Experience in Non-Conventional Wastewater Treatment Techniques Used in the Czech Republic

L. Felberova, J. Kucera, E. Mlejnska

T. G. Masaryk Water Research Institute, Podbabska 30, Prague 6, 160 62, Czech Republic
(E-mails: LADA_FELBEROVA@VUV.CZ, JIRI_KUCERA@VUV.CZ; EVA_MLEJNSKA@VUV.CZ*)*

Abstract
Among the most common non-convetional wastewater treatment techniques used in the Czech Republic belong waste stabilisation ponds (WSP), subsurface horizontaly flow constructed wetlands (CW) and vertically flow groundfilters (GF). These extensive systems can be advantageously used for treatment of waters coming from sewerages where is not rare when the ballast weighting makes more than a half of dry-weather flow. The monitoring was focused at 14 different extensive systems. Organics removal efficiencies were favourable (CW - 82 %; GF - 88 %); in case of WSP only 57 % due to the algal bloom.Total nitrogen removal efficiencies were 43 and 47 % for WSP and GF; in case of CW only 32 % due to often occured anaerobic conditions in filter beds. Total phosphorus removal efficiencies were 37, 35 and 22 % for WSP, GF and CW, respectively. Often occuring problems are: the ice-blockage of surface aerators at WSP during wintertimes, the pond duckweed-cover or the algal bloom at WSP during summers; a gradual colmatage of filter systems; and the oxygen deficiency in beds of subsurface horizontaly flow constructed wetlands.
Czech legal regulations do not allow treated wastewater disposal into underground waters. There is only an exception for individual family houses. Up to now, knowledges gained by monitoring of a village (which uses the infiltration upon a permission issued according to earlier legal regulations) have not shown an unacceptable groundwater quality deterioration down the infiltration areas.

Keywords
Constructed wetland, extensive, groundfilter, non-conventional, stabilisation pond, wastewater treatment

INTRODUCTION

Within a frame of research connected to wastewater treatment issue, our department is engaged in operation assessment of different types of non-conventional and untypical ways of wastewater treatment in small agglomerations. Among others, the project reacts to Council Directive 91/271/EEC demands concerning urban wastewater treatment, which sets that all member states shall ensure that urban wastewater entering collecting systems (agglomeration of less than 2 000 p.e.) shall before discharge be subject to an appropriate treatment.
For this purpose we have made a register of these kinds of wastewater treatment systems in the Czech Republic, together with their operation history and have started a regular monitoring of some selected systems. An attention is paid also to a possibility of treated wastewater disposal into underground waters.

METHODS

The operation of 14 systems with the extensive technique of wastewater treatment (6 stabilisation ponds, 5 constructed wetlands and 3 groundfilters) has been monitored since spring 2005. Until at the data for this paper were analysed, there were carried out twelve 2-hour measurements and two 24-hour measurements on each system. The monitoring was focused on hydraulic assessment and removal efficiencies of organics, nutrients and bacteria.

Monitored physiochemical water quality indicators were: water temperature, concentration of dissolved oxygen, pH, conductivity, suspended solids, biochemical oxygen demand - BOD_5, chemical oxygen demand - COD_{Cr}, inorganic nitrogen forms ($N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$), total nitrogen, orthophosphates and total phosphorus. Monitored microbiology indicators were counts of thermotolerant coliforms, *E. coli* and enterococci.
Sampling and analyses were carried out in conformity with European Standards.

RESULTS AND DISCUSSION

Old collecting systems built mostly within do-it-yourself village activities are typical for small agglomerations in our country. The sewerages are generally of poor quality and with significant infiltration of other waters (it is not rare when the ballast weighting makes more than 50 % of dry-weather flow). Pollution concentrations in these sewer systems often meet effluent requirements. Even despite this fact, there is a necessity of wastewater treatment, because it contains easily degradable organic material and other pollution which cause aesthetic and other difficulties in a watercourse. In these situations we can not use conventional wastewater treatment systems based on activated sludge technologies but a kind of an extensive treatment. Building-ups of a new separate sewerage with an activated sludge wastewater treatment plant can not squeeze in economical options of small agglomerations.
Among most common extensive techniques in the Czech Republic belong: waste stabilisation ponds, constructed wetlands, groundfilters and their combinations.
For a long-term monitoring, there has been selected a spectra of extensive techniques most truly reflecting the real situation of their usage in the Czech Republic. Brief characteristics gives the Table 1.

Table 1 Main features of localities with extensive wastewater treatment technique monitored within this project (the population equivalents (p.e.) matches with the actual organic load;
1 EO = 60g BOD5.day-1).

	Locality	Number of agglomeration inhabitants	Population equivalent	Pretreatment	Secondary treatment
Waste stabilisation ponds	**A**	110	80	no central pretreatment; individual septic tanks attatched to houses	1 biological pond (5000 m^2), without aeration
	B	170	60	no central pretreatment; individual septic tanks attatched to houses	1 biological pond (3600 m^2), without aeration
	C	180	350	central simple settlement basin	1 biological pond (5000 m^2), without aeration
	D	850	340	central double-storied septic tank	2 biological ponds (5000 m^2), surface aeration of the 1st pond (out of order during winters)
	E	340	210	central double-storied septic tank	2 biological ponds (5500 m^2), surface aeration of the 1st pond (out of order during winters)
	F	550	310	central double-storied septic tank	2 biological ponds (4700 m^2), subsurface fine-bubbled aeration of both ponds in permanent operation
Constructed wetlands	**G**	90	60	central double-storied septic tank	1 circle-shaped reed bed (315 m^2)
	H	70	50	central double-storied septic tank	2 square-shaped reed beds (770 m^2), series-connected
	I	100	470	central simple settlement basin	3 square-shaped reed beds (2300 m^2), series-connected
	J	800	170	central double-storied septic tank	2 square-shaped reed beds (2400 m^2), parallel-connected
	K	200	60	central septic tank	3 square-shaped reed beds (2300 m^2), series-connected
Groundfilters	**L**	500	240	central double-storied septic tank	1 groundfilter (530 m^2)
	M	60	60	central double-storied septic tank	1 groundfilter (150 m^2)
	N	380	130	central double-storied septic tank	1 groundfilter (280 m^2)

Stabilisation ponds

According to available data, there are approximatelly 25 stabilisation ponds in the Czech Republic (considering agglomerations of more than 50 inhabitants). Their capacity ranges between 40 - 800 p.e. The systems have been built since 1980s. In some cases was used an already existing ordinary pond under a village, usually without any mechanical pretreatment. On the other hand there are some waste stabilisation ponds of higher level, being built especially for wastewater treatment purposes, equipped with mechanical pretreatment (racks, Emscherbrunnen) and pond aerators. There are used mostly surface aerators; only one systems in the Czech Republic operates with an undersurface fine-bubbled aeration automatically controlled by oxygen sensing head (locality F).

Wastewaters drained into the wastewater treatment plants using the waste stabilisation ponds as a secondary treatment are highly diluted by ballast and rain waters. The average inlet COD concentrations are 100 $mg.l^{-1}$ and the hydraulic load ranges from 60 to 85 $l.m^{-2}.day^{-1}$. The organic load is rather lower (2g $BOD_5.m^{-2}.d^{-1}$) in comparison with the most often citated values in literature, which are 3 - 6g $BOD_5.m^{-2}.d^{-1}$ (Racault et al., 1995; Salek, 1997).

Treatment efficiency in waste stabilisation ponds is strongly influenced (either primarily or secondary) by atmospheric changes (Schetrite and Racault, 1995; Graae *et al.*, 1998; Ingallinella *et al.*, 2002).

The best treatment results were reached by effectively aerated stabilisation ponds in locality F (BOD_5, N_{total} and P_{total} removal efficiencies: 81 %, 47 % and 40 %, respectively). On the other hand, the poorest results were reached by the simple „down a village“ ponds (locality A, B - BOD_5, N_{total} and P_{total} removal efficiencies: 41 %, 42 % and 28 %, respectively), which are not equipped by a pretreatment and an aeration. Water levels of these simple ponds (A,B) are for a most of the year coved up; either by ice during the wintertime or by duckweed in summers. This fact negatively affects the oxygen difussion into the water and the outflowing waters are very often putrescent, with oxidation reduction potencial values around minus 180 mV.

Annual data evaluation shows that the treatment efficiency is mostly influenced by oxygen conditions in ponds and a rate of algal bloom. The algal bloom is a reason why the detected annual organics removal efficiency (expressed as BOD_5) was only 57 %. Just *et al.* (2004) features the organics removal efficiencies in waste stabilisation ponds in range between 70 - 80 %. Schumacher and Sekoulov (2003) pointed out that the algal overgrowth causes a secondary pollution which can raise the values of BOD_5 in effluent water by another 60 - 90 %.

Detected total nitrogen removal efficiency was 43 %. Citated values concerning nitrogen removal efficiencies are various. They range from almost 0 % to approx. 60 % (Just *et al*., 1995; Racault *et al*., 1995).

Detected total phosphorus removal efficiency was 37 %; the most often citated values range between 50 - 70 % (Racault *et al*., 1995; Kadlec, 2003; Just *et al*., 2004). The phosphorus removal efficiency is dependend on a fact, what amount leaves a water column for a sediment (and other way round). This process is influenced by dissolved oxygen concentration in water. Anoxic conditions are generally perceived as a stimulator for phosphorus release from the sediment (Zhang *et al*., 2004). In case of three waste stabilisation ponds, there were analysed also the nitrogen stores in sediments. The organic part of the sediment dry mass was between 15 - 45 % and the phosphorus content in the sediment dry mass ranged from 0,13 to 4,3 $mg.g^{-1}$.

Microbial analyses showed satisfactory removal; effluent concentrations of coliforms were under 2000 $cfu.ml^{-1}$, thermotolerant coliforms under 400 $cfu.ml^{-1}$ and enterococci under 200 $cfu.ml^{-1}$.

Constructed wetlands

Constructed wetlands have been built in the Czech Republic since 1990s and their number counts about 160 systems. The smallest ones are designed for individual houses, the biggest ones for agglomerations of 1000 p.e. Most of the applications are in settlements of 300 - 500 p.e. An average bed area ranges between 125 - 3900 m^2 and the number of beds within one system is from 1 to 6. Typical are also lower concentrated inflows, even not in such volume like in the case of the waste stabilisation ponds. The average inlet COD concentrations are 280 $mg.l^{-1}$. The actual organic load is three times lower than values presented in the literature and recommended for projects, which is 12g $BOD_5.m^{-2}.d^{-1}$ (Geschlossl and Stuible, 2000). All systems are equipped with a mechanical pretreatment, most often septics or Emscherbrunnens. Constructed wetlands in our country are almost entirely with a subsurface horizontal flow where the beds are permanently flooded. This design sometimes causes an anaerobic condition occurrance in reed-beds which leads to sulphates reduction. Considering prevalent anoxic or anaerobic conditions in reed beds, there is only low transformation of ammonia to other forms of nitrogen. Ammoniacal form of nitrogen is hardest for removal due to high oxygen demands of nitrification. In addition, there is a competition for oxygen with easy-degradable organic matter removal processes (Kadlec, 2003; Mulder, 2003). In cases when inflow water contains oxidized forms of nitrogen (mostly nitrates, which confirmes an in-leak of ballast waters into sewer systems) - it leads to their effective removal. Detected annual total nitrogen removal efficiency was 32 %.

Phosphorus removal in reed beds is long-term realized only by sedimentation accretion via particulate sedimentation, chemical precipitation and accumulation of refractory plant detritus (Polprasert *et al*., 2005). The removal efficiency is usually quite low and outflow concentrations depend on inflow pollution variancies. This is a reason why we often detect higher phosphorus concentrations in outflow than in inflow waters. The annual total phosphorus removal efficiency was 22 %, which is in conformity with often citated values in literature which range between 5 - 60 %, in average around 20 % (Just *et al*., 2004).

A degree of organics removal (expressed as BOD_5) can be evaluate as satisfactory (82 %) and stable (there are no such annual fluctuations in comparison with waste stabilisation ponds where the elimination of organics is strongly influenced by the proliferated phytoplankton). Organics removal is collectively citated as good. Most often are the removal efficiencies in the Czech Republic above 70 %; in half cases reach 90 % (Rozkosny, 2004).

Groundfilters

As groundfilters we consider filter systems designed for a slow biological filtration of pretreated wastewaters. The systems are with vertical flow and a top usually with grass-covered earth. As a filter media sand or gravel is used. The groundfilters are recommended as a part of domestic wastewater treatment facilities: septic tank – groundfilter. There is no much use for bigger settlements or even whole villages. In the Czech Republic we have only 4 groundfilters designed for more than 50 p.e. Due to a fact, that filter beds are not permanently flooded and are ventilated from bellow, aerobic conditions are kept inside the filter. Sewage collectings of these newer systems are not as old and weighed by ballast waters as those of the waste stabilisation ponds. That is a reason of the achieved equality between actual and proposed values of hydraulic loads. The actual organic load is one third lower than designed values for extensive vertical flow filter systems, which are 24g $BOD_5.m^{-2}.d^{-1}$ (Geschlossl and Stuible, 2000). A level of pollution removal ensured by this non-convential wastewater treatment technique is favourable. The average annual BOD_5 removal efficiency was 88 %. Particularly because of more effective transformation of ammonia (due to aerobic conditions in the filter) was the total nitrogen removal 47 %. Phosphorus elimination was 35 %. The best pollution removal efficiency results are not just effects of lower dilution of inflowing waste waters (average inlet COD concentrations are 430 $mg.l^{-1}$), but also because a fact that this technology is more intensive than waste stabilisation ponds (filter media works as biomass carrier) and (as contracted to the horizontal flow constructed wetlands) runs under aerobic conditions.

The Table 2 gives main figures concerning inflowing loads and removal efficiencies in all discussed non-conventional waste water treatment techniques.

Table 2 A summarized survey of actual inflowing loads and removal efficiencies of non-conventional wastewater treatment techniques.

		Inflowing loads				Removal efficiencies		
System type	Flow rate	Hydraulic load	Organic load	Nitrogen load	Phosphorus load	BOD_5	N_{total}	P_{total}
	$m^3.day^{-1}$	$l.m^{-2}.day^{-1}$	$g\ BOD_5\ m^{-2}.day^{-1}$	$g\ N\ m^{-2}.day^{-1}$	$g\ P\ m^{-2}.day^{-1}$			
WSP	397	81	2,0	1,4	0,16	57%	43%	37%
CW	67	52	4,3	2,3	0,28	82%	32%	22%
GF	75	183	17,6	8,2	2,52	88%	47%	35%

Often occuring problems

Main problems connected to operation of waste stabilisation ponds are: the ice-blockage of surface aerators during wintertimes and the duckweed-cover or the algal bloom during summers. Subsurface horizontaly flow constructed wetlands must very often deal with oxygen deficiency. A common problem of both, constructed wetlands and groundfilters, is their gradual colmatage. An intensity of the bed-choking depends mainly on wastewater composition, on a kind of mechanical pretreatment, on filter-bed material and not least on maintenance. Sometimes, the reed bed distribution zone colmatage is evident after not even 5 years of operation.

Water disposal into underground waters

Treated wastewaters from small communal pollution sources can be discharged into a watercourse or infiltrated into groundwaters. Engineering characteristics of soil infiltration systems for sources of up to 50 p.e. are gathered in the Technical Report CEN/TR 12566-2. The document mentions certain removal efficiencies of recommended infiltration objects without detailed specifications.

Czech legal regulations do not allow treated wastewater disposal into underground waters. There is an only exception for individual family houses, where the infiltration could be allowed on the basis on a hydrogeological expert's testimony (we can count hundreds of such cases in our country). There is a couple of bigger settlements using infiltration as a method of treated wastewater disposal, which have a permission issued according to earlier legal regulations, which is going to fall into abeyance soon. In order to assess wastewater infiltration impacts on groundwater quality, we have studied this process at a place, where the infiltration is long-term realised in a relatively large scale (flow volumes of approx. 0,1 $l.s^{-1}$). Via a passage through the ground, which is 50 metres long, is evident a rapid decrease of pollution. The Table 3 shows the pollution decrease from the point of infiltration (PI) to a point, where the infiltrated water springs back up on the ground. From chloride parameter we are able to deduce a volume of wastewater dilution by underground waters.

Table 3 Pollution decrease after a 50 metres long passage of pretreated waste waters through the ground.

	COD_{Cr}	SS	$N\text{-}NH_4^+$	$N\text{-}NO_2^-$	$N\text{-}NO_3^-$	P_{total}	$P\text{-}PO_4^{3-}$	Cl^-	Intestinal enterococci	Thermotolerant coliforms
	$mg.l^{-1}$	$mg.l^{-1}$	$mg.l^{-1}$	$mg.l^{-1}$	$mg.l^{-1}$	$mg.l^{-1}$	$mg.l^{-1}$	$mg.l^{-1}$	$cfu.l^{-1}$	$cfu.l^{-1}$
Springtime										
Point of infiltration **(PI)**		18	13	0,36	1,4	2,1	1,9	30	360	7 000
Spring area (50 m from the **PI**)		3	0,3	0,04	6	0,46	0,34	16	1	6
Summertime										
Point of infiltration **(PI)**	315	140	47	0,04	0,15	7,8	5,8	305	3 800	88 000
Spring area (50 m from the **PI**)	28	5	1,8	0,04	6	0,32	0,16	131	2	39

CONCLUSIONS

The most common techniques for wastewater treatment in small towns and settlements are in the Czech Republic technologies with underloaded activated sludge processes. Extensive wastewater treatment techniques are also used. Number of their realizations and knowledges from observation enable us for their potentiality assessment.

Extensive wastewater technologies can be advantageously used for treatment of waters coming from sewerages of poor quality, in which the wastewaters are diluted by in-leaking ballast waters. Extensive techniques are able to deal with insufficient organic load. The system can even be, in some cases, independent on the electric energy supply, which lowers operation costs. On the other hand, these technologies are quite difficult to control. A reduced need of servicing and maintenance, often highlighted as benefits, may have serious consequences; not regular emptying of a pretreatment contributes to quicker filter beds clogging, which are reparable only by filter media replacement.

Waste stabilisation ponds show quite satisfactory elimination effects, if consider ordinary high ballast weighting ratio. Treatment difficulties can occur in winters in case of non-aerated ponds or in summers, when the water level occurs to be fully covered by duckweed. During such situations, the ponds may slip into anaerobic conditions. The outflow water quality is also negatively affected by an excessive algal growth.

Constructed wetlands (in the Czech Republic most often designed with subsurface horizontal flows) treat the waters predominantly under anaerobic conditions. A lower nitrogen removal efficiency is connected to this fact, because there can not be properly run the process of nitrification. There is a need of pointing out, that the constructed wetlands are not designed with the aim of reaching especial outflow nutrient removal efficiencies, but for a purpose of good-class organic removal. That is in most cases satisfactory and stable.

Groundfilters in the Czech Republic are more often built only in a small domestic scale. Larger systems, which were subjects for our monitoring, are favourable in organic pollution removal and reached the best results in nitrogen removal within all observed extesive techniques.

The non-conventional wastewater treatment techniques can not be generalized as suitable for all small municipal sources. However, they do have some indisputable adventages and due to them can be successfully used in certain localities.

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