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Abstract
In the Aurignac wastewater treatment plant, six intermittent sand filters with three different media: river sand, crushed sand and river sand with reeds and two different media heights: 25 and 65cm are used as a polishing treatment. Their hydraulic behaviours are studied by a tracing method and infiltration rate monitoring. Filters are fed by treated water from only one facultative waste stabilisation pond. The study shows that infiltration rates differ for each kind of medium which is the sign of different hydraulic behaviours explained more precisely by tracing results. The hydraulic behaviour of the filters has been compared for three points: feeding regime, filter medium characteristics and the presence or not of a deposit on the top of the filters.

Keywords
Hydraulic; infiltration rates; intermittent sand filters; sand characteristics; tracers; waste stabilisation ponds.

INTRODUCTION
France can count about 3 000 Waste Stabilisation Ponds (WSPs) mostly made up of 1 facultative and 2 maturation ponds in series. The European regulation specifies that maximum SS concentration should be 150 $mg.L^{-1}$ even for WSPs receiving more than 120 $kgBOD_5.d^{-1}$. However, for small communities, the effluent quality is not always sufficient according to the limits set by the French regulations (Racault *et al.*, 1995). In the case of fragile receiving bodies, Intermittent Sand Filters (ISFs) can complement WSP treatment. In the future, we would like to propose that rural districts use a combined sewerage system; a treatment process combining WSP hydraulic capacities with ISF residual organic matter elimination and nitrification performance (Boutin *et al.*, 2004).
To be really efficient in nitrification such ISFs should be in fully aerobic conditions which means that the sand must be kept unsaturated and thus drained. To distribute the effluent equally over the whole surface of the filters, a batch feeding process must be installed together with a distribution network. This ensures that the effluent to be treated will reach all points of the filter as fast as possible to avoid both over and under loading areas. It has been proven that this batch feeding enhances aeration by convection which acts as a plug flow to push the gas below the water level and aspirate the air from the atmosphere under it once the surface of the filter in operation becomes free of water. Nevertheless, the main aeration process is considered to be gas diffusion which takes place between 2 batches and during the rest periods when another filter is in operation.
The choice of the sand for the filter medium must be a technical compromise related to the granulometry of the sand. It must be fine enough to ensure the retention of algae and coarse enough to avoid surface clogging and maintain correct aeration. For economical reasons, the possibility of gravity feeding and the wish to replace the 3rd pond by ISFs, the thickness of the sand layer must be as small as possible. In order to try to answer to the problem of thickness it was decided to test two heights of medium: 25cm and 65cm.

The choice of filter medium is important in order to ensure long term reliability of the system. Due to environmental concerns, river sand extraction will probably be more restricted in the future. Hence it is opportune to test crushed sand as an alternative medium for ISFs. The positive action of reeds in maintaining sufficient hydraulic conductivity of granular medium is well known (Molle *et al.,* 2004); it therefore appeared interesting to study their use in comparison to non-planted filter media.

An experimental plant using an association of WSP and ISFs has been built in Aurignac with European Funding as part of LIFE program. This poster presents a comparison between hydraulic behaviour (from tracer test results) of the 6 different ISFs and the infiltration rate monitoring. As the plant has been in operation for less than one year, the removal performances are not presented in this paper.

MATERIAL AND METHODS

Wastewater treatment plant description

The Aurignac plant has been designed for 300 p.e. (people equivalent) and consists of one pond and 6 filters in series (Boutin *et al.,*2002). This pond is designed in accordance with the French practice: 6 $m^2.(p.e.)^{-1}$) for the 1st facultative pond. After the pond, there are 6 independent ISFs filled with 3 different media whose characteristics are presented in table 1. For each kind of media two filter heights are used: 25 and 65cm. The river sand has been chosen according to the up to date recommendations in France (Liénard *et al.*, 2001). The main differences between the 2 sands (crushed and river) are their shape and their uniformity coefficient, which is about double for the crushed sand. The two kinds of sand have the same mineralogical characteristics because they have the same origin: the Garonne flood plain.

Table 1. Characteristics of the filter media used in Aurignac

	d10	CU	Fines content	Density	Porosity	Infiltration rate of the virgin media	
	mm		%	$kg.m^3$		$m.s^{-1}$	
		-			-	25cm	65cm
River sand	0.25	4.7	2.1	2684	0.42	> $1.5.10^{-4}$	> $1.5.10^{-4}$
Crushed sand	0.19	9.3	4.0	2753	0.44	> $1.5.10^{-4}$	1.10^{-4}
Planted River sand	0.25	4.7	2.1	2684	0.42	No data*	No data*

d10: mesh diameter allowing 10% of the sand mass to go through,
d60: mesh diameter allowing 60% of the sand mass to go through
CU: coefficient of uniformity = ratio d60/ d10
Fines are particles less than 80µm.
* In order to ensure good development of the reeds, the water level was voluntarily maintained high in the planted filters during August 2003. This was done by using an elbow arrangement at the outlet of the collector pipe.

As is normal for primary treated wastewater (Boutin *et al.*, 1998), ISFs are alternately fed. The two filters of the same medium but with different heights are fed at the same time during 3 or 4 days and then rested for 1 week. ISFs have been designed with a safety margin:1 $m^2.(p.e.)^{-1}$ split into 6 filters with the same area) with two aims:

- to retain SS corresponding to relatively small sized algae coming from the only facultative pond
- to complete nitrification.

This plant has been in operation since July 2003. Each filter is $50m^2$ in area: 2m in width and 25m in length. Each batch feeding volume is about $5m^3$ over $100m^2$ area of filters. It is carried out with a high flow pump ($58m^3.h^{-1}$).

The hydraulic behaviour of the filters has been studied by 2 methods: tracer tests and monitoring of infiltration rates.

Tracer tests

The tracer used for the tests is sodium chloride (NaCl) which can be monitored by conductimetric sensors. With the amount of salt used, 8kg per $5m^3$ of batch volume, the highest tracer concentration is relatively low ($1.5g.L^{-1}$) and in these conditions the influence on the attached biomass is considered to be negligible (Molle, 2003).

Generally tracer tests are done and interpreted on continuous reactors with adequate calculations. In our case filters are intermittently fed and this batch regime is maintained for tracing. The calculations on the results are done by the classical method (continuous reactor) but must be carefully interpreted because of the feeding regime.

The tracer tests have to be made after moistening the filter. It is then considered that 4 batches must precede the tracing batch. This one has an electric conductivity of about $2000\mu S.cm^{-1}$, which has to be measured precisely. At the outlet of each filter, the flow and the conductivity are continuously measured and recorded. In order to retrieve all the salt, 8 to 12 batches are necessary after the tracing one. With such monitoring it is possible to calculate the average residence time which is the average residence time of each water particle in the filter. The amount of salt returning could also be calculated all the time throughout the whole monitoring period.

Infiltration Rate determination

There are 2 ultrasonic water level sensors in the middle of each filter, one about 5m and another about 15m from the manifold. Hence the height of water on the filter is continuously measured. For each batch, the water level increases during the feeding period and then decreases. During this decreasing period the infiltration rate is calculated in relation to the registration period (1minute). The two sensor results are compared in order to measure the total infiltration rate of the filter rather than local infiltration rates. To calculate this parameter, it is also necessary to determine the slope of the height of the water curve on the filter over time. This calculation is carried out point by point. This parameter is relatively simple to determine.

The monitoring which was started in September 2003 is still being done, the recorded data are downloaded and interpreted each week. The results presented in this paper correspond to the data from January to April 2004. For the planted filters the recorded data of June 2004 will also be presented.

RESULTS AND DISCUSSION

Tracers and infiltration rates have been studied in order to characterise the hydraulic behaviour of the filters. They have been compared for three points:

- Filter operation: effect of the feeding regime.
- Filter characteristics: kind of media (crushed or river sand), media height (25 or 65cm), and the presence or not of reeds.
- The presence of a deposit on the top of the filter.

Effect of the feeding regime on infiltration rates

Figure 1 presents the infiltration rates for the 65cm river sand filter during a single feeding period (3 to 4 days). The flow rate applied in this period was more or less constant (about $0.2m.d^{-1}$ hydraulic loading rate and 1 batch approximately 4.5 hours).

A reduction of infiltration rate can be directly related to time. Infiltration rates decrease progressively with each batch. This tendency has been observed for all filters. It should also be noted that after a certain number of feedings (15 batches approximately) infiltration rates remain stable. The same phenomenon has been observed in vertical flow constructed wetlands (Molle, 2003). The fast infiltration at the very beginning of each feeding period can be related to the high pressure differences due to the low humidity inside the filter bed. As filters are fed and become moist, infiltration rate decreases. At the end of the cycle infiltration rates become stable.

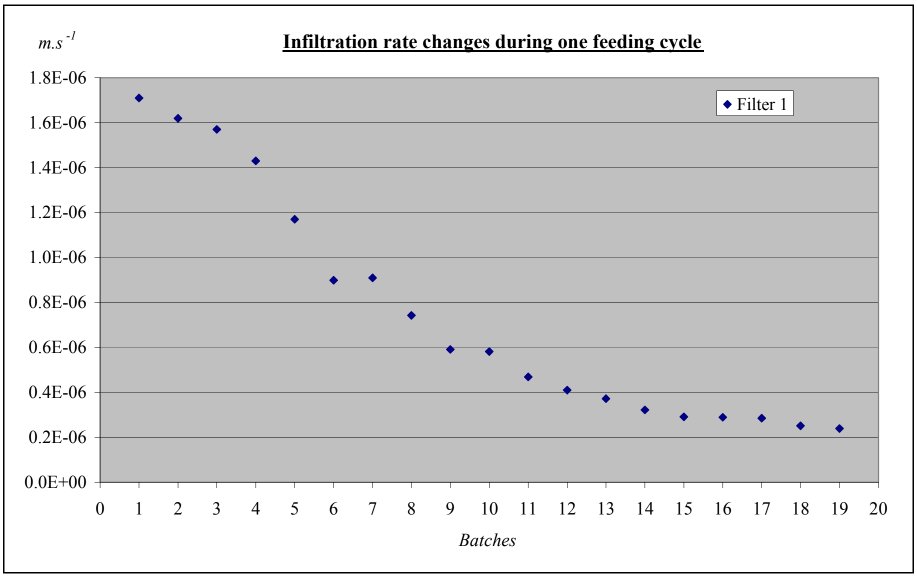

Figure 1. Follow-up of the infiltration rates during a feeding cycle in the river sand filter (15/1/2004, after 6 days of resting)

Effect of the filter height

It is no surprise that the tracer results show that water flowing out through the filter is faster for the 25cm height filters than for the 65cm ones (figures 2 and 3). Moreover, with the same feeding regime for each kind of media (6 batches per day for the river sand and 7 for the crushed sand), the 25cm height gave a residence time that was lower by about one batch. This means between 1 and 2 batches for the 25cm filters (i.e. from 5 to 8 hours) and between 2 and 3 batches for the 65cm filters (i.e. from 10 to 11 hours). These results can be explained by the flow resistance increasing with filter height. However the gap observed is remarkable as there is quite a small difference between the two filter heights. Infiltration rates are greater for the 25cm heights than the 65cm. This confirms the results obtained with tracer tests.

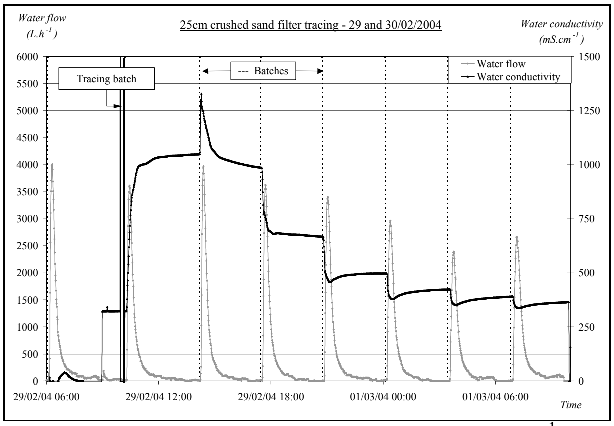

Figure 2: 25cm ISF tracing: 8 batches.d^{-1}
2nd day of function

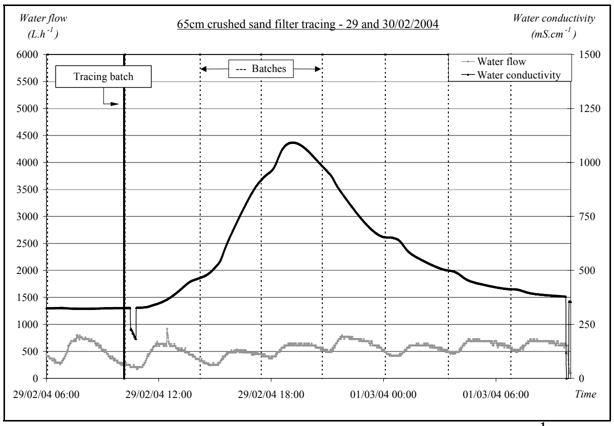

Figure 3: 65cm ISF tracing: 8 batches.d^{-1}
2nd day of function

Effect of the kind of sand

For the 25cm height filters no significant difference could be observed between the hydraulic behaviours through the two kinds of non planted ISF. However for the 65cm height, the outflow through the filters is faster for the river sand than for the crushed sand (figures 3 and 4). In this way outflow just before the next feeding the river sand filter is minimal which is not the case for the crushed sand filter. Consequently there is more water stocked and so less oxygenation in the

crushed sand than in the river sand filter. Moreover the residence time is longer in the crushed sand filter (3.2 batches i.e. about 11 hours with a feeding regime of 7 batches per day) than in the river one (2.2 batches i.e. less than 10 hours with a feeding regime of 6 batches per day). These results mean that the greater the angularity of the sand the lower the flow through the filter is. In this case the filter porosities are similar. The main differences between the two kinds of sand are only in their form and their uniformity coefficient (*cf.* table 1). Hence the higher volume of stocked water in the crushed sand could be explained by the hypothesis of higher capillarity forces, due to diameter heterogeneity and sharper form in relation to river sand.
For the filters of 65cm infiltration rates are lower for crushed sand (about 1.10^{-5} $m.s^{-1}$ for the 1st batch) than for river sand (about 4.10^{-5} $m.s^{-1}$ for the 1st batch). These differences are confirmed for all feeding cycles. These results would again confirm the hypothesis set out above for tracer tests.

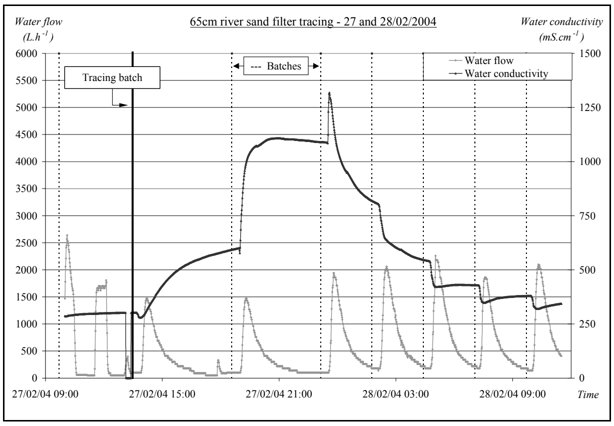

Figure 4: 65cm ISF tracing: 8 batches/day – 3rd day of function

Effect of a deposit on the top of the filters

In autumn 2003, clogging of the filters appeared. As a first hypothesis, they could be attributed to a hydraulic overload applied in conjunction with high concentrations of algae (mainly *Scenedesmus*), SS (about $50mg.L^{-1}$) and COD (about $150mg.L^{-1}$) from the facultative pond. By decreasing the hydraulic load it was possible to maintain the operation of the system.
The 7mm deposit layer on the top of the 25cm river sand filter which was very clogging was removed in February 2004.
Two tracer tests have been done on the 25cm river sand filter, once with the 7mm deposit and a second time after this layer was removed. The hydraulic behaviour in these two cases was really different despite the low deposit height. The outflow was faster after the layer removal and thus the water stockage was lower. During the tracer tests, the highest amount of salt retrieved from the filter outlet was observed between the 2nd and the 3rd batches in both cases. Nevertheless the quantity of salt was very different in the two cases. Between the 2nd and 3rd batches, 13.2% of the salt injected was retrieved at the filter outlet when there was a deposit and 30.7% after the layer removal. Therefore the hydraulic behaviour of the filter is really modified by clogging due to the surface deposit. This has also been demonstrated through the continuing monitoring of infiltration rates. The infiltration rate values with and without this deposit were very different: between 10^{-6} and $10^{-7}m.s^{-1}$ with the deposit (i.e. filter did not infiltrate at all) and greater than $1.5.10^{-4}m.s^{-1}$ after removal of the clogging layer. These results show that the surface clogging, even with very fine layers, limits the surface infiltration and hence has a negative influence on the hydraulic behaviour through the filter.
Filters with *Phragmites* also suffered a severe clogging in winter. If removal of the accumulated deposit layer on the ISFs can be recommended, this operation is impossible on the planted filters. In this case, it is necessary to adapt the ISF design to the worse winter conditions from a hydraulic

point of view. The deposits were therefore not removed from planted filters and consequently, infiltration rates were low during the cold period (about 10^{-6} m.s^{-1} and between 10^{-5} and 10^{-6} m.s^{-1} for the 65cm and 25cm filters respectively). Nevertheless, without any special management of filters, infiltration rates increased progressively in summer: infiltration rates measured in June are mostly higher than $1.5.10^{-4}$ m.s^{-1} for both filters. This fact can be explained by the mechanical action of the reeds which had grown considerably during the spring. According to Molle (2003) reeds allow water to go along the stems via the tubular spaces formed by their oscillation, thus reducing the braking role of the deposit layer. Moreover it is reasonable to think that the temperature increase also contributed to drying and mineralisation of the deposit which is mainly composed of algae. Given the fact that the surfaces of the non planted ISFs have all been cleaned, it is not possible to estimate the effect of each mechanism.

CONCLUSION

Tracer tests and infiltration rate monitoring have been performed on the 6 different filters: (3 media: river sand, crushed sand and planted river sand and 2 heights for each medium: 25 and 65cm). Tracing results provide a lot of information but it is not the easiest method of studying the hydraulic behaviour of ISFs. Infiltration rate calculations are another more simple way of determining their hydraulic characteristics than tracing, especially as both methods lead to similar conclusions.

The infiltration rates on all virgin media are almost the same at about 10^{-4} m.s^{-1} for the first batch and about 10^{-5}m.s^{-1} after several batches. During a feeding cycle of 3 to 4 days, infiltration rates gradually decrease before stabilisation at a value 10 times lower. This trend is directly linked to filter porosity which decreases with biomass development.

It is not a surprise that the water flowing out from shallow filters is faster than from deeper ones; but it is remarkable that with just 40cm more height, the residence times are significantly superior (from 1 to 2 batches more i.e. 3 to 5 hours more).

The main differences between river and crushed sand are their geometric shape and uniformity coefficient. Their hydraulic behaviour is similar for shallow media but quite different for the 65cm filters. Higher capillarity forces in crushed sand could be the explanation for a greater volume of water retained in the filter.

In winter filters suffered from clogging damage with lowest infiltration rates ranging between 10^{-6} and 10^{-7} m.s^{-1} according to the filter. For the non planted filters the removal of the deposit layer involved a huge increase in infiltration rates, a 100 times. Tracer test results performed before and after the removal of the deposit layer showed that the greatest amount of salt was returned at the same time. Despite the infiltration rate rise, the calculated residence times remained similar between 2 and 3 batches. For the planted filters it has been necessary to wait until June 2004 to reach infiltration rates between 10^{-4} and 10^{-5}m.s^{-1} and an augmentation of 10 times compared to the value of March 2004. The mechanical effect of the reeds seems to be demonstrated once more.

During the next winter (2004-2005) the average hydraulic loads applied will be limited to $0.25m^3.m^{-2}.d^{-1}$ because of both economical and technical considerations. In these conditions we would like plant monitoring to confirm that infiltration rates for all filters are suitable.

With these conclusions, focused only on hydraulic behaviour, the best operating conditions cannot yet be defined. Furthermore it will be necessary to associate the results from physical, chemical and bacteriological analyses to give a better overview.

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