23
	Global	95	98 6	98	93	96	46

()* = (numbers of values)

The outlet quality of the 1st stage was measured one time in August 2001. At that time, the measured organic load reached 86% of the nominal organic load and the primary stage received an high average load of 123 g COD m⁻².d⁻¹ compared that one generally proposed for a classical design (section;4.2). The good effluent quality could be explained by the summer season and by the small effect of the “organic overload “ during a period limited in the duration.

In terms of nitrogen, the effluent quality is very good. The nitrification is almost complete and the average content in N Kjeldahl reached 5 mg.L⁻¹.

5.2. Queige plant

This plant, built in 1998 treats a pollution from 500 PE coming from a village located in the Savoie department known, to be cold in winter season due to its altitude (600 m).

This plant is a typical one, composed, at the 1st stage, by 3 A filters (Fig.1) and, at the 2nd stage, by 3 B filters (Fig. 2). The 1st stage total area, cut in 3 equal units is 855 m²; the 2nd stage area is 750 m², cut also in 3 equal units. The B filters are not drained and directly infiltrate in the flood plain of the receiving body.

Table- 2

Average evolution of concentrations and yields in Queige plant

		COD	BOD ₅	SS	N-NK	N-NH ₄ ⁺	TP
Concentrations in mg.L ⁻¹	inlet	494	250	178	62	49	9
	Outlet 1 st stage (8)*	123	40	26	25	19	9
	Outlet 2 nd stage (3)*	42	9	12	14	12	6
Removal in %	1 st stage	75	84	85	61	60	7
	2 nd stage	66	77	54	44	49	54
	global	91	96	93	78	80	58

()* = (numbers of values)

“Rhone Mediterranée Corse” water agency has asked for some campaigns. The results, obtained from 8 daily values and measured between 2000 and 2001 are in table 2. The removals are calculated from the average of the inlet and the average of the outlet concentrations.

5.3. Montromand plant

Commissioned in 1994, designed for 200 PE and fed by a combined sewerage system, the plant only receives domestic sewage (Liénard *et al.*, 1998). In order to increase the influent surface load, only three primary stage filters are fed. The total planted area is



2.2 m² per PE, comprising 1.15 m² per PE and 1.05 m² per PE at 1st and 2nd stages respectively.

After 15 months of operation spanning two winters, an assessment was carried out over a continuous period of 48 h in February 1996, during which temperatures rose and fell between - 8.5 °C and + 6.5 °C.

During the two days of measurement, the plant received the same inflow of around 29 m³.d⁻¹ representing a hydraulic load slightly in excess of plant design capacities (115%). The average influent hydraulic load to the operating filter was 450 mm.d⁻¹.

The volume of each batch feed (2.2 m³) applied over an area of 65 m², or little more than 35 mm wastewater depth, may appear low in terms of achieving uniformly distributed loading. Yet, since they are physically retained at the surface, the TSS cause a rapid build-up of clogging deposit which contributes to full usage of the A filters. This deposit is broken down to some extent during the filter rest period. The Montromand plant receives a mean organic load corresponding to 67% of its capacity. The A filters primary stage received an average load of 73 g COD m⁻² and the operating filter 3 times this amount.

At the primary stage outlet, the target water quality level has almost been reached in terms of organic characteristics (table 3). The high TSS removal (90 % on average) is a result of the physical filtering action associated with rigorous compliance with batch and rotation feeding procedures, maintaining a sufficiently high infiltration rate. The biological action of the microorganisms attached to the gravel is illustrated by the major reduction in the dissolved COD (\approx 60 % on average). This effect is confirmed by the both examples of Roussillon and Queige (tables 1 and 2).

Table- 3
Change in wastewater quality, and pollutant removals at Montromand (Rhône)

		TCOD	dCOD	BOD ₅	TSS	TKN	TP	PO ₄ ³⁻ -P
Influent*	mg.L ⁻¹	495	190	215	225	42.8	8.5	6.4
1 st stage outlet *	mg.L ⁻¹	92	70	-	18	19.6	5.8	5.3
Plant outlet*	mg.L ⁻¹	58	40	16	12	10.2	5.6	5.1
Removal**	%	87.5	80	92.5	94.5	76	40	28

*: average of the two daily values measured.

** : average removals calculated from plant inlet-outlet pollution loads.

TCOD= total COD dCOD= dissolved COD measured after centrifuging or filtering

Table- 4
Change in nitrogen content at Montromand (mg.L⁻¹)

	Influent		Outlet 1 st Stage		Outlet 2 nd Stage	
	1 st day	2 nd day	1 st day start of cycle filter 1	2 nd day fed for 24 h filter 1	1 st day end of cycle filter 7	2 nd day start of cycle filters 5 and 6
TKN	37.5	48.2	15.5 (58 %)*	25.2 (47 %)*	10.8 (30 %)*	9.7 (61 %)*
NH ₄ ⁺ - N	21.0	30.9	13	23.4	8.1	6.75
NO ₃ ⁻ - N	2.85	2.85	7.15	4.4	10.3	19.5
TN	40.65	51.25	23.15 (43 %)*	30 (41 %)*	21.4 (7 %)*	29.45 (0 %)*

* : removal calculated from concentrations.

The role of the secondary stage is to ensure further treatment of organic compounds and the reliability of the system.

With reference to the nutrient nitrogen (Table 4), the initial nitrate concentration of 2.85 mg.L⁻¹ is due to significant ingress of run-off water (of the order of 50% of the flow). Measured nitrite concentrations were invariably less than 0.5 mg.L⁻¹. The primary stage removes 50% of Kjeldahl nitrogen (calculated from concentrations). The filter ensures almost complete ammonification of the organic nitrogen content. Nitrate formation occurs but its rate varies with time.

The secondary stage is the site of strong nitrogen mineralisation; residual organic nitrogen content is low (3 mg.L⁻¹ on average). The mean Kjeldahl nitrogen content is very close to 10 mg.L⁻¹. Nitrate content is variable and depends on the feeding cycles: 20 mg.L⁻¹ at the start to 10 mg.L⁻¹ at the end of a cycle. During a rest phase, nitrates are formed from ammonia ions adsorbed by the filter material; they are subsequently washed out at the start of the next feeding phase (Guilloteau *et al.*, 1993). These concentrations, although sometimes low, are always significant in spite of very low outside temperatures. Due to washing out of nitrates, total nitrogen losses in the second stage are low.



6. THE EXPERIENCE OF GENSAC LA PALLUE PLANT

Since 1987, Gensac la Pallue wastewater treatment plant, built with Cemagref's assistance, consists of a primary stage similar to the type A filters. This previously described installation (Liénard *et al.*, 1990a, 1993) was the subject of a series of measurements performed in February 1996 and in March 2001.

6.1 Ageing

The sludge layer at the surface remains self-managing if operating procedures are complied with alternating feed and rest phases. In Gensac la Pallue (8 RBF as primary treatment), the changing of filter is done every day during the working days but the one put in operation on Friday is fed until the next Monday.

Table- 5

Operating conditions and Performances achieved for the A filters at Gensac la Pallue

		tCOD	dCOD	BOD ₅	TSS	TKN	summer flow	winter flow
for 9 years	Mean daily load	117 kg		40 kg	53 kg		145 m ³	255 m ³
	Daily load / total surface area	60 g.m ⁻²		--	--		75 mm	133 mm
	Daily load / on filter in operation	490 g.m ⁻²		--	--		605 mm	1065 mm
1998-1992 (ten 24h or 48h campaigns)	Average removal of A filters (%)	68.1	-		87.2	28.9		
	Standard deviation	6.3			2.3	8.9		
Feb 96 (one 48h campaigns)	Effluent quality from A filters (mg.L ⁻¹)	110	70		20	31		
	Removal of A filters (%)	80	50		92	33		

tCOD = total COD dCOD = dissolved COD

In February 1996, the raw wastewater's characteristics were similar to average values and the filter effluent proved to be of similar quality in February 1996 to that previously measured (table 5). Even if the young shoots of the reeds hadn't cross the sludge layer, old one's did not prevent the 945 mm of wastewater filtering through the filter.

Values presented in Table 5 show that the ageing of the filters can be considered as satisfactory and that the removal rates tend to increase due to the biological activity in the growing sludge layer.

6.2 A look on sludge accumulation

Primary sludge accumulates on the first stage of RBF. The results from the Gensac la Pallue plant highlights the major advantage of RBF fed with raw sewage: the management of a minimal amount of primary sludge that they require.

Reed stems growing from rhizome nodes break through accumulated organic deposits and thereby ensure a declogging effect. Ring spaces, which form around the stems, allow water to pass and percolate along roots and rhizomes, even in winter. It is at the end of winter, prior to spring growth, when winter deposits have yet to be mechanically worked, by the growth of young shoots, and dried under favourable temperature and hygrometric conditions, that the greatest risk of clogging exists.

In April 1996, mapping of deposits revealed heavier accumulation at the feed pipe outlet inside the distribution gully, which was subsequently considered unsuitable: maximum measured height = 27 cm. The minimum height at the opposite side was 6 cm. The cover was the same for the 8 filters. The average height can be estimated at 13 cm, which corresponds to a rate of accumulation of 1.5 cm per year, for an installation receiving approximately 60% of its nominal organic load. The average VSS is 75%, with that of the surface layer being approximately 85%.

A mass balance was performed:

The SS, retained during 9 years on the filter is estimated to 32.5 kgSS.m^{-2} .

The total input is estimated to $53 \times 0.9 \times 365 \times 9$, versus 157 000 kgSS.

If we compared the input to the total area (1910 m^2), we conclude that 60% of SS, at least, was mineralised and the resulting dissolved salts were washed out with the effluent.

This sludge removal was required in 1996, not because of a deterioration in effluent quality, but due to this unequal height of sludge (causing distribution problems) and the little remaining freeboard available (causing risks of spill over in winter). This poor



distribution was due to the feeding system (pumping station very far from the distribution gully) which precluded a high rate of inflow. After this first withdrawal on 6 filters, in 1999, the pump and the distribution device have been changed to allow a better distribution of the SS on the surface area.

Table- 6
Quality of the sludge on the A filters in Gensac la Pallue

		Dry Matter (g.kg ⁻¹)		Organic Matter(% of DM)	
Filter 7	Top layer	181.0		61.2	
	Middle layer	205.0	Mean = 261,8	54.9	
		214.5		51.5	
		365.9*		22.5	
	Lower layer	291.6		39.8	
Withdrawal sludge**	284.0		34.3		
Filter 6	Top layer	154.0		54	
	Middle layer	213.2		48.3	
	Lower layer	218.1	Mean = 264,3	45.3	Mean = 41,5
		310.5		37.8	
Withdrawal sludge**	217.8		49.2		
Stored sludge since the first withdrawal in 1996		583.0		10.4	

* this important content is explained by the location of this sample: at the end of the filter. In fact, between 1987 and 1999, this point was very few fed because of the distribution device failure.

** sample made with several mixed sludge taken out during all the withdrawal of one filter.

In 2001, the sludge accumulated on the 2 filters, which has not been removed from the beginning of their functioning in June 1987 reached approximately 25 cm on the entire surface and the freeboard was not sufficient to guarantee a treatment of the daily hydraulic peaks. From these measurements, it has been estimated that the sludge height grows of about 1,5-2 cm per year for this plant, which receives about 60% of the organic nominal load.

Several samples of the different layers of sludge have been analysed in order to know their degree of mineralisation (Dry Matter and Organic Matter). They could be compared with samples of the on-site stored sludge of the first withdrawal (table 6).

During the week, the weather was very rainy and due to measurements of hydraulic conductivity carried out, large amounts of influent had to be introduced in the filters, so the drying period before the withdrawal was very short. Although, the dry matter

content is always superior to 20%, except at the top where the SS become just to be retained by the filter (table 6). At the inferior layer, the DM content of the since oldest accumulated sludge is more important and could be explained by the mineralisation process occurred during those all 12 years. The lower OM content is in accordance with this hypothesis (40 à 45 %).

The rate of mineralisation of the since 5 years on-site stored sludge is excellent. Perhaps, their structure prevents their damp.

A new mass balance can be done, such as the one made after the 1st withdrawal.

Based on a daily quantity of SS evaluated to 60 kg SS, a SS removal of 90%, the during 14 years SS input applied on the 2 filters could be evaluated to 72 000 kg SS.

The evacuated mass (the mean height was 22.5 cm, the DM content was 25% and the surface of the 2 filters is 520 m²) is estimated to 29 000 kg SS, and represented 40% of the wastewater SS content. The mineralisation rate reaches 60% and is in correspondence with the previous estimation of 65%(Boutin *et al.*, 1997).

6.3 Sludge ability to agricultural spreading

The agronomic interest of the sludge is definite by Nitrogen content in Kjeldahl nitrogen, Phosphorus content in P₂O₅, total calcium in CaO, total potassium in K₂O and total magnesium in MgO (table 7). From the arrêté of 8th of January 1998, the sludge ability to be spread on an agricultural area is also function of the heavy metals contents (table 8).

Table- 7
Agronomic contents of the A filters in Gensac la Pallue

Units	DM %	N Kjeldahl % DM	P ₂ O ₅ % DM	K ₂ O % DM	CaO % DM	MgO % DM
Filter 6 withdrawal sludge	21,8	0,74	1,46	-	11,23	0,46
Filter 7 withdrawal sludge	28,4	0,72	1,46	0,37	9,80	0,84
Stored sludge since the first withdrawal	58,3	0,34	0,71	0,25	29,33	0,69
Sludge from the first pond	3,4	0,10	0,13	0,01	21,70	0,49



Usually, the sludge from domestic wastewater treatment is poor in heavy metals content. In Gensac La Pallue, the CU content, very important, is probably in relation with the wine growing and the vineyards treatment with copper sulphate (table 8). Some metallic contents (Cu, Hg and almost Zn) of on-site stored sludge decreased by lixiviation. Those elements are now in the underground because the sludge was in non-tightness storage.

Table- 8

Metal contents in the sludge on the A filters in Gensac la Pallue (mg.kgDM⁻¹)

Metal	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Cr+Cu+Ni+Zn	
Regulation limits*	15	1 000	1 000	10	200	800	3 000	4 000	
Withdrawal sludge	F6	<5	<50	1 334	2,1	33	103	1 055	2 422
	F7	<5	<50	930	1,5	32	74	747	1 709
	Mean	<5	<50	1 132	2	33	89	901	2 066
Stored sludge	<5	<50	196	0,6	26	50	221	443	
Evolution rate during 5 years [ad]	1	1	0,17	0,33	0,80	0,56	0,25	0,21	

*from "Arrêté du 8 janvier 1998 fixant les prescriptions techniques applicables aux épandages de boues sur les sols agricoles".

If we look at the copper contents measured in the filter 6, it will not possible to spread the just removed sludge on agricultural soils, due to higher copper contents compared to limiting values (Arrêté du 8 janvier 1998).

Based on of the 2 limiting values: 1 000 mgCu. kgSS⁻¹ and a during 10 years deposit of 1,5 gCu/m² of soil, all the 10 years produced sludge, (the mean height was 16 cm, the DM content was 25% and the surface is 1 910 m² versus 76 400 kgSS), could be spread on 5.1 ha of agricultural soils.

In general cases, without wine growing, the Zn content, coming from the roofs, becomes probably the limiting element. Based on the maximal Zn contents measured in the sludge (1 055 mgZn. kgSS⁻¹ and a during 10 years deposit of 4.5gZn/m² of soil), the spreading area should be estimated to 1.8 ha.

Some similar evaluation is calculated for a RBF which would treat a pollution from 1 000 habitants (1 250m² for the 1st stage) and would receive an organic load at a rate of only 80% of its capacity. In this case, it would be necessary to book about 1.5 ha of agricultural soil in the aim to spread the sludge deposited during 10 years on the 1st stage.

6.4 Permeability Evolution

In March 2001, some hydraulic conductivity measures were conducted on different filters (table 9).

Table- 9
Hydraulic conductivity measured in 2001

	Year of sludge withdrawal	Hydraulic conductivity before withdrawal (m.s^{-1})	Hydraulic conductivity after withdrawal (m.s^{-1})
Filter 3	1996	$3.2 \cdot 10^{-5}$	
Filter 4	1996	$5.6 \cdot 10^{-6}$	
Filter 5	1996	$2.5 \cdot 10^{-5}$	
Filter 6	2001	$3.2 \cdot 10^{-5}$	$>1. \cdot 10^{-4}$

The permeability measured on the filter which was drawn out in 1996 show no difference with the value measured on the filter 6 recovered with 25 cm of deposits before its withdrawal. The hydraulic conductivity of this 25 cm height deposit was evaluated to $3 \cdot 10^{-5} \text{ m.s}^{-1}$. This impact of this sludge layer is very important in the month of March, still in winter season in France. At this period, the reeds are not active and their benefits during the rest period are poor.

At the filter surface, its possible to see after the withdraw, the original gravel (granulometry between 3 to 8 mm) in used since 14 years. The hydraulic conductivity reached more than 10^{-4} m.s^{-1} . (Kadlec *et al.*, 1996) estimate the hydraulic conductivity for such gravel, but without biomass, 100 times more superior. Such measured hydraulic conductivity is in the same order than this one proposed for a colonised sand used in Intermittent Sand Filters. To day, we consider that the growth on biomass decreases the permeability of clean sand of a 10 factor. More studies on that subject have to be conducted.

7. OPERATION AND MAINTENANCE REQUIREMENTS

Cleaning of bar screens and the opening and closing of gates to change the filter in operation must be done once or twice a week.

Obviously, the surrounding areas have to be managed and if there is a pumping station, its satisfactory operation must be controlled.

Cleaning of the storage tank, the siphon and the feeding pipes must be done at least once a year.



Otherwise reed beds must be weeded in the 1st year of operation and the reeds cut (in autumn or spring) in the subsequent years.

Taking in account the experience acquired in Gensac la Pallue, sludge can accumulate for 14 years before it has to be removed (section 6). After a sludge removal and without any additional operation, young reeds growth from old rhizomes. Replanting is not necessary.

8. COSTS

8.1. Investment costs

The economic approach is halfway between the statistical and the engineering approaches. (Alexandre *et al.*, *in press*). Each wastewater treatment plant was split in functional units. A standard treatment chain, assembling the strictly necessary functional units for a good result defined each process.

This method was repeat for three sizes of plants: 100 PE, 400 PE and 1 000 PE. Simultaneous, by examination and decomposition of many building contracts, the mean costs per functional units were estimated through linear adjustments for each size.

But, be careful because those costs are just a part of the total investment cost. In fact, it's necessary to add the annexe costs such as, for example, the costs of the land purchase and of the project manager (Boutin *et al.* 1998).

Table- 10

RBF investment costs, in relation with their capacities (in € - tax free- year 2 000)

	100 PE	Variation	400 PE	Variation	1 000 PE	variation
Manual screen	1 500	35%	1 500	35%	1 500	35%
Flowmeter (2)	3 000	35%	3 000	35%	3 000	35%
Feeding disposal (2 siphons et 2 storage tanks)	1 500	30%	5 500	30%	13 500	30%
Filter (distribution, media, drainage)	12 000	35%	37 000	40%	82 000	60%
Liner	3 500	20%	12 000	20%	32 000	20%
Reeds	12 000	50%	17 000	50%	21 500	50%
Making the site suitable	7 500	50%	8 500	50%	13 500	50%
Pipes, manholes and by-pass	6 500	20%	9 500	25%	16 000	10%
Maintenance shelter	1 500	50%	1 500	50%	1 500	50%
TOTAL in €-tax free	49 000		95 500		184 500	
cost.PE ⁻¹ in €-tax free	490		240		185	

To known investment RBF costs, 12 many building contracts from RBF located all over the country were studied. The costs (table 10) were actualised in 2000.

RBF investment costs are not significantly different to those of WSP when no artificial liner is required and if they are designed for 100 PE: WSP investment costs are estimated to about 420 €/PE.

The capital cost of an extended aeration activated sludge plant designed for 400 PE (with a sludge thickener, a degasification chamber between the aeration tank and the final clarification tank and a six months storage tank for the excess sludge), is a around twice this price (400 €/PE) compared with the one, given in table 10 for RBF (240€/PE).

8.2. Operation costs

Operation costs have also been estimated after the definition of the best operation services, taking into account the time but also the different professional qualifications needed for each type of system. When required, the energy consumption (a pumping unit, the aeration process, ... for the activated sludge system) has also been calculated. On the other side, it has been assumed that RBF and WSP can be fed by gravity.

The results (Alexandre *et al.*, *in press*) are as following :

- for the size 400 PE : WSP : 13.2 €/habitant per year ;
RBF : 20.2 €/habitant per year
Activated sludge : 30.1 €/habitant per year.
- for the size 1000 PE: WSP : 6.2 €/habitant per year,
RBF: 11.8 €/habitant per year,
Activated sludge : 18.7 €/habitant per year.

However, it should be mentioned that **the treatment and disposal of the sludge outside of the treatment plant is not included in these operating costs**, whatever the system is (Boutin *et al*, 1998).

In April 1996, sludge at Gensac la Pallue plant was removed by different methods. Using a digger backhoe loader, approximately 5 working hours were required to remove the sludge covering 100 m² of filter and to dump it less than 500 m away with a truck.



In 2001, with a larger bucket, the time needed reduced about twice (half a day for one filter which the area is 220m²).

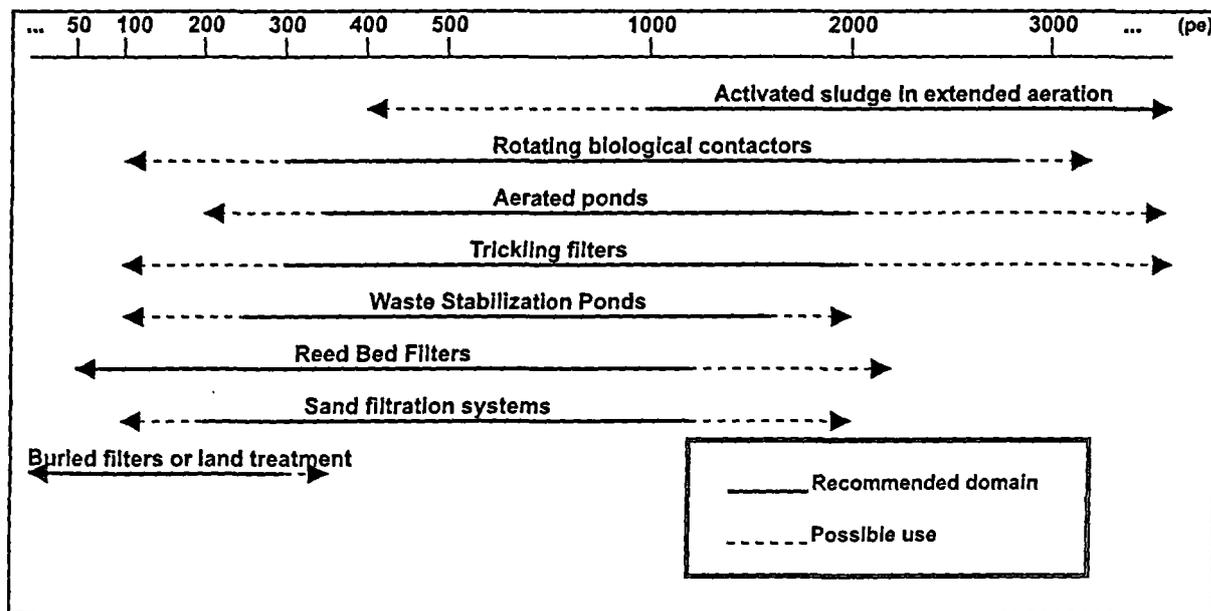
9. LEGISLATION

In France, the size of population for which Reed Bed Filters are recommended, among other types of wastewater treatments, is schematically presented in Table 11.

Taking in account that the recommended domain of utilisation of RBF is below 2000 PE, the requirements are those of the "arrêté du 21 juin 1996" (Ministère de l'Environnement, 1996) which gives the minimum technical prescriptions for the collection and treatment of wastewater for daily pollution loads between 12 and 120 kg of BOD₅.

Table- 11

Recommended and possible domain of utilisation of different types of wastewater treatment plants for rural communities in France



These prescriptions are directly related to the level of quality assigned to the receiving water body and particularly to the dilution of the treated effluent at low water levels (Circulaire du 17 février 1997). The assigned water quality is often based on appropriate living conditions for fish. In this case, ammonia concentrations are often the limiting factor.

When applied to the most stringent situations, the requirements may exceed the technical and economical capacities of the communities to invest in appropriate treatment systems and to operate them. In such conditions, on site infiltration of the treated effluent will probably be promoted.

10 - RESEARCH

10.1. Construction of an experimental plant.

In order to study the comparative efficiency of vertical and horizontal filters at the second stage (the efficiency of vertical filters at the 1st stage is now established and give satisfaction), an experimental plant has been built. It will be put in operation next summer 2003. Each filter is fed by its own pump and has a specific weir at the outlet. Both equipments will allow an easier and more accurate follow-up.

This plant is located in a small village (Eview) in the Ain department and it designed for treating 200PE.

The 1st stage is composed with 3 A filters and the 2nd stage is composed with different types of filters (Fig.3).

There are 2 heights of siliceous sand as top layer on the vertical RBF (30 and 90 cm) to examine their influence on the quality of the outlet and removal rates. Half of their area will also remain unplanted to investigate the role of the reeds on the removal rates in these 2nd stage filters (rhizosphere effect).

The horizontals RBF are built with siliceous pea gravel with a larger specific area (1.2 m² per PE, compared to only 0.8 m² per PE for vertical RBF). In addition with comparative removal efficiencies, these different designs will also allow some hydraulic tracer studies and residence time measurements at different periods of the plant:

- at the very beginning with clean media and tap water influent and
- later when the media will be colonised with biomass when fed with 1st stage effluent.

An other but secondary aim of these horizontal RBF, will also be to evaluate their denitrification potential in the relatively anoxic conditions of water saturated media, taking in account that controlled amounts of raw wastewater can be introduced in the pumping unit of the 2nd stage filters as carbon source.

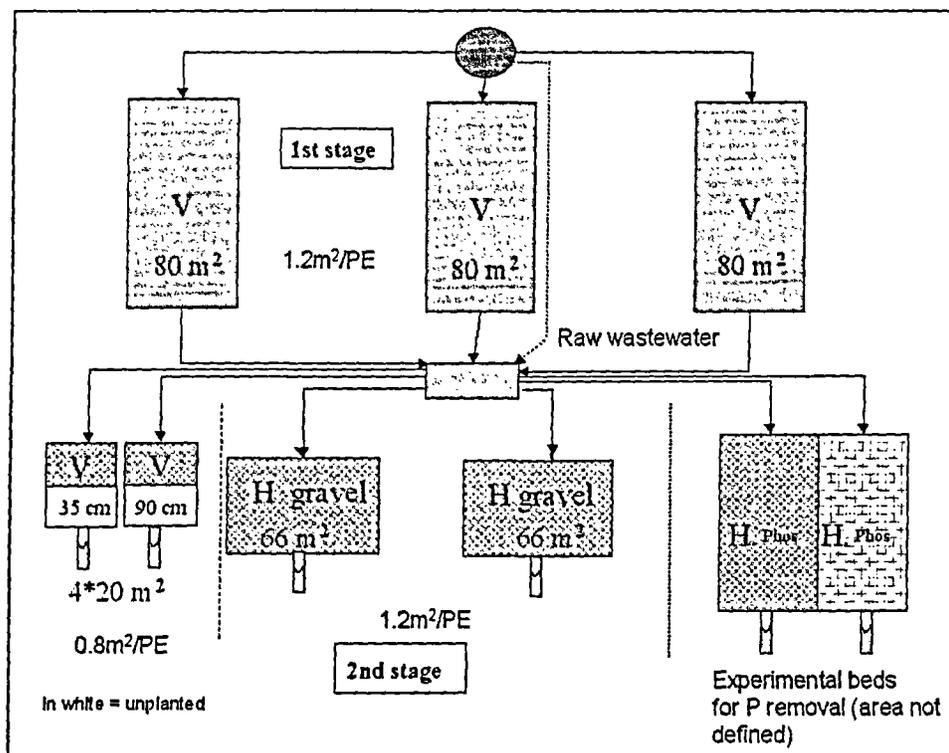


Figure- 3
Schematic layout of the experimental plant recently built

In addition, this plant should have to measure the phosphorus retention capacity of one or two specific media previously selected with laboratory experiments. Unfortunately, the duration of such experiments has been much more long than expected (see section 10.2), and we were unable to define now which media has to be put in those filters.

10.2. Phosphorus removal and calcareous materials (Molle *et al.*, 2002)

Phosphorus removal from wastewater has been of growing interest for decades to avoid eutrophication in surface water. Small communities wastewater treatment needs low operational cost and simple maintenance. Constructed wetlands could meet these criteria. Vertical RBF are known to achieve high quality effluents in terms of organic matter and nitrification, but phosphorus removal remains poor. In sensitive areas it is thus necessary to focus on this aspect and a research project has been set up to investigate the capacity of different media to retain phosphorus.

In horizontal subsurface constructed wetlands (EC/EWPCA group, 1990), surface reactions in the liquid-solid interface are promoted thanks to saturated conditions and, it would be therefore preferable to design horizontal flow RBF as a 2nd stage treatment.

The P sorption mechanisms of both calcareous materials [Recycled Crushed Concrete (RCC) and Calcite] lead to point out that:

- Batch experiments and Langmuir estimations are not sufficient to define long term P removal in constructed wetlands.
- The choice of P inlet concentration in column experiments could lead to wrong saturation capacities estimation regarding to mechanisms implied with calcareous materials.
- Crystal growth seems to be the final P removal mechanism with calcareous materials.

Despite some good sorption capacities, RCC and calcite are not appropriate for P removal in constructed wetlands. Calcite, as well as RCC (once lime is used) make it impossible to respect the 2 mgP.L⁻¹ levels, that will be surely require for small communities in sensitive areas. Furthermore RCC will be responsible for high pH value which would not be compatible with discharge consents.

Crystal growth could be promoted by other seed materials, closer to the obtained precipitate (hydroxyapatites). Some studies in progress confirm this hypothesis.

In order to use a specific material as seed, some more studies should be done to estimate the lost of crystal growth rate due to biomass development in one hand, and the clogging risk by crystal growth in other hand.

10.3. And what limiting values for the hydraulics load?

This short section presents the results obtained at the Manspach plant during the year 1998, which deserve to be mentioned as an example of high hydraulic loading (Boutin *et al.*, 2000a).

The Manspach plant, located in the Haut-Rhin department and built in 1994 treats domestic wastewater from 500PE. The combined sewerage network receives some drainage water. It's the reason why the nominal hydraulic load was fixed to 150 m³.d⁻¹. It corresponded to a produced per PE wastewater volume to 300L.d⁻¹ (instead the classical used value of 150L.d⁻¹).



This design of this plant is not common: As asking the Rhin-Meuse Water Agency, the effluent is pre-treated by a settlement tank before its treatment by two stages of RBF. At 1st stage, the total area of the 2 similar B filters (Fig.2) is 730 m². The 2nd stage is composed by 2 similar small horizontal RBF which the total area is 230m².

During two weeks, one in February 1988 and the other in September 1998, some daily measurements took place and gave the following results (tables 12 and 13).

Table- 12
Loads on Manspach plant

	Hydraulic load		Organic load	
	m ³ .d ⁻¹	load rate	kg COD.d ⁻¹	load rate
Nominal loads	150		60	
Measured load in winter (mean of 7 values)	300	200 %	25	40 %
Measured load in summer (mean of 7 values)	230*	150 %	16	25 %

*During this period, the average outlet flow is only 150 m³.d⁻¹

In winter, the height of water applied on the fed B filter reaches 820 mm.d⁻¹.

Table- 13
Treatment quality in Manspach plant (mg.L⁻¹)

Parameters	Winter season				Summer season			
	COD	SS	NK-N	NO ₃ ⁻ -N	COD	SS	NK-N	NO ₃ -N
B Filter inlet	80	30	10.9	1.5	75	21	15.5	<0
Horizontal Filter inlet	39	6.3	3.4	7.5	29	<5	<1	13.4
Outlet	28	<5	2.6	7.3	25	<5	<1	13.4

In summer and in winter also, the concentrations of COD are less than 30mg.L⁻¹. The yields calculated from the loads reaches 65% in winter and 75% in winter. The nitrification is almost complete, nitrate contents are higher in summer (13.5mg.L⁻¹) than in winter (7 mg.L⁻¹) but due to the decrease of the outlet flow in summer, the thrown out nitrates load, is the same at the both seasons.

The impact of the horizontal filters, which area is only 25% of the total surface is relatively small.

This example shows that it's possible to treat high hydraulic load with RBF.

Some researches on a plant, built in 1994 and located in Colomieu are in progress. In this case, it's easy to add clear water coming from a fire reserve on this plant soon connected to a combined sewerage network. During different periods, we can simulate the income of both rain and drainage waters, separately or in addition and can measure in each situation the influent quality, especially regarding the nitrate contents.

In general situation, to maintain oxygen renewal in vertical filters and limit the clogging risk, RBF are used if they are connected to a separate sewerage network. The conclusions of those researches will be helpful to design RBF connected with combined sewerage network (rain and/or drainage water).

11. SPECIFIC TOPICS

11.1. Experimentation with milking parlour effluents

Washing down of milking and milk storage equipment generates wastewater for which it is not always technically or economically feasible to mix and disperse with the liquid manure produced on farms.

A research programme into wastewater treatment plants suited to the specific nature of these effluents and to the constraints involved with farming, was therefore set up on a national basis.

The program begun with the characterisation of the water to be treated and an experiment of 3 processes supposed to fit 3 principal criteria:

- i) low building costs
- ii) easy operation
- iii) reliable performances even if they don't reach the same quality level than the one achieved for domestic wastewater.

So investigations concerned:

- i) oxidation ponds similar to WSP but initially adapted in New Zealand,
- ii) the Intermittent Sand Filters
- iii) RBF, started in France in 1992 – 1993



At the end of the experimentation program (Liénard *et al.*, 2002), ISF have not been accepted because of fast clogging. The WSP process is not yet clearly defined because of an insufficient number of plants built according to the new guidelines adopted during the program. This latter recommends to come back to aerobic conditions in the second basin onwards just after an anaerobic process in the first one which is at least 2 meters deep.

RBF could be used for treatment of such effluent.

As showed on figure 4, the main differences between domestic wastewater and washing parlour effluents are:

Septic tank implementation

Raw domestic wastewater can be treated by RBF without primary settlement.

A septic tank placed before the filters is necessary for washing parlour effluents for many reasons.

The reasons are listed in the order they were studied for the adaptation of the treatment process.

1. Batch feeding implementation difficulties :

Because of low daily treated volumes (485 to 680 l in average for 3 surveyed farms) it wasn't possible to miniaturise a self-priming siphon for the batch feeding without frequent clogging risks.

2. Necessary reduction of the superficial permeability and the SS flow reduction :

To obtain a satisfactory repartition on the first stage filters, it is necessary to add a sand layer on the surface in order to limit fine gravel [2 to 6 mm] permeability. This fine gravel is normally the operating filtering layer of domestic wastewater filters. When a superficial sand layer has been added, it is necessary to reduce the wastewater SS to minimise the clogging risks.

3. Buffer action on washing water pH :

The successive washings with alkaline products for disinfections, then acids for the

dissolving of the precipitates in the piping are giving a water pH between 2 and 12.

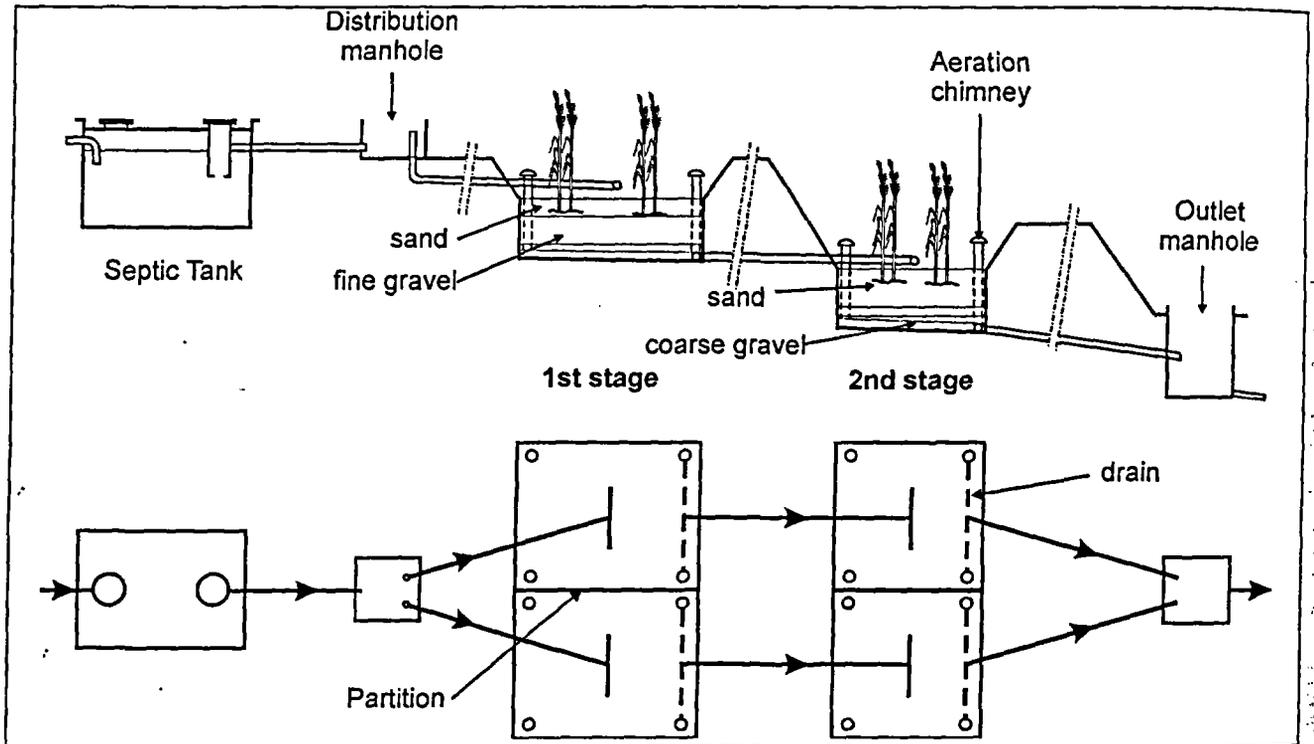


Figure- 4
Functional sketch of RBF for the treatment of washing parlour effluents

Two filters series alternating every week

For domestic wastewater, the mineralization of organic deposits on the 1st stage filters and, together, the re oxygenation of the filters by diffusion require a rest period which has to be double from feeding period. In order to achieve that, 3 filters are needed with a feeding alternating twice a week, so that there are 7 days rest period for 3 to 4 feeding days. In order to simplify the operation and the follow-up, decision has been made for a treatment process with only 2 filters in series.

Dimensioning of the total filter surface is based on a maximum surface load of 70 g Global Organic Demand $m^{-2} d^{-1}$. This surface is split into 65% for the 1st stage filters and 35% for the 2nd one. Finally, in order to simplify the procedures given to the technical services in charge of the system installation in the cattle-breeding, following global dimensioning criteria have been decided (Table 14).



Table- 14
Dimensioning criteria for washing parlour effluents treatment plants

	Septic tank		Reed Bed Filters (m ² /cow)	
	< 100 cows	100 – 150 cows	1 st stage	2 nd stage
white water	3 m ³	4 m ³	0.17	0.08
white water + green water	6 m ³	9 m ³	0.27	0.13

11.2. Sludge dewatering with reed bed filters

The agricultural recycling of sludge coming from wastewater treatment plants is more and more difficult. That's why the process, which consists in drying sludge on reed bed filters, is becoming attractive. In France this process is really being developed since 1996 and today more than 120 plants are fitted out with such treatment.

Beds are designed in order to be able to store a volume of sludge based on the dry matter quantity produced by the plant, the final dry solids content of the sludge and the storage duration.

With following hypothesis:

- ✓ Dry Matter 40 g.d⁻¹.PE⁻¹ (15 kgDM.year⁻¹.PE⁻¹),
- ✓ 5 years storage for sludge with 20 % dry content,

the design (Liénard *et al.*, 1995) is 5 PE.m⁻² [75 Kg DM.m⁻².year⁻¹] for 2 m bed height,

4 PE.m⁻² [60 Kg DM.m⁻².year⁻¹] for 1,5 m height.

According to a survey based on 120 plants, it appears that the present design of planted sludge beds, for a yearly load of 50-75 kg DM.m⁻² and accumulation heights of 2 and 1.5 m, is sufficient, with regards to the PE pollution and the plant overcapacity. This design allows a 5 years sludge removal cycle (Lesavre *et al.*, 2002).

The dry solids contents are low (12-17 % in average) in spite of strongly higher values (30%) claimed by the constructors. High dry solid contents can only be obtained in case of a long rest period during summer months to profit of reed evapotranspiration. To be able to achieve such process, 4 beds are the required minimum so that a regular emptying of the beds can be done.

Climatic conditions, especially before emptying, have an important role for the final dry content level of the extracted sludge.

A sludge mineralization has been observed during the bed storage: the organic fraction decreases from 70 to 55 % from surface to bed bottom on an accumulated sludge height of 1 m.

For the small treatment plants, the volume of planted beds is almost identical to the storage capacity for liquid sludge. So investments are comparable.

Operating costs for planted sludge beds are, in any case, lower because of no energy consumption and no chemical reactant and because of the low transport costs during land spreading due to the important sludge volume reduction.

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