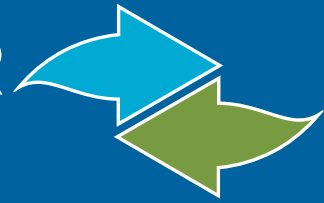


SUSTAINABLE MANAGEMENT

WATER

1-2005



CONCEPTS TOWARDS A ZERO-OUTFLOW MUNICIPALITY

ZERO M



A GENERAL INTRODUCTION

Domestic water supply and wastewater treatment as we presently know and practice it is a "Victorian art". Though we have improved the techniques used, the approach is still the same. We have to ask whether such an approach, which was developed some 100 years ago for very specific conditions is still appropriate nowadays and more particularly, under completely different conditions.

P. 3

CLEANER PRODUCTION



P. 6

Industrial pollution initially was treated by concentration and storage or dilution and discharge into natural systems. Environment degradation and the new waste treatment technologies led first to end-of-pipe solutions and today to sustainable development.

ANAEROBIC PRIMARY TREATMENT



P. 15

The development of low-cost technologies for adequate collection and treatment of wastewater could help responding to the increasing demand for sustainable sanitation and wastewater management in developing countries.

SANITARY FACILITIES



P. 36

Efficient use of drinking water especially in regions of water scarcity will get great importance in the next decades. On one side people are longing for comfortable tap water, on the other side this advantage will automatically lead to a wasteful use of water.



This project is funded by the
EUROPEAN UNION



Sustainable Water Management is an initiative of the project “Sustainable Concepts towards a Zero Outflow Municipality” (Zer0-M). The project is part of the Euro-Mediterranean Regional Programme For Local Water Management of the European Union (MEDA Water) and the Countries bordering the Mediterranean Sea.

Zer0-M aims at concepts and technologies to achieve optimised close-loop usage of all water flows in small municipalities or settlements (e.g. tourism facilities) not connected to a central wastewater treatment – the Zero Outflow Municipality (Zer0-M). This means application of water-saving technologies as well as separate collection of different wastewaters and treatment and re-use according to their quality. Several technologies are already available, which allow efficient wastewater treatment and re-use without hygienic risks on a low-cost and easy-to-handle level. These include sanitation systems with low water consumption, segregation of grey- and blackwater, biological treatment of grey water and re-use for non-drinking purposes (e.g. irrigation, toilet flushing), bio-membrane reactors for intense treatment, constructed wetlands for extensive treatment, sludge-hygenisation for re-use as fertiliser.

This journal is meant to provide a platform for the dissemination of such techniques, of ecosanitation, as they are widely called. It is initiated by Zer0-M but should live on beyond the lifetime of the project. Its main goal is to provide a hard copy information tool beside the internet based means of exchange, which are not yet available to all water technicians in the countries concerned.

Funding for this project is provided by the MEDA Water Program (also see backcover) of the European Union (80%) and national governments or organisations (20% all together).

Applicant for the project is the AEE Institute for Sustainable Technologies in Gleisdorf, Austria, www.aee-intec.at.

The partners in the Mediterranean countries are from research institutions in Egypt, Turkey, Morocco and Tunisia. Partners of the European Union are from Italy, Germany and Austria. The complete list of the consortium members is as below:

- (1) AEE Institute for Sustainable Technologies (AEE INTEC), Austria
- (2) Associazione Ambiente e Lavoro Toscana – O.N.L.U.S. (ALT), Italy
- (3) Tübitak-Marmara Research Center (MRC-ESERI), Turkey
- (4) Water Research & Pollution Control Department, National Research Centre, Dokki, Cairo, (NRC), Egypt
- (5) Institut National de Recherche Scientifique et Technique, Laboratoire Eau et Environnement (LEE), Tunisia
- (6) Institut Agronomique et Vétérinaire Hassan II, Wastewater Treatment and Reuse Unit (WTRU), Morocco
- (7) Institute for Geography and Regional Research, University of Vienna (IGR), Austria
- (8) TU Berlin, Central Co-operation and “Fachgebiet Verfahrenstechnik I” (TUB), Germany
- (9) University Hannover, Zentrale Einrichtung für Weiterbildung (weiter-BILDUNG), Germany
- (10) Fachvereinigung Betriebs- und Regenwassernutzung e.V. (fbr), Germany

Information about the program and the other projects of the program can be reached via the homepage of EMWIS/SEMIDE: www.emwis.org or www.semide.org. The articles of this journal and further information is also available on the website of this project: www.zer0-m.org. This website also provides a forum for questions and discussions about sustainable water techniques. You are all warmly invited to join in for a lively exchange.

We hope this journal responds to a need in the countries where it is published and would be very pleased if it furthers the issue of ecosanitation in order to protect the environment and preserve our precious water resources.

For the Consortium: *Martin Regelsberger*

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SUSTAINABLE WATER MANAGEMENT

GENERAL INTRODUCTION

By MARTIN REGELSBERGER*

Domestic water supply and wastewater treatment as we presently know and practice it is a “Victorian art”. Though we have improved the techniques used, the approach is still the same. We have the right and obligation to ask whether an approach, which was developed some 100 years ago for very specific conditions, is still appropriate nowadays and, more particularly, under completely different conditions. Actually the obvious answer is no. But let us look at it step by step.

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HISTORY OF WATER SUPPLY AND SEWERAGE

Until the second half of the 19th century, Londoners were still drinking water from the same portions of the Thames river into which the open sewers were discharging.

After several outbreaks of cholera, it was in the wake of the Great Stink of 1858, when the stench from the Thames caused the parliament to go into recess, that authorities finally took action.

The construction of the central London sewer system started in 1859.

19th century European large towns (London, Paris, Vienna, Berlin) had

- increasingly high population density,
- a lot of water due to the humid climate,
- very bad water supply and waste disposal, thus
- a huge sanitary problem with epidemics spreading and disturbances because of bad smell.

The towns were near to the sea or other large recipient waters like big rivers. Thus the key idea of a separation between water supply and wastewater, familiar to ancient towns around the Mediterranean sea already, was reborn by implementing a central water supply system and water borne waste transport in sewers towards the large recipient. The water demand was no preoccupation in this area and at that time, nor was the treatment of the collected wastewater. There was enough water, due to the humid climate and the large recipients were deemed sufficient to deal with any amount of immissions.

APPROACH

The measures were successful in solving the sanitary problems at the time and stopping epidemics. Later when it was discovered that the receiving waters could not cope with the loads of nutrients released, treatment plants were added and progressively upgraded according to new findings about the environmental impact of wastewater releases.

The preconditions, however, lead to the indiscriminate use of pure potable water for everything in a one-way manner, from drinking to waste transport. Not only households but also trades contributed to this all-to-the-sewer approach, regardless of treatment requirements further downstream, and whether these could be met with the obtained mixture. Equally not considered was the value of the discarded substances or the hazards they would cause.

This certainly very convenient system, the most widespread sanitation nowadays, has important shortcomings, especially but not only under water stress conditions. Water demand tends to be very high. The demand increased throughout decades with the spreading of the system to an increasing part of the population and new water dependent commodities added (see fig. 1, data for Germany). System costs are

Photo: <http://www.lovelyworld.com/> – Dominique G.



very high, as large amounts of water have to be produced, transported and provided with sufficient pressure, collected again and then centrally treated for a variety of very different polluting substances.

As clean water is not always available in sufficient quantity, utilities resort to mixing water qualities or using low quality water even for sensitive purposes because there is only one system for such different uses as drinking water and water for toilet flushing. This has resulted in resorting to bottled water for drinking for those who can afford it, further increasing the overall cost.

Besides the system costs it turns out that separating the substances contained in the wastewater is difficult if not impossible. This prevents their further reuse or makes it very difficult. Some pollutants, once added to the water can not be removed any more at acceptable cost. This is the case for a wide range of very hazardous substances at very low concentrations, the endocrine disruptors, substances occurring in drugs, particular tensides, solvents, disinfectants etc.

Thus the water and sanitation system developed in the nineteenth century actually results in an inefficient use of water and nutrients, and the unnecessary pollution of clean water, both through overconsumption and the remaining pollution after treatment.

The problems resulting of this wasteful practice are amplified under water stress conditions with often conflicting interests regarding water use. Tourists, who do not take into consideration water scarcity in their behaviour but are an important source of income in Mediterranean countries, often aggravate such conflicts (see for example Claude Llena, "Tozeur, ravagée par le tourisme", in *Monde Diplomatique*, July 2004 <http://www.monde-diplomatique.fr/2004/07/LLENA/11308>).

Credit: Provided by the Sea WIFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE



ALTERNATIVES

"... Because the best way to deal with pollution and wastes is to avoid creating the problem in the first place."

The increasing costs for water services were first felt by industry, which led to a reorientation in the use of water. Closed cycle production processes have been and are still developed as far as possible, in order to reduce water demand and wastewater output. On site pre-treatment or treatment of trade and industrial wastewater is more and more common, responding to the specific characteristics of this type of wastewaters. Particularly hazardous or valuable substances are removed at source, e.g. silver at photo labs, mercury at dentists.

The domestic sector, too, started to grow attentive to the issue, partly because the services became very expensive, partly because even humid countries ran short of clean water. Thus, public water utilities and responsible administrations raised awareness for their difficulties among their client population, partly, it must be said, under pressure of these same clients. The result is clearly visible in fig. 1, showing the evolution of the water demand in Germany which stabilised in the early 80s, actually against all predictions, and started to decline since 1990 to reach an average of



Fig. 1: **WATER DEMAND FORECAST AND ACTUAL DEVELOPMENT IN GERMANY**
(Gundermann, 1993)



by a variety of measures, from efficient appliances to a new user behaviour, including incentive tariffs.

What has become widely accepted with solid wastes in many countries, i.e. separate collection of different categories of waste, should also be generalised with wastewater. This would allow more efficient treatment and easier reuse of water and substances contained, most of all nutrients.

Techniques considered are separate greywater collection (greywater is non-toilet wastewater) and direct reuse of this rather little polluted wastewater with or without treatment; or urine collection, storage and recycling as a fertiliser in agriculture. Both lead to new opportunities in the treatment of faeces and the reuse of organic matter contained.

The aim of these changes in domestic sanitation is to achieve a most widely possible reuse of water and nutrients. Water can be treated towards recycling or used in a cascade of purposes with or without intermediate treatment with gradually decreasing requirements to its quality, e.g. showering, toilet flushing and landscaping. Nutrients can be directly returned to agriculture or treated before use.

Some techniques are already available. But a lot of research in technical systems has still to be done in order to

slightly above 120l/(c.d) nowadays. Water consuming appliances are replaced with new, more efficient ones and people get more heedful with their behaviour regarding water consumption. Leaking water taps, loosing as much as 30 l per day, get repaired more readily, it seems.

Water technicians are now looking for new solutions to water supply and wastewater disposal. Progressively, alternatives to the "traditional" system are being developed and introduced, partly resorting to techniques used since centuries but abandoned with the introduction of piped water systems, e.g. rain water collection and storage.

OUTLOOK

Zer0-M and other organisations, actually the whole MEDA Water program, tend to develop a more sustainable use of water. Zer0-M chooses an integrated approach to water and wastewater services. Considering both, water supply and wastewater treatment together when designing domestic sanitary systems, should lead to more flexible and sustainable solutions, i.e. less waste.

Increasing water efficiency is certainly a first step to a more sustainable use of water. This can be achieved

develop convenient, safe and affordable solutions for all. A main concern in the reuse of treated wastewater is the hygienic risk. This must be another field of future research in hazards, their mitigation and appropriate regulations.

To introduce these more sustainable water and wastewater techniques, they have to be made acceptable in the first place, acceptable to a wide range of target groups. Beside the general public, these include the water professionals and the policy makers at all levels. This will need working examples, training possibilities for professionals and tools for the flexible use of available techniques. This is the major goal of the project Zer0-M and this journal, which will be published twice a year, to introduce new water techniques to water professionals and policy makers, to explain how they can be used and what are the possible inconveniences and even more, their advantages.

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CLEANER PRODUCTION

By LATIFA BOUSSELMI*

At the beginning, the pollution generated by industrial activity was treated by concentration and storage or dilution and discharge in natural systems. Lately, the awareness of pollution and environment degradation risks and the development of waste treatment technology lead first to end of pipe approach then cleaner technology and today to sustainable development.

The “end of pipe (EOP)” approach has developed since the 1970s with the set up of environmental legislation. It is based on the collection of the polluted streams of the industrial process and their treatment in a wastewater treatment plant (WWTP) to fit the standards of discharge fixed by the regulation. This approach permits the reduction of the pollution and the development of treatment technologies adapted to the type of pollution and to the end concentrations required.

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However, most of the treatment technologies proposed have a certain number of inconveniences that make their utilization more and more criticised.

Pollutants in wastewater are concentrated in the solid phase by physical, chemical and biological reactions. This transformation can have a high cost due to the use of chemical reagent and generate a polluted sludge which must be transported in the appropriate landfill.

As the legislation becomes more and more strong, a gradual technical improvement of the end of pipe technology is developed, increasing the total cost.

For most of the industry the principal purpose is to fit the legislation than to protect the environment, so the implementation of WWTP is not the result of an environmental strategy which could be totally absent on the company. EOP approach doesn't incite enterprises to invest in research in order to develop innovative less polluting production processes.

CLEANER PRODUCTION APPROACH

The definition of cleaner production (CP) according to the United Nations Environmental Program (UNEP) is „the continuous application of an integrated preventive environmental strategy to process, products and services to increase overall efficiency and reduce risks for humans and the environment“. This new concept is developed since 1980.

The CP attacks environmental problems at the source rather than its effects. It includes a manufacturing process which:

- reduces effluent and other waste production,
- maximises product quality,
- maximises the usage efficiency of raw materials, energy and any other inputs.

The principal advantages are :

- economy of raw materials and energy,
- economy of depollution cost,
- valorisation of by-products, and
- improvement of the quality of products and the capacity of innovation.

This approach pushes industries to develop innovative production systems to prevent the pollution to the source. The wasting of raw materials, the excessive consumption of water and energy and the cost of the WWTP increase the production cost and decrease the competitiveness of the enterprise.

However, the implementation of CP requires the knowledge of all criteria and parameters of the process, and the possibilities of recovery and reuse. The choice of technology often requires the realization of pilot tests to confirm the theoretical selection. The setting up of CP doesn't generally solve completely the problem of the pollution but permits to reduce the quantity and/or the toxicity of pollutants before treatment and therefore to reduce the dimension of the WWTP.

ORGANISATIONAL IMPROVEMENTS (GOOD HOUSEKEEPING)

Simple tools can lead to easy-to-implement measures, improving both the economic and ecologic performances of companies.

The improvement of the chemical reagent manipulation in textile sector could reduce the pollutant load by 10 to 50% (BOD, COD, heavy metals, color, toxicity, etc.). The good management of chemical reagents and solvents will eliminate the risk of the discharge of the spread pollutants (either accidentally) on the sewage system or on the atmosphere. Also a good Inventory control of chemicals will prevent wasting chemicals, which have expired.

The maintenance of equipment is simple but important action. The leakage or lost of water and energy can be avoided as well as default in the final product and its discharge.

PROCESS OPTIMIZATION

Process optimization requires a systematic analysis of the process to identify the most resource and reagents consuming steps. The analysis of effluents will detect the type of pollutants and localize the polluting steps. From both information, the polluting reagents are identified as well as the opportunities of recovery and recycling. This approach normally generates "start of pipe" solutions as opposite to the "end of pipe" solutions. The principal steps are presented below and illustrated with example from textile SME with dyeing and washing out jeans activities.

1. Detailed characterization of all process steps (water, chemical, energy and raw material balances): Considering water balance, table 1 presents water consumption by final product. A ratio of 50% to 67% of the water consumption during the process is used for rinsing steps (fig. 1). It is notable that the optimisation of water use or wastewater reuse of this step will lead to important water savings.

2. Characterisation of the effluent streams: Follow-up on the COD reveals that chemical pollution of washing out of jeans process is superior to the dyeing one (table 1). In fact, the highest COD is recorded for the stone wash step (8,8 g.l⁻¹) partially due to the use of Alkylphenoethoxylates compounds at this step (fig. 2). By way of comparison, for the dyeing process, the colouring bath presents a high COD (5 g.l⁻¹) followed by neutralisation with acetic acid (1 g.l⁻¹).

It is clear that pollution expressed in COD is concentrated in steps that reject less than 20% (stone wash

Activity	l. kg ⁻¹	g COD. kg ⁻¹
Dyeing	92	78
Washing out Jeans	50	94

Table 1: WATER CONSUMPTION AND POLLUTION PROFILE

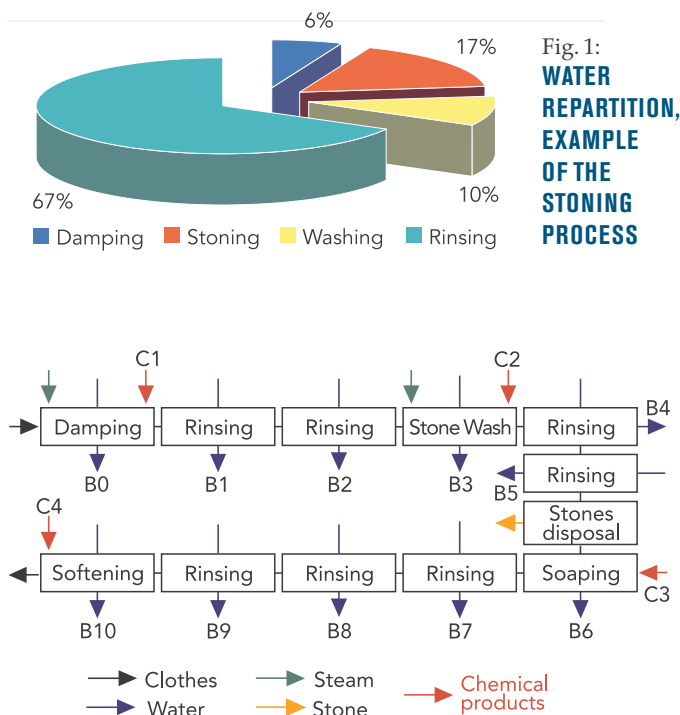


Fig. 1: WATER REPARTITION, EXAMPLE OF THE STONING PROCESS

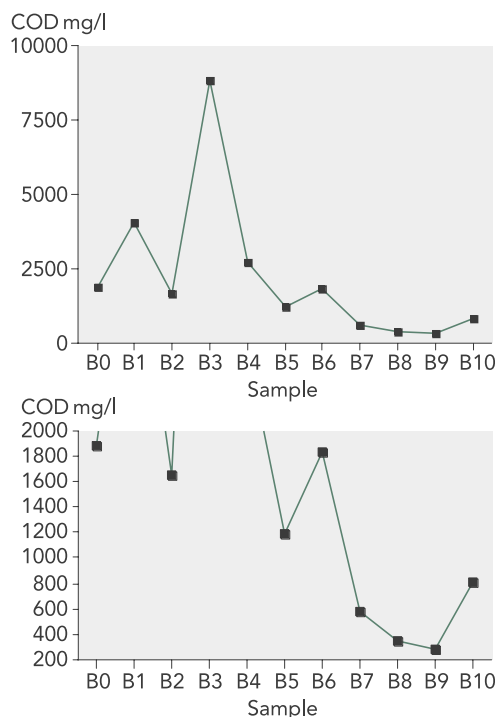


Fig. 2: STONE WASH PROCESS AND THE RELATED COD

and coloration) of global wastewaters. Their separation will increase the recycling possibilities especially of the rinsing wastewater.

3. Identification of technically feasible process optimization and water reuse opportunities according to the detailed characterization of the process and effluents: Optimising processes involve changes in the process flow and/or improvements of process control. Replacement of technology, or pathway can be introduced in order to run the processes at higher efficiency with a minimum generation of waste.

Measures with a high initial investment cost are scarcely considered such as modification of raw material, equipment or final product. The optimization of

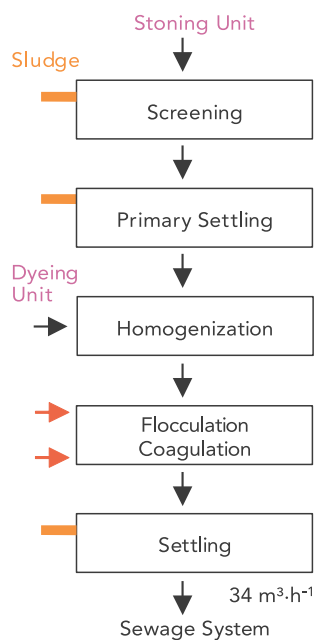
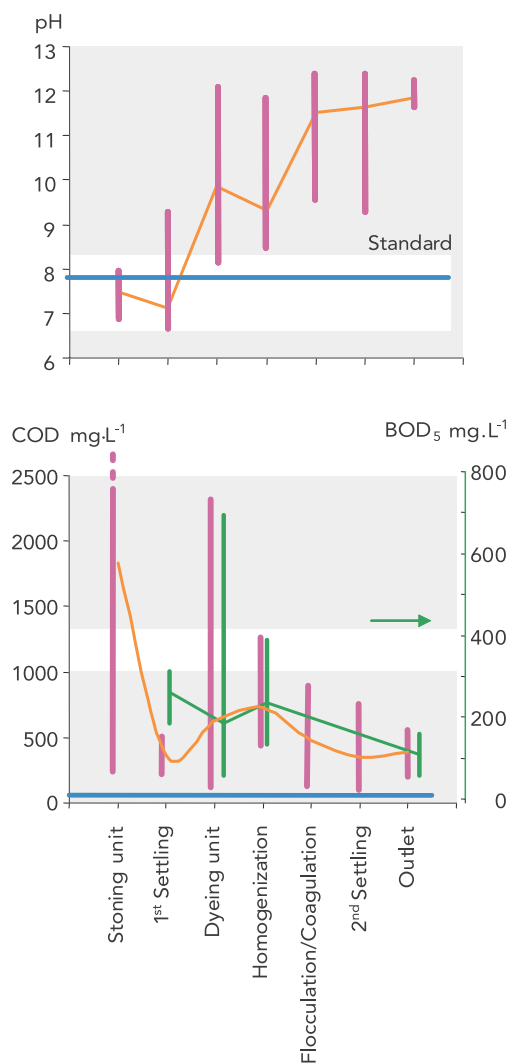


Fig. 3:
**WWTP EFFICIENCY,
COMPARISON WITH
STANDARDS FOR DIS-
CHARGE IN THE SEWAGE
SYSTEM (WHITE AREA)
AND WATER PROCESS
(BLUE LINE)**



the chemical reagent utilization is one of the most profitable technical interventions. It is based in general, on laboratory tests to select the adapted ones and to reduce doses to the necessary and sufficient minimum.

4. Characterization of the treatability of the final effluent on the WWTP: The EOP technology implemented in textile SME is presented in fig. 3 as well as the COD and BOD₅ reduction. After flocculation-coagulation, an important decrease of the COD (45% to 65%) and BOD₅ (50%) is obtained, the quality of treated wastewater obeys the discharge standards in the sewage network with the exception of the pH. However, the treated wastewater is still coloured and the reached depollution level does not allow the recycling. It is necessary to add a complementary treatment (adsorption, membrane separation, oxidation...) to permit a total or partial recycling.

SUBSTITUTION OF HAZARDOUS COMPOUNDS

The chemical reagent substitution is achieved to improve the efficiency of the process and the quality of the final product and to minimize the pollution impact.

The use of water and energy can be closely linked to the nature of the chemical reagent. The suitable substitution could decrease their consumption. Also auxil-

iaries use can vary according to the chosen chemical reagents and they can be eliminated by using the adapted reagent or by adapting the quality of the water process.

Alkylphenolethoxylates compounds (0.5 to 1 g of COD/g) responsible of the high COD detected at damping and stone wash steps (fig. 2) could be substituted by ethoxylates. Also the use of mineral acid for the neutralization step instead of acetic acid will decrease the chemical pollution.

EQUIPMENT MODIFICATIONS

Modification of the existing equipment can be undertaken by the addition of measuring and controlling devices, installing cleaner equipment, introduction of computer controlled system or automated dosing system. These modifications sometimes generate high investment costs and they are used in last recourse when all other possibilities have been analyzed. Given to the long life time of a lot of industrial equipment associated to their high capital cost, the alternative of new cleaner equipment installation is often eliminated by enterprises.

RECYCLING

Economical benefit can be obtained from recovering and re-using the raw materials and by-products. Reuse and recycling of chemicals, water and waste alternatives depends on the process and can require intermediate treatment. It will save water and raw material but also energy (recycling of hot water). The recycling solution must be efficient, cost effective and easy to operate.

For water recycling it is necessary to separate different wastewater streams to increase the possibilities. The pollutants in this case are well identified as well as the physico-chemical characteristics of the effluent (e.g. acidity, COD) which allow an adapted pretreatment if necessary or the recovery of reagents. However, the segregation of effluents implies the multiplication of discharge and storage systems and the management of the different parts of the recycling unit.



In general after scanning the process different methods of water reuse can be identified as the recycling of cooling water or rinsing wastewater in some cases (fig. 4). Adjustment of the chemical reagent concentration before the recycling is a sensible operation which requires a storage step and dosing devices. The treatment of wastewater before recycling can be a simple one as decantation, filtration, neutralization, or a more sophisticated one as a membrane system or oxidation process related with higher costs. The membrane system is implemented mostly when there is a recovery of reagent which will decrease the total cost of the recycling operation. The final discharged effluents (not recycled) are mixed and treated in WWTP. Today the combination of biological, physical and chemical technologies allow the recycling of the treated wastewater totally or partially with an optimisation of the cost.

CONCLUSION

The implementation of cleaner production in one country is highly dependent on the type of environmental regulation and standards as well as incentives. Its development is also function of the supplier chain, research institutes, economical structure, NGOs pressure, and the development of green market. Obstacles are often the lack of information and high implementation cost.

Lots of international and national organisations developed tools to help and support companies to implement cleaner production. As example, Environmentally-focussed Technology Assessment (EnTA) is a decision support tool developed by the United Nations Environment Programme for the specific purpose of enhancing the decision quality by selecting the most appropriate technology. Environmental Impact Assessment (EIA) is a planning tool used to predict and analyze environmental effects of a proposed technology action. At the operational level, an Environmental Management System (EMS) results in considerable benefits. The normative context is illustrated by the international system of environmental management ISO 14000 or the Eco-Management and Audit Scheme (EMAS). These voluntary environmental management systems seek to assist firms in evaluating, reporting and improving their environmental performance.

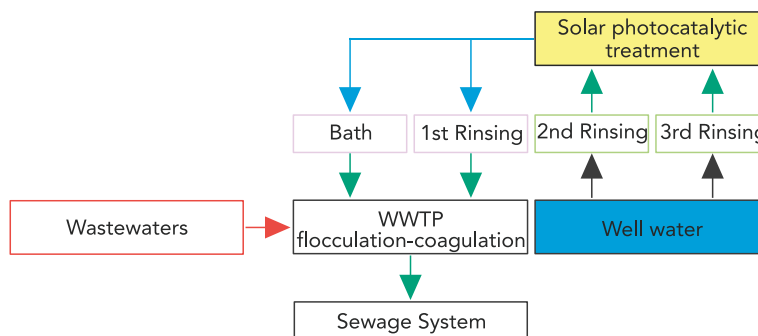


Fig. 4: **RECYCLING SYSTEM FOR TEXTILE PROCESS**

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WATER RECYCLING IN GERMAN HOUSEHOLDS

“NOTHING TO WRITE HOME ABOUT”
OR
AN INNOVATION MANY HAVE LONG
WAITED FOR?

By ERWIN NOLDE*

Water recycling in households, which has been almost forgotten, is different today from what it has been 40 years ago.

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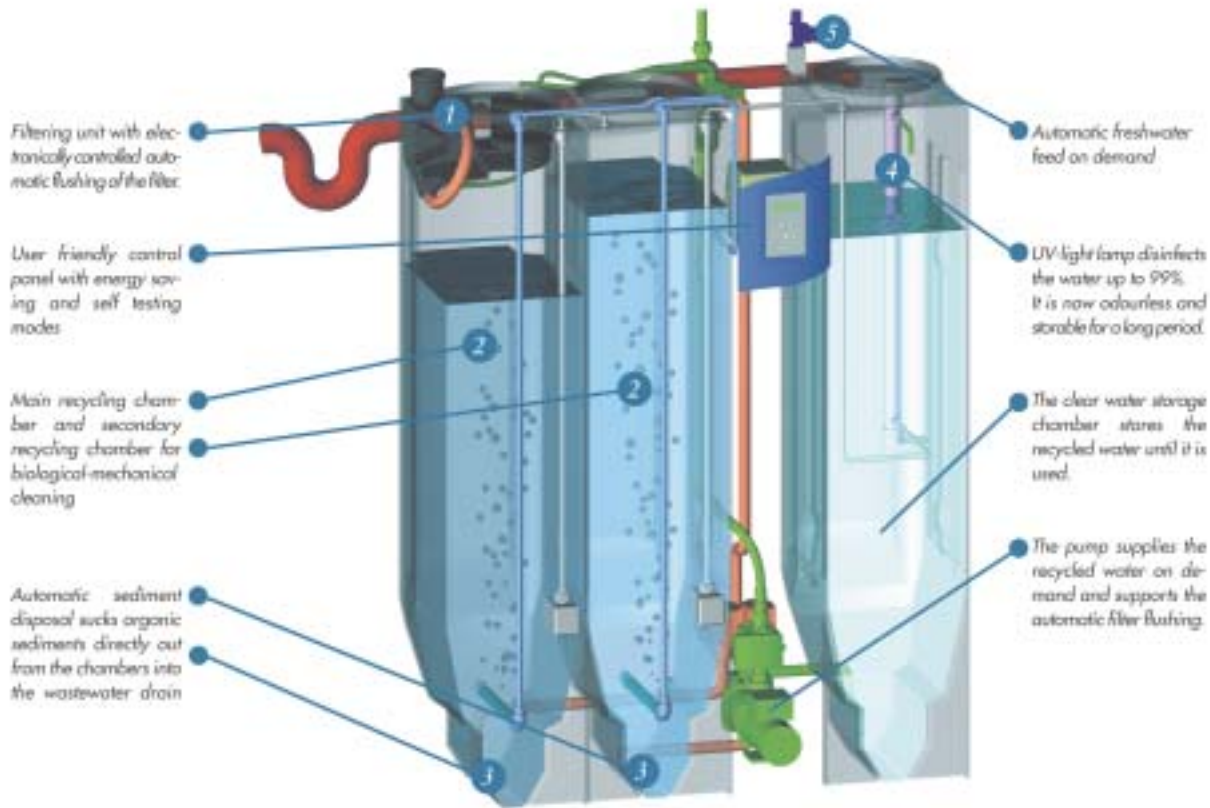
During that time, our grandmothers did not simply spill away the rinse water from washing fruits and vegetables; instead they reused the water to irrigate the garden. 40 years ago, Saturday was the bathing day for the whole family. Water was heated in large pots over a wooden stove and the children were bathed one after the other in a movable zinc tub. The bathing water was not replaced but solely kept warm by adding hot water to the tub. In rural areas, rinse water from the kitchen was even collected and given to the animals.

From an ecological point of view, water recycling in households is not new but the demand for comfort has changed strongly ever since. Nowadays, taking a shower is a luxury and a quality of life and none of us is really willing to do without.

ECOLOGY–WITH(OUT) TECHNOLOGY?

During the 80s and 90s when the initial attempts to develop greywater recycling plants were made, the recollections of the 60s were still present. Greywater was not only a horror scenario for the opponents of water-saving measures. Also ecologically engaged individuals who initially used their untreated or insufficiently treated shower and bath water for toilet flushing lost sooner or later their interest and zeal when it came to cleaning their scruffy bathing tubs or smelly cisterns and tanks. Scientific investigations in Hannover and Berlin have clearly shown that independent of whether experts see a health risk or not in the use of recycled water in households, water recycling nowadays is only accepted by the population when the user does not have to make cuts in his habitual comfort.





▲ Fig. 2:
**PATENTED CLEANING PRINCIPLE
OF THE AQUACYCLE® (PONTOS)**

◀ Fig. 1:
**HOUSEHOLD WATER TREATMENT
SYSTEM AQUACYCLE® 900**

- 1 Pre-Filtration**
Larger particles like hair and textile fragments are collected. The filter is automatically flushed by a special spray pump – sediments are washed away into the main wastewater drain.
- 2 Two-fold biological treatment**
In the main and secondary recycling chambers the dirt particles are decomposed by bio-cultures. The water is pumped to the next station in three hour intervals.
- 3 Sediment disposal**
The organic sediments which are produced during the recycling process are regularly sucked out from the chambers and diverted into the wastewater drain.
- 4 UV-Sterilisation**
On the way to the storage chamber the recycled water flows through a UV light lamp, which disinfects it. The high quality of the water now conforms with the E.U. Directive for Recreational Water.
- 5 Automatic freshwater feed on demand**
Should the supply in the storage unit drop below a certain level, freshwater will automatically be fed into this chamber to ensure there is enough supply for flushing the toilets.

SUCCESSFUL CONCEPTS

In the past 15 years, several systems have proved their effectiveness and were equally ranked as regarding the water quality they produced. The least contaminated wastewater from showers and bath tubs is preferentially used. Wastewater is treated successfully using a planted soil filter or a submerged trickling filter system. Nowadays, membrane reactors are also undergoing intensive investigations for their suitability to recycle wastewater.

In Germany, about 650 systems are in operation which implement the multi-stage Sequencing Batch Reactor (SBR). All systems use treated water for toilet flushing and about half of them have the possibility to

use the treated water for laundry. These systems are also operating in other countries such as in Spain, Saudi Arabia, Australia, South Africa and the Maldives. This new technology will be discussed here in more details.

All above mentioned systems are exclusively mechanical-biological systems without the addition of chemicals. The treated shower and bath water, designated as “clear water” in the herein described system (DIN-Standard designation is “process water”), has undoubtedly earned its name. Judged solely by its appearance, clear water is almost indistinguishable from drinking water. In pilot plants, some million litres of clear water have been produced so far. Measurements which have been made since 1995 even show that in the practice parameters for the hygiene requirements

fall below those laid for recreational waters within the EU by a factor of 10 up to 100.

From the very beginning, it was incomprehensible for many why such a high-quality clear water should be only used for toilet flushing. In the meantime, several well-known manufacturing firms such as Miele, Kärcher and Gardena have shown a positive interest towards multiple use as long as this “non-drinking water” demonstrated a high quality.

SEQUENCING BATCH REACTOR (SBR)

The AquaCycle 900 is a household water treatment system which functions according to the principle of the Sequencing Batch Reactor. Once taken into operation, the system will cause no problems due to the high degree of automation. The foam material in the treatment tanks which was initially colonised by bacteria appear much the same after seven years of operation as during the initial seven weeks following system start-up. Wear-out phenomena are not detected. Bacteria and foam material not only clean the water but also the inner walls of the tank. The filter in the water supply line is rinsed automatically with clear water before it becomes clogged and the sludge which builds on the tank floor is regularly removed and discharged into the sewer without the assistance of the operator. With 0.6 kWh per day for the system electricity, the yearly energy costs are calculated to be around 30 Euro. This is not more than what a small refrigerator requires. In the meantime, the system developers are working on utilising the energy in the warm greywater (ca. 25–30°C) in order to use for preheating.

The compact design of the initial pilot plants of the AquaCycle 900 has found much acceptance among clients in addition to the very low noise level. Moreover, the system is independent of rain events and it daily treats household water to give high quality clear water without the addition of chemicals. Due to the closed construction design, no smell or humidity emissions escape from the system. Based on a client questionnaire, the appealing design of the AquaCycle 900 is valued by many clients such that they find it inappropriate to “hide” the system in the cellar.

For the qualified sanitary trade, an additional interesting field of activity unfolds similar to the solar technology. The whole system is made up of two parts which can be bolted together on site and delivered on a Europallet. For installation and connection to the provided pipe network, the qualified plumber requires one working hour. The system is started from a clearly arranged display with a membrane keyboard. During the initial start-up of operation, the degrading bacterial cultures are given an adaptation period of about two to three weeks. Following this start-up period, the system moves automatically to the normal mode producing high-quality clear water for many years.

MODULAR CONSTRUCTION

Many planners who have already installed a second pipe network in their households have been waiting long for a professional household recycling system. The AquaCycle 900 is particularly valued for its modular construction. With a total reservoir volume of 900 litres, the system can easily treat the clear water demand for 2 to 3 families without any further enlargement. For row houses and condominiums, all three stages can be enlarged according to the specific needs through the incorporation of additional tanks which are identical in construction. Due to this modular construction, the system is also very suitable for use in the commercial and industrial sectors such as in hotels, guesthouses, sporting facilities and camping sites.

For a larger clear water demand, a dual pump system may be installed which will secure the water supply in the commercial and multiple-family house sectors. The modular technology contributes to improving the economic efficiency and profitability of the system. System amortisation is at its best when many families are connected at the same time to the system. In contrast to rainwater harvesting, planners and end-users can be certain that with comparable investment costs not only the drinking water costs will clearly drop but also the usually higher wastewater costs will also decrease.

AquaCycle 900 functions automatically to the greatest possible extent. With regard to maintenance and operation, the system is comparable to a central heating system. However, an important maintenance aspect is the UV disinfection unit. The UV-tube should be replaced following 6000 hours of operation and the client will be alerted in time by the automatic display. By this time, the plant has already disinfected up to 1.4 million litres of biologically treated household water. For UV-tube replacement, the qualified tradesman is responsible. A warranty period of 10 years applies for the container while for the rest of the system components a two year guarantee is applicable.



Fig. 3: AQUACYCLE® 900 (PONTOS)

FUTURE PROSPECTS

It seems that in the near future there will only be winners in the water recycling sector, at least on the long run. At the beginning, responsible persons in the water supply and wastewater disposal sectors are expected to complain when initial client bills turn out low. However, at a later stage they will recognise that decentralised systems will also save on their costs for the drinking water treatment and its distribution as well as for wastewater treatment. These investments will not be required anymore as a result of the ecological water recycling. In this connection, it is no secret that foreign water suppliers consider to offer their end clients water recycling systems in the future coupled to an operator agreement in order not to miss out on this innovative ecological technology.



Photo: NASA (Colourcoded infrared picture of Istanbul)

HISTORICAL WATERWORKS IN TURKEY

By AHMET BABAN and KEMAL GUNES*

The existence of water scarcity and lacking of natural springs nearby lead people to construct wells or try to collect surface water in storage basins. For this purpose cisterns served as water storage tanks and sedimentation basins for water purification throughout the history. The earliest known waterworks in Istanbul date from the Roman period. In this period an extensive water system was constructed /1/.

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Vitruvius /2/ stated that if the ground is hard or if the water layers lie too deep, water supply must be obtained from roofs of the buildings or higher ground and be collected in cisterns. It was mentioned that an insulating layer for the interior surface should be fixed to improve the taste and clearness of the water. As these tanks are divided in two or more compartments, the transferring of the water between the different compartments leads to a purification process. It would make the water much more healthy and sweeter to use. By introducing oxygen and letting it dissolve by means of the transportation process, the water will keep its taste and get rid of any possible smell. In this way, mud and any suspended material included in the water is to settle, otherwise it will be necessary to clear it by adding coagulation agents. These explanations demonstrate and give evidence that Roman period cisterns were used like rainwater tanks.

THE ROMAN PERIOD

During the Roman period Istanbul's water requirements were met by transporting water from Thrace by channels and aqueducts. The remains can still be seen (fig. 1). Due to the threat of cutting the supply by enemies, the Byzantines built large cisterns. The water transported by the channels was stored in several large accumulation and distribution reservoirs. Water was then distributed from these reservoirs placed in relatively high elevations by underground channels. Studies for the waterworks of this period revealed that the first water supply lines have been built in the time of Emperor Hadrian, (A.D. 117-138) /3,4/.

THE BYZANTINE PERIOD

The water storage facilities built in the Byzantine period can be considered in two groups as open reservoirs and underground cisterns that have been placed beneath the buildings. Cisterns are also common in central Anatolia. The largest one was referred as Basilica Cistern and in the Turkish period as the Yerebatan Palace (see fig. 2). The dimensions of the cistern are 140 m x 70 m and it can store about 80,000 m³ water. Water still flows into it and it is known as the world's largest cistern. Its present form was shaped during the reign of Justinian (A.D. 527 - 565). The other cisterns in Anatolia have different architectural structure in both, inside and outside appearance (for example see fig. 3).

The Ottoman water administration system dated back to the reign of Mehmet II, who established a department of water. It was a vast organization and included waterway maintenance men, surveyors, watchmen, carpenters. A special waterproof plaster was made by mixing lime with olive oil and used for leakage prevention. Water-sellers (called saka) carried water in skins for public distribution to the houses by pouring it into small stone tanks near each house. Some houses were equipped with tiny tanks placed in the walls from which water flowed to taps in the living

Fig. 1: **VALENS (BOZDOGAN) AQUEDUCT**

rooms and lavatories. These were filled in the same way by pipes from the tank at the entrance door /5/. The water director had to supervise the water supply for the palace, mosques, hamams (public baths) and public fountains. He had to guarantee for the maintenance of the system, to collect the water fees from regular users as well as to develop new projects. Water carried in skin bags by sakas was distributed.

Fig. 2:
**YEREBATAN
CISTERN IN
ISTANBUL**Fig. 3:
DOME-SHAPED CISTERN IN ANATOLIA

CONCLUSION

Collecting and storing rainwater is not a new idea; it was known and applied from Roman times around the Mediterranean, which resulted in the development of a rainwater catchment culture at all those places where water resources were limited. Many of the systems including the Roman system had a pool in the house, which served purposes as having microclimate by evaporation and use of water for domestic purposes.

As a result of urbanization and population growth the consumption of water increased. This led to the development of covered cisterns mostly built in the courts. In this way storage capacity was increased and evaporation losses were reduced. Furthermore, the cisterns served as a protection against water pollution. The more sophisticated houses had a shallow pool in the atrium and the rainwater from the roofs flowed into the pools and an overflow drained into the cisterns. At this time rainwater catchment techniques were decentralized and probably the reason why they lost momentum is the increasing need for water and the development of centralized supply from the sources to the urban areas /6/.

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ANAEROBIC PRIMARY TREATMENT

By BOUCHAÏB EL HAMOURI*

The development of low-cost technologies for adequate collection and treatment of wastewater could help responding to the increasing demand for sustainable sanitation and wastewater management in developing countries. In this respect, practical alternatives to meet increasing capacities and relatively larger communities (several hundreds or thousands of homes) must be urgently implemented where common individual or small cluster of houses approaches showed their limits.

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However, any alternative system must meet fundamental prerequisites when addressing low-income communities to guarantee its sustainability. The success of any sanitation project is to be analysed in the context of low funding capabilities, increasing resource depletion and greater environmental protection measures.

In the following the development of a low-cost technology for the pre-treatment of sewage in small communities in Morocco is described. This technology could be implemented in southern, Mediterranean countries.

LIMITS OF THE OPEN ANAEROBIC POND

The open anaerobic pond is often used as a pre-treatment unit¹. However, this system has many drawbacks:

- occurrence of short-circuiting and thermocline formation leading to deficient hydrodynamics (Pena & Mara, 2004),
- occurrence of negative feedback and pH inhibiting conditions since primary sludge sedimentation, complex organics hydrolysis and acetate transformation into methane do take place in the same space and the same time.

The result of these limits makes the open anaerobic pond a space consuming and a strong offensive odor generator system. BOD₅ removal rates do not exceed 50 to 60% for 4 to 5 days hydraulic retention time (HRT) under Moroccan climate (Actes du projet MOR 86/018).

OPTION FOR HIGH-RATE ANAEROBIC REACTORS

The adoption of upflow anaerobic reactors proved to be an excellent alternative to open ponds for sewage pre-treatment. In these systems the contact between the incoming wastes and anaerobic bacteria is improved and leads to higher performance and to shorter hydraulic retention times. On another hand, particulate COD is highly concentrated in urban sewage (between 40 and 60% of total COD) necessitating a settling and hydrolysis step upstream of the methanization step, notably at low temperatures. Therefore, two-step reactors do better in these conditions than one-step reactors (Wang, 1994).

High-rate anaerobic systems are often called “pre-treatment” while unit placed downstream are called “post-treatment”. Post-treatment units are in charge of nutrients and pathogens removals particularly if the effluent is to be reused for agriculture purposes (Lettinga et al., 1997; Zeeman and Lettinga, 1999).

The anaerobic reactor system developed in Rabat is a two-step upflow anaerobic reactor (TSUAR, see El

1) The fundamentals of sewage anaerobic digestion can be found in Malina, 1962, and McCarty, 1964.

Hafiane & El Hamouri, 2002 for more details). In this system, the choice, not to manually remove any excess sludge for operation simplicity, was deliberate. This option distinguishes the TSUAR from the widely known UASB (upflow anaerobic sludge blanket) in which the operator decides on how much sludge to remove, from which depth of the reactor and at what frequency in order to keep an optimal sludge concentrations in the reactor.

IMPLEMENTATION OF A TSUAR SYSTEM

A TSUAR unit was constructed in the campus of the Institute of Agronomy and Veterinary Sciences (IAV) (1,500 students) in an urban environment and put in service in December 1996. The TSUAR system includes two reactors in series: Reactor R₁ and R₂, an external settler and a gravel filter.

REACTORS R₁ AND R₂

Reactors R₁ and R₂ are cylindrical with a diameter of 3 m. They are respectively 5.30 and 5.00 m deep. The part constructed above ground is 2.50 m for R₁ and 2.00 m for R₂ (fig. 1 and table 1). In both reactors, upflow velocity was maintained in the range of 0.1 to 0.6 m h⁻¹ depending on the admitted flow, which varies during the day.

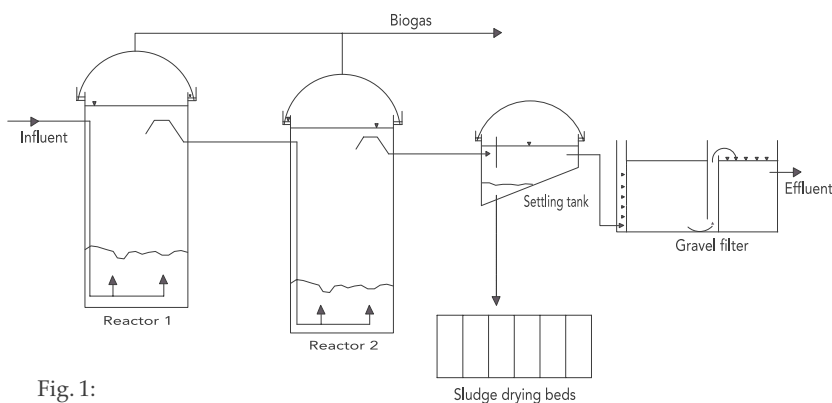


Fig. 1:
THE PRETREATMENT UNIT OF
THE IAV TREATMENT PLANT

BIOGAS COLLECTION AND ANTI-ODOUR SYSTEM

Biogas is collected from the reactors using hard, external cupola-shaped covers made of acid-resistant polyester material. The base of the covers is inserted into a channel surrounding the reactors external wall with dimensions of 0.40 m width and 0.40 m depth. This channel is filled with effluent from the HRAP (high rate algae pond) to act as water seal preventing biogas and offensive odours escaping from the reactor. The water of the seal channel is replaced by freshly treated effluent every week.

The IAV plant produces between 4 and 10 m³ of biogas per day. The lowest production (4 - 6 m³) coin-

	Reactor R1	Reactor R2
Depth (m)	5.30	5.00
Area (m ²)	7.06	7.06
Diameter (m)	3.0	3.0
Volume (m ³)	33	31
Average HRT (h)	24	23
Average Solid retention time (d)	32	32
Over flow (m h ⁻¹)	0.1 - 0.6	0.1 - 0.6
Number of inlets	2	2
Number of outlets	1	1
Average HLR (kg COD m ⁻³ d ⁻¹)	0.76	0.40

HLR: hydraulic loading rate

Table 1:
DIMENSIONS AND OPERATING PARAMETERS FOR THE
TSUAR

cides with the coldest period of the year i.e. from December to February, where the average air temperature is around 15°C. The TSUAR biogas specific production was found to be 0.25 m³ kg⁻¹ removed COD, which corresponds to 0.19 m³ CH₄ kg⁻¹ removed COD. The main components of the IAV biogas and their relative proportions were determined by using gas chromatography analysis. The main components were methane, CH₄ (77%), nitrogen, N₂ (14%), oxygen, O₂ (4%), carbon dioxide, CO₂ (2%) and hydrogen sulphide, H₂S, which were found in traces.

The possibility of burning biogas to produce electrical power was tested using a pilot-scale unit including a 7.5 KVA electric generator powered by a combined diesel-biogas engine. The air admission device of the engine was modified such that biogas could be admitted with air to be burned inside the engine. Assuming that 1 m³ of methane is equivalent to 2.8 kWh then the facility at the IAV might generate 21.5 kWh/day or 0.34 kWh/m³ of treated wastewater.

SLUDGE MASS AND SLUDGE AGE

Both sludge mass and age (or solid retention time) are directly linked to the reactor performance. The idea behind the control of sludge mass and age is to optimise the contact of the anaerobic digestion bacteria or clusters of bacteria with the incoming influent waste. The sludge age in the reactor is the amount of sludge hold in the reactor expressed as kg TSS divided by the sum of the daily amount taken out with the effluent and daily discarded (or removed) from the settler expressed as kg TSS/d.

Sludge specific production is given in kg of TSS or VSS per kg COD, BOD or TSS admitted (or removed) in the reactor. At the Institute of Agronomy and Veterinary Sciences (IAV) the TSUAR generated 0.22 g TSS g⁻¹ COD admitted or 0.28 g TSS g⁻¹ COD removed. The VSS/TSS ratio for produced sludge was 0.53 and the specific sludge production was found to be 4 kg per capita and year.

SLUDGE WITHDRAWAL FROM THE REACTORS

The choice not to manually or mechanically withdraw excess sludge, from the reactors for operation simplicity, made it necessary to adopt the “maximum sludge hold up” mode (van Haandel & Lettinga, 1994). Following this mode, sludge accumulates in the reactors (sludge washout is minimal) until a maximum concentration is reached in the reactor. This concentration is followed by an episode of sludge washout and so on. The duration of a washout/accumulation cycle depends on the season and on the campus activities, with an average solid retention time in the reactors of 32 days. Monitoring of the sludge layer inside the reactors showed, however, that the beds never fall under 1 m in both reactors even during intense washout periods.

At the IAV plant, no sludge has been manually withdrawn from the reactors since 1997. The continuous washout of well digested-low density sludge helped removing the excess sludge from the reactors. Washed out sludge leaving the reactors with the effluent was trapped in the settling tank, from which it was daily removed. The worker in charge of the plant operation and maintenance daily opened the valve located in the bottom of the settling tank. Hydrostatic pressure helped conveying the thickened sludge to the drying beds. Sludge volume discarded daily varied from 60 to 100 litres d⁻¹. Dry matter content of the removed sludge amounted 2% in which 53% was organic.

Stability tests, applied to the sludge removed from the settling tank, showed that 7% of the removed mass was still able to produce methane meaning that the sludge expelled by the TSUAR was stabilised to 93%. For this sludge, the ration VSS/TSS was around 0.53; a sludge with a ratio higher than 0.7 needs further stabilization treatment steps.

SETTLING TANK

One of the main features of the TSUAR concept is the deliberate choice of constructing a settling tank located outside the reactor rather than adopt an integrated settling unit, as this is the case with the UASB reactors. A rectangular shaped settling tank was designed for a two-time normal flow and an overflow rate of 1.5 mh⁻¹. The unit was covered to avoid offensive odors emanations.

GRAVEL FILTER

Reactor R₂ effluent was analysed for particle size distribution. The bulk of the sludge found in the effluent was made of two types of particles:

- reticulated particles with diameter between 100 and 350 µm having a sludge velocity Index (SVI) of 20 mg/l and
- low-density particles with a diameter of 60 µm and a SVI of 35 mg/l.

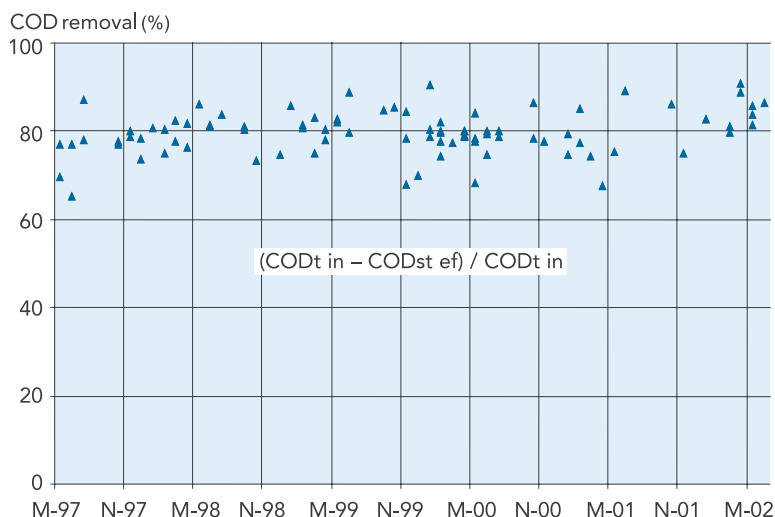


Fig. 2:

COD REMOVAL RATES ACHIEVED BY THE TSUAR DURING THE FOLLOW UP PERIOD

The low-density troublesome particles are stopped using a two-step horizontal unit (HU)—vertical unit (VU) flow gravel filter, which consisted of a rectangular shaped basin. Both units have dimensions of 2 m width and 2.5 m length. The depth of the filtering medium was 0.8 and 0.6 m respectively for the HU and the VU and a hydraulic loading rate 12.6 m³ m⁻² d⁻¹.

PERFORMANCE OF THE TSUAR

Empirical equations were established relating COD removal rate to the HRT in anaerobic reactors. COD removal rates achieved by the TSUAR during the five consecutive years of monitoring at the IAV plant are shown in fig. 2. They demonstrate the stability and the consistency of the performance of the TSUAR as a reliable pre-treatment system.

For health related parameters, the performance achieved by the TSUAR confirmed earlier reports on the performance of an anaerobic system for the removal of pathogens. At the IAV plant, helminth eggs were not found at the outlet of the gravel filter. Fecal



	Influent	Reactor 1		Reactor 2		Settling tank		Gravel filter	
	Value	Value	RR	Value	RR	Value	RR	Value	RR
CODt (mg/l)	800	530	34	380	28	310	18	110	86
CODst		285		159	44	59	-		
CODs (mg/l)	420	270	36	120	56	120	-		
BOD ₅ (mg/l)	390	200	49	150	25	120	20	70	82
TSS (mg/l)	330	300	9	280	7	230	18	15	95
VSS (mg/l)	190	150	21	160	-	105	34	5	97
KTN (mg/l)	72	60	17	66	-	65	2	61	15
N-NH ₄ ⁺ (mg/l)	46	48	-	50	-	50	-	49	-
Total P (mg/l)	8.2	8	2	8	-	8	-	8	-
PO ₄ ³⁻ (mg/l)	5.7	6	-	6	-	5	15	6	-
FC/100 ml	3.6 E7					7.1 E5		7.1 E5	1.7*
Helminth (egg/l)	13					0		0	

CODt: total COD; CODst: COD after 30 min settling period; CODs: soluble COD; KTN: Kjeldhal (total) nitrogen; N-NH₄⁺: ammonia nitrogen; PO₄³⁻: orthophosphates, FC: fecal coliforms removal in log10; RR: removal rate.

Table 2: **AVERAGE PERFORMANCE OF THE TSUAR SYSTEM.**

coliforms concentrations were also reduced in the system. Regularly, 1.7 logarithmic units were removed by the TSUAR.

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CONSTRUCTED WETLANDS

By FABIO MASI

Constructed wetland technologies have showed in the last three decades a clean-cut increase both in scientific knowledge of these engineered complex ecosystems and number of applications. The capital costs of these technologies can be compared with other wastewater treatment techniques, but the operation is simple and inexpensive, assuring a quick expansion both in developed and developing countries.

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A main part of the pollutants contained in wastewater are nutrients that can be removed in wastewater treatment plants by reproducing natural self-purification processes. Conventional treatment plants like activated sludge plants enforce biological organisms's action with energy-intensive mechanical equipment to decompose complex compounds, to incorporate the nutrients in biomass and finally to separate that biomass from the purified water. Thus such plants are energy intensive reactors with relatively small area demand that are suitable for centralized wastewater treatment.

Constructed wetlands are acting as "extensive systems", giving a big role to a wide range of natural degradation processes like filtration, sedimentation, chemical and biological oxydation and reduction and nutrients uptake. The high degree of biodiversity present in these systems allows multiple and various removal mechanisms for several classes of compounds, also at micropollutants level, and therefore higher performances in comparison with the technological treatment plants in which only few families of specialised bacteria are grown. The purifying processes take place without input of "human produced" energy by, for instance, oxygenating pumps. Furthermore, there is no excess sludge to be removed, since there is a balance of biomass growth and decomposition in the constructed wetland system. As a compensation to the low energy demand there is a relatively large area demand (that is why they are defined as an extensive technique). Accordingly, constructed wetlands are usually suitable and cost effective for small and medium size wastewater treatment.

Within the last 20 - 30 years various types of constructed wetlands have been developed in different countries.

APPLICATIONS

Treatment of domestic or municipal wastewater is currently a conventional application. Since more than 15 - 20 years there are several thousands of operating constructed wetlands worldwide and the most used are the subsurface flow systems. The most available sets of monitoring data (like the North American Database, the UK Wrc database, several European collections etc.) are related to this kind of application.

There are numerous possibilities also for the treatment of industrial wastewaters like chemical industry, laboratory effluents, landfills, acid mines, and agricultural or agro-food wastewaters like wineries, olive oil mills, dairies and in general all the waste waters with high organic load.

DIFFUSE POLLUTION

A lately developed application of constructed wetland is related to the diffuse (or non-point) pollution treatment. Several kinds of diffuse pollution, like agricultural or urban or infrastructures runoff can be



Fig. 1:
A 6.000 m²
COMBINED CW
FOR THE TREAT-
MENT OF WASTE-
WATER OF A 3.500
INHABITANTS
COMMUNITY

faceted using extensive natural treatments, which show high effectiveness in the removal of nutrients (nitrogen and phosphorus) and micropollutants, like persistent organic compounds (i.e. polycyclic aromatic hydrocarbons generated by vehicles fuel engines). The effectiveness makes this kind of techniques very suitable for watershed scale approaches wherever a specific local treatment turns out to be inapplicable.

Rain and other liquid that flows through the landfill comes into contact with buried waste. The liquid is called leachate and picks up many contaminants on its way to the bottom of the landfill. Leachate must be treated before it can be safely returned to the environment. Usually tanks are provided for the collection of this leachate which is then transported to large wastewater treatment plants. Local treatments seem to be a preferable option for several aspects. Constructed wetlands achieve interesting results for the leachate treatment with a very high removal of the main pollutants (organic matter, ammonia, nitrates, heavy metals etc.) and a reduction of the wastewater quantity because of evapotranspiration.

SLUDGE DEWATERING

Reed beds can also be used to dewater and stabilize excess sludge from technical plants. About the 70% of the operating Activated Sludge Plants in Denmark have adopted this kind of treatment instead of the existing mechanical processes. This application can also be used to treat the primary sludges (coming from Imhoff or septic tanks) in small or medium size facilities. The stabilized material has to be removed periodically (like every ten years, and, according to its chemical quality, it can be used as soil fertiliser.

ADVANTAGES OF CONSTRUCTED WETLANDS

- Less expensive to build than other treatment options
- Simple construction, operation and maintenance
- Low operation and maintenance costs
- High ability to tolerate fluctuations in flow and inlet quality
- High process stability (buffering effect)
- Sludge produced only by the primary treatment stage
- High pathogen removal—good water reuse and recycling options
- Optimal aesthetic appearance

CLASSIFICATION OF CONSTRUCTED WETLANDS

Constructed wetlands can be classified according to the life form of the macrophytes (plants) in the system:

1. Floating macrophyte-based system (i.e. *Lemna* spp or *Eichornia crassipes*)
2. Submerged macrophyte-based system (i.e. *Elodea canadensis*)
3. Rooted emergent macrophyte-based system (i.e. *Phragmites australis*, *Typha* spp,..)

The third type is described in more details because it is the most commonly used in Europe and worldwide.

It can be categorized according to the flow pattern:

- a) Systems with free water surface (FWS)
- b) Systems with horizontal subsurface flow (SFS-h or HF)
- c) Systems with vertical subsurface flow (SFS-v or VF)
- d) Hybrid or combined systems (combinations of a,b,c)

In the subsurface type, the water flows under the ground, in a gravel bed (or sand or soil) located within a waterproof liner or layer, usually planted with Common Reed (the common short name used for this kind of CW is RBTS = Reed Bed Treatment Systems).

The free water surface type is represented by a series of shallow ponds containing different plants with various purification potentials (such as *Phragmites*, *Scirpus*, *Typha*, submerged macrophytes). In all the CW systems the main role of the aquatic plants is to act as catalyzers in the purification process: The vegetation has no significant effect on nutrient removal, its contribution is in the order of 10 - 20% during the vegetative season). The macrophytes offer instead a very efficient support for the growth of aerobic bacteria on their rhizomes; air is pumped towards the root zone.

HF REED BED TREATMENT SYSTEMS

Horizontal flow RBTS consist of a properly designed basin that contains a filling substrate, wetland plants and microorganisms; the bed is fed with wastewater coming from a suitable primary treatment by a simple inlet device, if possible by gravity. The filling material is sized to offer an appropriate hydraulic conductivity (the most used media are coarse gravel, fine gravel and coarse sand) and to furnish a large available surface for the biofilm growing.

The HF systems are most appropriate for treating primary wastewater, because there is no atmosphere/water interface and this fact makes this technology particularly safe from the public health point of view. Therefore, these systems are actually useful for on-site treatment of septic tank effluents and grey water.

The beds are waterproof, equipped with plastic membrane liners (HDPE or PVC) or clay. The water level always remains under the surface of the bed; the wastewater flows horizontally by a slope (about 1%) obtained by a sand layer under the membrane liner. The subsurface flow prevents development of odours and mosquitoes and permits public access in the wetland area. This kind of CW is particularly efficient in removal of suspended solids, carbon and pathogens as well as for denitrification, while, due to its prevalently anoxic conditions, nitrification is quite limited.

The bed depth depends on the used macrophytes; when using phragmites it is commonly set to 0.6 - 0.7 meters. The preferred values for the width/length ratio are $W/L > 1$, with 3 meters $< L < 30$ meters. It is advised to use a large size filling material like stones in order to prevent clogging in the inlet and outlet zones.

Dimensioning of HF systems depends on many parameters that have to be checked during the preliminary feasibility assessment. After defining the requirements on the treatment efficiency and the treatment scheme, the sizing procedure can be performed using the well known and scientifically approved methods, like the various first order kinetical equations commonly used.

As alternative and more simple way it is possible to use "thumb rule" approaches to the design, based on areal coefficients like "area per p.e." or "area per gram of COD". The EPA (US Environmental Protection Agency) itself, in its last manual for Constructed Wetlands for municipal wastewater treatment, advise the use of an Areal Loading Rate, in terms of number of m^2 per p.e. for each specific pollutant, as a "conservative" approach to ensure reliable functioning and the respect of fixed concentration limits.

Until now only simple deterministic models can be calibrated for the prevision of performances assuming the horizontal subsurface flow system as a plug-flow reactor and so applying the first-order removal equations. It is well proved that many pollutants decline exponentially to a background concentration (C^*) on passage through a water-saturated environment and the net pollutant decrease rate (J) can be expressed by the



following equation: $J = k(C - C^*)$ where C is the inlet concentration and k the semiempiric kinetic constant. The net pollutant removal rate is the mass removal per unit wetland surface area ($g\ m^2\ yr^{-1}$), and the kinetic rate constant k is proportional to the amount of active area, such as biofilms, plants and algae per unit wetland area.

VF REED BED TREATMENT SYSTEMS

Vertical flow reed beds (VF) differ from the horizontal reed beds in the feeding method, the direction of the water flow and the filling media. In these systems the wastewater is applied through a distribution system on the whole surface area and passes the filter in a more or less vertical path. The pre-treated wastewater is dosed on the bed in a large batch (intermittent feeding), thus flooding the surface. During the time between the feedings of the pores within the filter media, air can fill up which is trapped by the next dose of liquid. Thus, oxygen requiring nitrifying bacteria are favoured and full nitrification can be achieved, but only a small part of the formed nitrate is denitrified under these aerobic conditions. The denitrification and thus total nitrogen elimination can be increased by a partial recirculation of the nitrified effluent into the first chamber of the septic tank. The treated water is collected in a bottom drainage system to be discharged. The beds are waterproofed by plastic membrane liners (HDPE or PVC) or clay. The water level can be maintained with a height of about 5 - 10 cm from the bottom of the bed, or otherwise the beds can be totally empty after each feeding pulse. The sand layer has to be at least 30 - 40 cm high, with an insulating top layer of gravel and a drainage bottom layer of the same gravel. The aeration of the bottom layers can be improved by connecting the drainage pipes to aeration pipes rising up to the surface, for direct contact with the atmosphere. VF beds depth is normally 0.9 - 1.0 meters. This kind of CW is particularly efficient in nitrification, car-

Fig. 2:
**HORIZONTAL
FLOW REED BED
TREATMENT
SYSTEMS
(HF RBTS)**

bon and suspended solids removal. Due to its prevalently aerobic conditions denitrification is poor. Sizing of VF systems is based on the oxygen balance inside the bed/reactor. The oxygen furnished by convectional and diffusional mechanisms has to be sufficient for the oxidation of ammonia and organic matter contained in the wastewater.

COMBINED OR HYBRID SYSTEMS

The combination of HF and VF systems shows the best overall performance when a high quality effluent is needed, for instance in case of in-house reuse or of discharge in sensitive water bodies. Each of the two systems shows some peculiarities and their combination can offer several advantages in comparison to their separated use. I.e. the use of an HF bed placed before a VF bed can strongly reduce the need of surface and the risk of clogging phenomena in the second stage, with an important increase in removal of organic matter, nutrients and pathogens. A similar combination has shown very interesting performances also for the removal of bioresistant organic compounds, classifiable inside the vast class of the Endocrine Disruptors.

DESIGN CRITERIA

Designing constructed wetlands, the aim is to maximise contact between the polluted water and various wetland components, like biofilms, plants and the sediment layer. The efficacy of contact is related to the flow path of water in the system, which in turn is related to both the physical dimensions and the residence time. Most of the constructed wetland specialists warn against the free use of simplistic guidelines for all situations. CWs must be designed individually for a particular set of objectives and constraints. Designing CWs entails:

- sizing for a particular wastewater flowrate, mass loading and desired removal efficiency of given pollutants.

- selection of inlet and outlet structures for water level control, recycling, flow splitting and distribution;
- choice of flow path configuration for cells in parallel and/or series;
- insertion of depth variations within and between cells for habitat diversity, if required, better flow distribution, and more efficient pollutant removal;
- planting details, including species selection, planting density, range of species;
- an operation and maintenance plan.

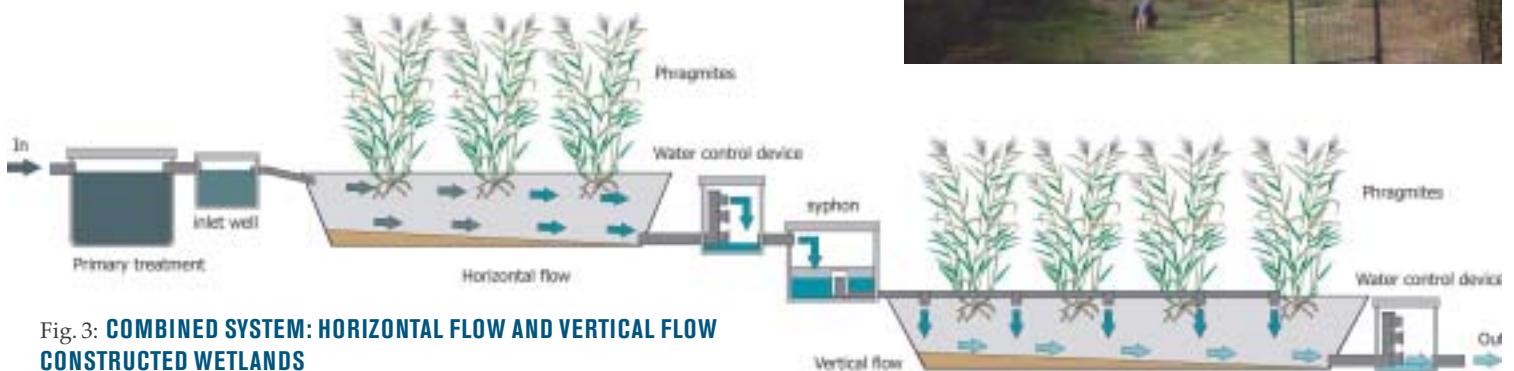


Fig. 3: **COMBINED SYSTEM: HORIZONTAL FLOW AND VERTICAL FLOW CONSTRUCTED WETLANDS**



Photo: Busse

GREYWATER TREATMENT WITH MEMBRANE COUPLED BIOLOGICAL PROCESSES

By RENÉ GILDEMEISTER and MATTHIAS KRAUME*

Greywater reuse will play an important role in the sustainable water management approach. Depending on its intended use different treatment technologies are needed.

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Wastewater generated by bathtubs, showers, bathroom sinks, and washing machines are consistently defined as sources of greywater in the literature. Wastewater from kitchen sinks and dish washing machines might be sometimes included, called “dark grey water”, but with a high potential to introduce microbial contaminants and/or oils and greases that would negatively impact the receiving treatment system.

Greywater treatment with membrane coupled systems can be either of physical or biological nature. Purely physical separation simply holds back the hazardous substances of greywater due to the membrane discharging a clean effluent. The polluted concentrate is collected and treated in a further step sometimes together with a different wastewater (blackwater). The biological treatment reduces degradable organic matter measured as the chemical oxygen demand (COD) and the amount of nutrients.

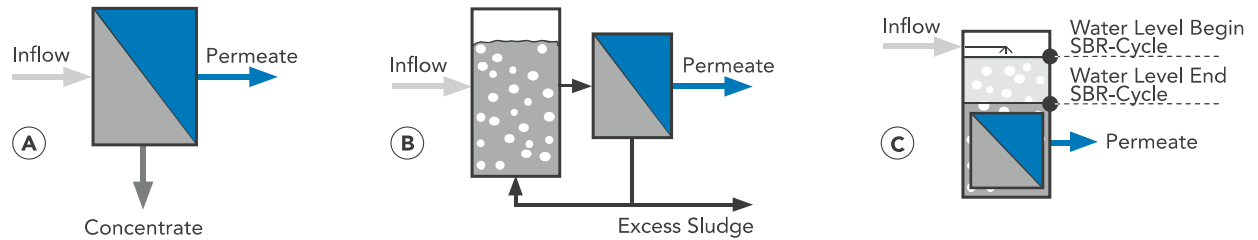
Within the last 20 years, biological treatment of wastewater coupled with a membrane separation unit (fig. 1) has come out of research into full scale application plants. It is an accepted and more and more used treatment technique for decentralised solutions ranging from small domestic implementations (family houses) up to wastewater treatment plants in municipalities with 80,000 inhabitants, equal to an amount of 48,000 m³/d (WWTP Nordkanal, Germany), as well as specialised industrial use [9]. In contrast to its big advantages of a small footprint and very good effluent quality stands its disadvantages of short membrane life time (up to 8 years [3]) and high membrane costs. A recent study shows that at a wastewater flow greater than 5,000 m³ MBRs needs lower investment capital as well as lower operation and maintenance costs compared to the conventional activated sludge treatment [3].

Within the Zer0-M project greywater treatment with a membrane coupled biological treatment is going to be investigated and monitored for its applicability in our Mediterranean partner countries. Although membrane bioreactors (MBR) are a high-tech application, they are anywhere suitable where space is of big concern, e.g. in hotels in tourism centres. The reuse of treated greywater plays a significant role in the sustainable water management approach, as the low polluted greywater (COD ~ 200 mg/L) represents 70% of the domestic water flow rate. Especially in regions where water restrictions are a severe problem, and water supplies are rapidly declining the utilisation of drinking water for toilet flushing seems to be inappropriate. Society has to become aware of efficient and appropriate water (re)use. Examples of such ‘demand side management’ improvements include the use of water saving devices (faucets, showers, toilets etc.), segregation of wastewater streams, and as already mentioned the reuse of greywater. [12], [1]

CHARACTERISTICS OF GREYWATER

The characteristics of greywater vary regionally and over time. Three factors significantly affect

Fig. 1:
GREYWATER TREATMENT SYSTEMS COMBINED WITH MEMBRANES. A: PHYSICAL SEPARATION; B: MBR; C: SM-SBR



greywater composition: "Water supply quality, the composition of the system that transports both gray and drinking water and the activities in the house" [4].

Depending on the final use of greywater different treatment technologies are needed, in order to remove substances "which may be harmful to plants, health and the wider environment" [1].

Usually simple treatment systems for the purpose of landscape irrigation, like sand/gravel filtration or settlement and flotation are operated to prevent clogging of the distributing system. A more sophisticated design is needed, if the treated water is used "in-house", e.g. for toilet flushing. A disinfection step is added to remove microbial contaminants since the potential for human contact is greatly increased in these applications. [14]

Treating greywater with an MBR goes one step further. On a very small footprint hygienically acceptable water is produced. Its application can be seen in hotels of water scarce tourism areas to save valuable drinking water due to the reuse of greywater from showers, and where else a high effluent quality is needed.

APPLICATIONS

As shown in fig. 1 three different types of greywater treatment systems combined with membranes are available. On the one hand there is the pure physical separation of pollutants and water. If used e.g. in cruise ships permeate will be disposed into the sea; the organic fraction is not decreased and accumulates in the concentrate which then is treated with the blackwater in an MBR [13]. On the other hand there are systems of membrane coupled biological reactors. Here the organic matter of the feed flow is reduced due to the activities of microorganisms. It also facilitates good removal of pathogens. Running the system with low sludge loading rates, greywater is needed more for metabolism than growth of bacteria, producing a low amount of excess sludge.

Looking at fig. 1c, the SM-SBR process eliminates the restrictions of a simply SBR process, because the effluent quality of an SBR process depends on its sludge settleability and its decanting facility. Several more advantages of the SM-SBR can be outlined:

- Reduction of the cycle time through partly simultaneity of biological degradation, solids settlement, and withdrawal;
- Increase of the MLSS concentration and thus reduction of the reactor volume;
- Improvement of the effluent quality through complete solids retention (including germs);

- Simple modification of process conditions dependent upon influent characteristics or effluent objectives—additional controlling needed;
- Possible reduction in operational cost;
- Improved process control leading to good nutrient removal;
- No entrainment of oxygen from pre-denitri-fication (as in MBR).

The membrane coupled SBR therefore can be technically and economically viable for application to greywater reuse. [2], [10], [7]

EXPERIMENTAL SETUP

In the Department of Chemical Engineering at the TU Berlin investigations were carried out using a 29 L bioreactor (see fig. 2) with a submerged plate and frame module (A3 GmbH) comprising twelve elements with a total membrane area of 0.38 m². The main goal is to minimise operational cost by optimised biological performance towards COD- and nitrogen removal. Permeate was removed using a peristaltic pump. The reactor volume was controlled by pressure transducers and together with the information from the probes (DO, pH and Redox-potential) recorded directly on a computer. Air was introduced through a fine bubble membrane diffuser (ENVICON GmbH) and controlled via a needle gauge. For complete mixing during the anoxic phase a stirrer was used. The process was automatically controlled using a programmable logic controller (PLC; Siemens-

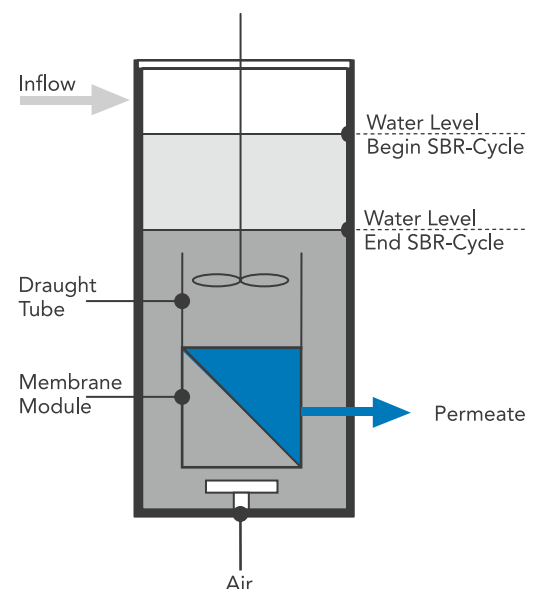
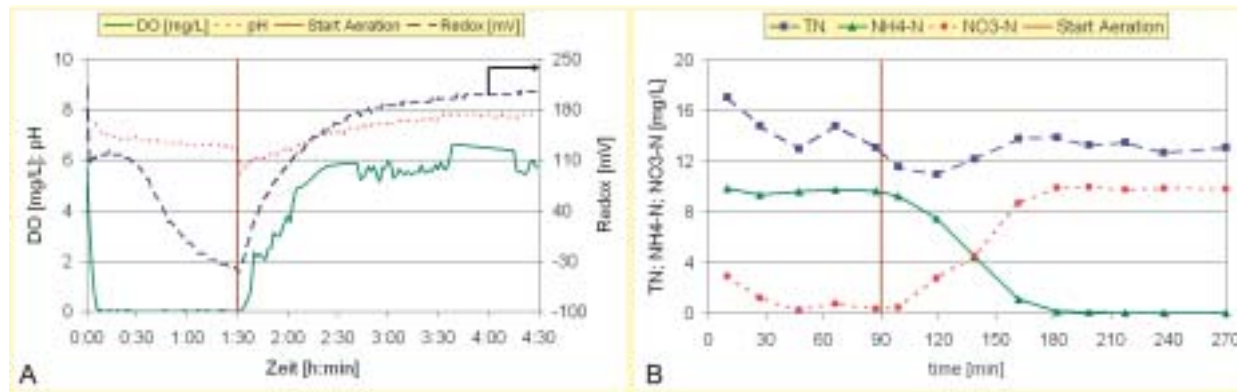


Fig. 2: SCHEME OF BIOLOGICAL REACTOR



VER = 0.5; Cycle time: 4.5 h; MLSS = 2105 mg/L; Anoxic Phase: 90 min; Aerated Phase: 180 min

Fig. 3:
**BIOLOGICAL
PERFORMANCE
OF ONE CYCLE**

**A:
ONLINE-DATA**

**B:
EXPERIMENTAL
RESULTS**

LOGO 12/24 RC). The solid retention time can be set 500 d, because no biomass was taken out, except for sampling.

The cycle time for the experimental set-up varies from 60 to 90 min for the anoxic/anaerobic and 180 min to 300 min for the aerated phase. The filling takes only 2 minutes at the beginning of the anoxic phase and can be therefore neglected. The air flow rate is set at 260 L/h, mainly for a sufficient shear stress on the membrane. The volumetric exchange ratio (VER) is the volume taken out divided by the total reactor volume, and is held so far at either 0.3 or 0.5.

The biomass was fed with synthetic greywater. The recipe was adapted from literature [6], [8] to represent a family household. The produced greywater concentrate was diluted to a COD of near constant 200 mg/L, as a typical value for that parameter [5]. To evaluate the biological performance, detailed cycle analysis have been carried out, measuring beside COD also TN, NO₃-N, NO₂-N, NH₄-N and PO₃-P. Online data are available for pH, Redox and DO.

RESULTS AND DISCUSSION

The reactor has been operated for seven month continuously without any major failures. First investigations on membrane behaviour were needed to determine the critical flux, important for the aerated cycle length. The critical flux was tested for $t_{\text{cycle}}=4.5$ h and a VER=0.5 and resulted in the flux of approximately 13.5 L/(m²h), when MLSS concentration was at 3500 mg/L. For working under sub-critical conditions the flux was hold between 9 and 12 L/(m²h) to minimise the fouling effects on the membrane.

Besides the membrane behaviour it is important to know its biological performance concerning COD and Nitrogen removal. Therefore the reactor worked with different boundary conditions as

- VER,
- cycle times for anoxic and aerated phase,
- and feed concentrations

were varied. As can be seen in fig. 3B, a decline in total nitrogen (TN) was achieved, resulting in a removal of ~50% for a VER = 0.5 up to 80% for a VER = 0.3. The COD removal went from 50% up to 85%, depending

on the feed concentration, with a final value in the range of 20 to 30 mg/L. For a higher feed COD, the better removal rate was reached. In fig. 3A, it's shown the online available data (dissolved oxygen—DO, pH and redoxpotential), recorded in a time step of 1 s.

An observed increase in MLSS concentration is due to the accumulation of non hydrolysable substances, e.g. from particles within the toothpaste. The VSS/SS ratio went down from 60% to a low value of 35%. That means the active biomass stays nearly constant at a value of 900 to 1100 mg/L, depending on the feed concentration. To use the advantage of membrane coupled systems, the sludge loading rates should be increased by minimising the cycle time. Bacterial growth than has to be expected.

CONCLUSION

The SM-SBR system is suited for domestic greywater treatment. Biological performance analysed is consistent to their corresponding boundary conditions throughout the operating period. The poor nitrogen removal has still to be optimised. Also the water quality is in the range for irrigation purposes [11], which means values for nitrate are under or around 10 mg/L. The constant increase in sludge due to accumulation of non-biodegradable substances asks for a smart sludge management, i.e. a reduction of the amount. Additionally a cleaning of the membrane should be done at least 2-3 times a year. Compared to other technologies, like constructed wetlands, the membrane coupled systems need less space for the same greywater flow rate. It also saves the additional disinfection step.

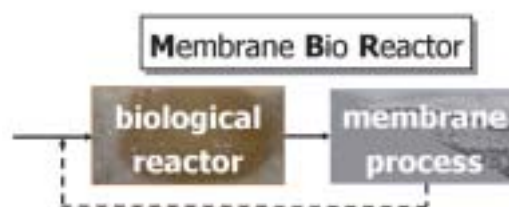
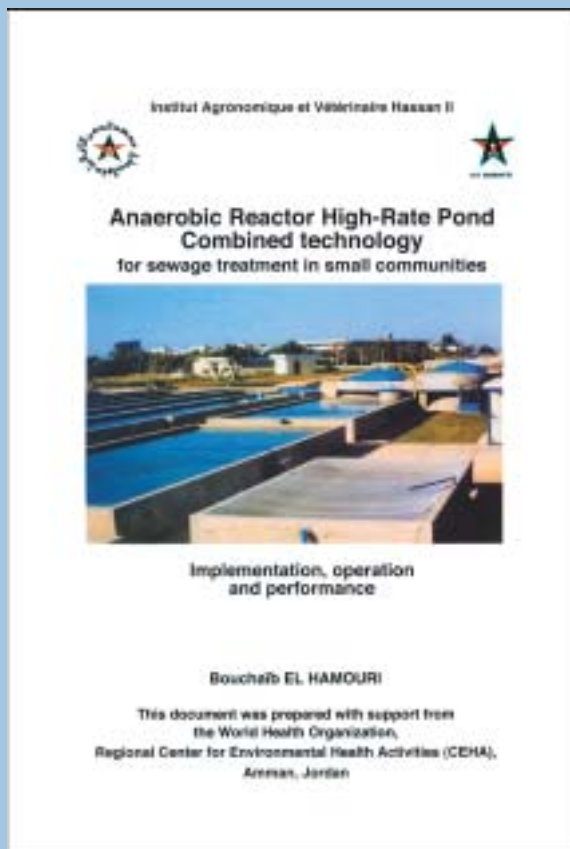


Fig. 4:
**MEMBRANE
BIO REACTOR**

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ANAEROBIC REACTOR HIGH-RATE POND COMBINED TECHNOLOGY FOR SEWAGE TREATMENT IN SMALL COMMUNITIES



The book describes a combination of high-rate anaerobic/aerobic (solar energy use only) wastewater systems used to achieve sustainable wastewater treatment for small communities under hot climate conditions. The technology removes the nuisances linked to offensive odour emission allowing the construction of treatment plants in the vicinity of the settlements reducing therefore the costs of conveying networks for wastewater transfer to the plant and for treated effluent transfer to the settlement for local reuse. Other advantages of the technology : the capital investment, O & M costs and the land area requirement are affordable for most developing countries. The quality of the final effluent allows its reuse either for restricted irrigation or for landscaping.

Institut Agronomique et Vétérinaire Hassan II

Anaerobic Reactor High-Rate Pond Combined technology for sewage treatment in small communities

Implementation, operation and performance
Bouchaïb EL HAMOURI

This document was prepared with support from the World Health Organization, Regional Center for Environmental Health Activities (CEHA), Amman, Jordan



PLANT YIELD PRODUCTION AND HEAVY METALS ACCUMULATION AS AFFECTED BY SEWAGE SLUDGE APPLICATION ON DESERT SOIL

By MAMDOUH F. ABDEL-SABOUR, HUSSEIN I. ABDEL-SHAIFY and A.R.A.G. MOHAMED*

The world wide production of sewage sludge was estimated to be around 20×10^9 T Year⁻¹ (Nriagu and Pacyna, 1988). Sludge safe disposal is a matter of major concern (Hansen and Chaney 1984). The substantial N (3%), P (2%) and other macro-nutrients (0.5% K₂O, 5% CaO, 1.5% MgO) concentration in sludge render it as useful fertilizer material. However, its high concentrations of trace metals limit both its utility as a fertilizer or as a natural sandy soil conditioner.

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Sewage sludge (Ss) amended-soils differ considerably from their equivalent unsludged control soils as they tend to have higher concentration of organic matters, macro- and micro-nutrients as well as non-essential trace elements. Nevertheless, sludge has a positive conditioning effect on most soils. Natural aeration and well draining system following sludge amendments can have indirect effect on growth, nodulation in leguminous plants and other properties (Roberts et al, 1988). Meanwhile, the organic matters of the Ss are degraded at variable rates according to the bacterial activities in the soil as well as the climatic regimes. However, the input of heavy metals to soil from Ss should be considered carefully. The level of metals in the sludge amended soil depends mainly on: the initial concentration of metals in this soil, the concentration of metals in sludge, the amount and the bio-availability of heavy metals in sludge-amended soils to crops (Abdel-Sabour, et al., 1998). The distribution pattern of heavy metals in soil profile, the relative interaction in terms of soil properties and the differences between crops species and cultivars can have a potential risk of heavy metals on both soil and groundwater pollution (Alloway and Jackson, 1991).

In recent years, research has concentrated on the conditioning effect of sludge on sandy soil. Fate of heavy metals have found little attention. Plants differ generally in their ability to uptake, accumulate as well as tolerate heavy metals (Abdel-Sabour and Abdel-Shafy 1990). Maize cultivars differ considerably in the uptake of Cd and Zn (Abdel-Shafy, et al., 2003). Therefore, it would be possible to select the least accumulating cultivars for growing on sludged soils (Hinesly et al., 1982 and Logan and Miller, 1985 and Reddy et al., 1987).

The purpose of the present study is to investigate the effect of different sewage sludge application at different rates to sandy soil on net aboveground production, seed yield and heavy metals accumulation by maize plant under the semiarid climatic conditions of Egypt with emphasis on the critical rate of sewage sludge to be applied.

MATERIALS AND METHODS

The selected soil is infertile sandy soil, very poor in organic matter content, and low water-holding capacity. Cylindrical lysimeters (1 m in diameter and 1 m in depth with open end) were established at the Nuclear Research Center in Inshas. Each lysimeter was filled with 256 kg sandy soils.

Cairo sewage sludge composted by the windrow technique was incorporated to 30 cm depth from soil surface in each lysimeter at rate of 2, 6 and 8% on weight basis (W/W). In parallel, untreated sandy soil of the same sample was used as a control. Each treatment was replicated six times in a completely randomized design. Eight seeds of Zea maize cv. single cross 10 were sown in each lysimeter in two successive years at the 3rd and 7th June in growing seasons 2003,

Table 1:
HEAVY METALS CONCENTRATION (MG/KG DRY WT.) IN CAIRO Ss AS COMPARED TO WORLDWIDE CONTENT AND MAXIMUM ACCEPTABLE CONCENTRATION IN Ss FOR AGRICULTURE USE. MAX.LIMIT VALUES****

Element	Cairo Ss**	Cairo Ss**	Worldwide***	Max.limit values****
	N	range		
Zn*	6	1263 - 1406	91 - 4900	2500 - 4000
Cu	6	436 - 440	50 - 8000	1000 - 1750
Mn	6	450 - 455	60 - 3900	500 - 3000
Fe*	6	36740 - 38100	-	-
Co*	6	25 - 30	1 - 260	20 - 150
Ni	6	150 - 165	6 - 5300	300 - 400
Pb	6	20 - 35	29 - 3600	750 - 1200
Cd	6	1 - 1.8	1 - 3410	20 - 40
Cr*	6	275 - 295	8 - 40600	1000 - 1750
Cs*	6	1 - 1.9	0.45 - 2.90	-
Sc*	6	8 - 8.5	-	-
Ba*	6	86 - 99	9 - 1004	-
Sn*	6	30 - 40	40 - 700	-
Rb*	6	12 - 15	-	-

N = number of samples

*) Determined by NAA method

***) Result presented here is the average of 6 different analyzed samples

****) Adapted from Alloway and Jackson (1991)

*****) Webber et al., (1984) and EC (1986)

2004 respectively. Twenty-one days after planting (DAP) the seedlings were thinned to five per lysemeter. Nitrogen fertilization was applied in three intervals as urea (46% N) at rate of 79.13 mg N/kg soil. The experiment was laid out using a drip irrigation system. The amount of water used for irrigation was estimated on the basis of maintaining available soil water content between 60 and 100% within the plant root of 30 cm depth.

At first harvesting on 100 DAP, the plant samples were partitioned to leaves, stem, husk and seed, air-dried, weighed and ground. All plant samples were acid digested according to the procedures described by APHA, 1995 and U.S. EPA, 1974. Samples were analyzed for heavy metals. Surface soil samples (0 - 15 cm layer) were collected before planting and at the second harvesting time (120 DAP). Both soil and Ss samples were air dried, ground and extracted by DTPA method according to Lindsay and Norvell (1978). Heavy metals in soil, Ss and plant samples were determined by Atomic Absorption Spectroscopy. Moreover, total Zn, Co, Cs, Cr, Ba, Sn, Rb and Fe in Cairo Ss were determined using non-destructive method (Neutron Activation Analysis technique NAA) as described by Abdel-Sabour and Abdel-Shafy 1990 and Abdel-Sabour et al., 1995.

At maturity (120 DAP) three replicates for each treatments were sampled. The plants were cut at ground level, the number of ears was recorded and detached. Ears and the remaining plant material were oven dried at 65°C for 72 h for the determination of net aboveground dry matter production. The ears were threshed by hand. Seed yield was determined following further oven drying.

LEVEL OF HEAVY METALS IN CAIRO Ss

Table 1 indicates that Cairo Ss is less than the other Ss and is within the permissible level according to the maximum limit values of E.C, 1986, *Webber et al.*, 1984 and Abdel-Shafy et al, 2003. Meanwhile, the level of heavy metals in Cairo Ss is found to be at the lower limit of the world range (Furr et al., 1976, Bowen 1984 and Kabata-Pendias and Pendias 1984). Usually the quality of wastewater discharged into the sewers determine sludge composition. When industrial and domestic wastewaters discharged together in combination, a rise in heavy metals content with wide variations in composition could be expected. Such variation depends mainly on types of industrial activities.

Comparing the total heavy metals content of Cairo Ss as extracted by DTPH could give an indication of relative availability of such metals to plants. Data in ta-



Element	7 Days after Ss application				120 Days after Ss planting			
	Rate of Ss applications				Rate of Ss applications			
	0%	2%	6%	8%	0%	2%	6%	8%
Fe	1.70	7.90	16.30	30.50	1.47	4.28	15.90	25.84
Mn	0.69	3.66	5.99	5.08	0.64	1.03	1.82	2.22
Zn	0.76	1.04	1.19	2.21	0.23	0.23	0.84	1.17
Cu	0.67	6.86	8.75	11.80	0.18	1.46	3.83	5.02
Cd	0.06	0.22	0.16	0.26	0.06	0.17	0.09	0.11
Ni	0.31	0.99	1.70	2.13	0.03	0.02	0.03	0.05
Pb	0.72	1.69	2.62	2.83	0.17	0.51	1.09	1.56
Co	0.12	0.19	0.18	0.23	0.11	0.19	0.11	0.14

Table 2:
THE LEVELS OF HEAVY METALS IN SOIL (AT DEPTH 0 - 15 cm) AFTER THE APPLICATION OF Ss AT VARIABLE RATES (0, 2, 6, 8%) AS mg/kg DRY WT

bles 1 and 2 showed that the availability of most of the tested metals is relatively low except for Cd, which ranged between 0.22 to 0.26 mg/kg dry wt as extracted by DTPA. It is confirmed that the concentration of heavy metals through the extraction by DTPA, procedure is remarkably low compared to the total content of metals in Ss (Sommers, 1977 and Abdel-Sabour, Mohamed, 1994 and Abdel-Shafy et al, 2003). Apart from variations in metal concentration determined by several sewage workers, individual work has quite marked difference in sludge composition (Sommers, 1977). He reported coefficients of variation for Cd, Zn, Cu, Ni and Pb to be 72, 41, 48 and 32%, respectively.

CONCENTRATION OF HEAVY METALS IN SLUDGE-AMENDED SOILS

The physical properties of the tested soil showed that the cation exchange capacity (CEC), pH, organic matter contents (O.M.), electric conductivity (E.C.) and the Bulk density are 1.39 meq/100g, 8.1, 0.10%, 0.32 mmho/s/cm/25°C, and 1.66 g/cm respectively. The soil texture was 93% sand, 4.5% silt and 1.5% clay. A useable sludge management program is always needed. This can be achieved by predicting the amount of metal uptake by plant. This is particularly true in case of sludge amended soil. In this study, soil samples were taken seven days before planting and 120 DAP, then extracted with DTPA to investigate the relationship between extractable levels and tissue con-

centration of these metals (table 2). Ss application to the sandy soil increased the amounts of extractable Fe, Mn, Zn, Cu, Cd, Ni, Pb and Co. The higher the percentage of sludge application is (2%, 6% and 8%), the higher is the level of metals in soil. The low availability of the tested heavy metals may be due to the effect of solid-state organic matter, which acts as a sink for metals in sludge-soil mixtures (Logan and Miller, 1985).

After 120 days of planting time, a notable decrease in the level of metals in soil was observed (table 2). The decrease in the level of metals (as extraction DTPA) after harvesting the mature plant comparing to the corresponding values at seven days before planting is due to both portion consumed by plant uptake and immobilization by soil micro-organisms. Another possible factor is leaching of organo-metal complex through the profile particularly with the degradation of organic compost as affected by time. Heavy metals bio-availability is strongly depending on several soil chemical properties (i.e., pH, speciation and adsorption mechanisms, organic matter, hydrous oxides and carbonates content). Sludge born heavy metals differ from most other sources of metal contamination in that it is an important source of adsorptive materials (organic matter, Fe and Mn oxides). The organic matter of sludge has a high adsorptive capacity at the time it reaches the soil (King and Dunlop, 1982).

SEED YIELD

Table 3 demonstrates the beneficial effect of Ss incorporation in sandy soil on net aboveground dry matter production and seed yield of maize plant. It is clear that Ss incorporation at different rates enhanced the aboveground dry matter production as well as the seed yield. This was true at all application rates, but with different magnitudes. As the Ss application rate increased from control to 2% the aboveground dry matter and seed yield increased from 59.2 and 33.6 to 75.8 and 44.0 g/plant (PL), respectively. However, at 6% Ss treatment the aboveground dry matter and seed yield increased from 127.4 and 71.4 g/PL. With further increase in the Ss application rate (8%) the aboveground dry matter and seed yield increased from 132.4 and 78.4 g/PL. A significant linear relation be-



Table 3:
ABOVEGROUND DRY MATTER, SEED YIELD AND TOTAL HEAVY METALS ACCUMULATION OF MAIZE PLANT GROWN ON SLUDGE-AMENDED SANDY SOIL

Ss application rate	Aboveground dry matter yield (g/PL)	Seed yield (g/PL)	Total heavy metals accumulation in Aboveground matter at 100 DAP (mg/PL)							
			Fe	Mn	Zn	Cu	Cd	Ni	Pb	Co
0%	59.2 D*	33.6 D	203 C	28.5 B	44.1 C	14.99 D	2.21 B	3.10 D	6.39 C	2.94 D
2%	75.8 C	44.0 C	298 B	31.1 B	44.2 C	21.32 C	3.01 B	5.76 C	52.4 B	4.54 C
6%	127.4 B	71.4 B	642 A	59.8 A	66.8 B	40.04 B	9.35 A	12.50 B	71.9 A	5.72 B
8%	132.4 A	78.4 A	494 A	61.1 A	111.3 A	56.36 A	10.97 A	39.89 A	77.0 A	6.99 A

Duncan Multiple Range Test was used to assess significant difference: Values preceded by the same letter are not significantly different at $P < 0.05$.

tween either dry matter yield or seed yield with Ss rate of application was observed as follow:

$$\text{Aboveground dry matter} = 4.21 + 18.81 \text{ Ss rate} \\ (R^2 = 0.954)^{***}$$

$$\text{Seed yield} = 33.45 + 5.85 \text{ Ss rate} \\ (R^2 = 0.995)^{***}$$

It could be safely concluded that incorporation of Ss to sandy soil improve the hydrophysical and chemical properties (Abdel-Sabour and Mohamed, 1994) which in turn has a positive effect on growth and seed production.

HEAVY METALS ACCUMULATION

Results presented in table 3 show that addition of Ss to the sandy soils at different rates significantly enhanced the tested metals accumulation in maize shoot. At 8% Ss application rate maize shoot accumulated heavy metals at the reported optimum levels but did not reach the toxic levels as reported by Kabata-Pendias and Pendias, (1984).

Comparison of heavy metals accumulated in several individual plant parts of maize at 100 DAP, table 4 shows a significant variation between in the accumulation of heavy metals by plant parts. Stem samples tend to accumulate Fe, Mn and Co than leaves, husk or seed samples. Surprisingly, seed samples accumulated more Zn, Cu, Cd, Ni and Pb than other tested plant parts, which may suggest a potential health hazard through food chain at higher Ss rate of application. Generally, if the used Ss compost contains high levels of toxic heavy metals, precautions should be taken and it is not recommended as organic fertilizer or soil amendment.

Data in table 4 reveal a significant linear relation between husk and seed content of heavy metals as shown below:

$$\text{Fe uptake (seed)} = 1.999 + 5.829 \text{ Fe (in husk)} \\ (R^2 = 0.567)^{***}$$

$$\text{Mn uptake (seed)} = 1.818 + 1.328 \text{ Mn (in husk)} \\ (R^2 = 0.689)^{***}$$

$$\text{Zn uptake (seed)} = 12.163 + 1.891 \text{ Zn (in husk)} \\ (R^2 = 0.979)^{***}$$

$$\text{Cu uptake (seed)} = 3.926 + 0.934 \text{ Cu (in husk)} \\ (R^2 = 0.989)^{***}$$

$$\text{Cd uptake (seed)} = 31.072 + 1.253 \text{ Cd (in husk)} \\ (R^2 = 0.989)^{***}$$

$$\text{Pb uptake (seed)} = 41.720 \text{ Zn (in husk)} - 17.50 \\ (R^2 = 0.994)^{***}$$

$$\text{Co uptake (seed)} = 3.338 \text{ Cu (in husk)} - 0.095 \\ (R^2 = 0.587)^{***}$$

CONCLUSIONS

The application of Ss to sandy soil as organic fertilizer or a natural soil conditioner has a beneficial effect on the growing crops. Our results demonstrated that the availability of heavy metals in sludged soil (pH 7) is usually low, however it should be mentioned that Ss compost, which contains high levels of toxic metals, should not be applied for agricultural use or food production. The elevated concentration of heavy metals in sludge-amended soil should be investigated to avoid their potential impact on human health through the food chain. Metals vary in their tendency to move along the soil to plant pathway.

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Plant parts	Ss application rate	Heavy metals accumulation							
		Fe	Mn	Zn	Cu	Cd	Ni	Pb	Co
Leaves	0	15.6 B*	6.67	9.92 C	3.75B	0.21C	0.29B	1.11C	0.25C
	2	10.8 B	6.53	10.2 C	2.78C	0.17C	0.46A	1.18B	0.65B
	6	43.8 A	8.30	13.5 B	3.10C	0.26B	0.47A	1.70B	0.61B
	8	45.3 A	7.29	23.9 A	4.85A	0.38A	0.48A	2.31A	1.16A
Stem	0	148 C	14.0 B	15.0 B	3.10C	0.58C	1.19D	2.40C	1.12D
	2	222 B	16.0 B	10.0 C	4.00C	0.97B	1.81C	4.60B	1.62C
	6	345 A	36.0 A	13.0BC	9.60B	1.65A	4.60B	10.4A	2.59A
	8	347 A	36.0 A	24.0 A	15.70A	1.61A	10.10A	10.3A	2.15A
Husk	0	8.5 B	1.70 C	3.30 B	1.40D	0.40C	ND	0.45C	0.29C
	2	9.5 B	2.0 BC	3.50 B	2.00C	0.60C	ND	1.44B	0.54B
	6	9.1 B	2.20 B	4.30 B	4.80B	1.23B	ND	1.20B	0.54B
	8	17.3 A	4.00 A	14.5 A	6.00A	1.71A	ND	1.71A	0.61A
Seed	0	12.8 C	5.53 B	11.9 D	5.38D	1.18C	1.18D	1.85D	1.01C
	2	28.6 B	3.74 B	16.5 C	10.60C	1.54C	2.86C	39.8C	1.30B
	6	30.8 B	7.85 A	29.9 B	18.90B	5.36B	5.00B	52.1B	1.47B
	8	39.6 A	8.23 A	38.8 A	24.70A	6.27A	23.80A	55.7A	2.43A

* Significance as in table 3;

ND = Not determined; NS = Not significant

Table 4:
HEAVY METALS ACCUMULATION OF MAIZE LEAVES, STEM, HUSK AND SEED AT 100 DAP (mg/PL)

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AEROBIC SLUDGE TREATMENT

NATURE-ORIENTATED TECHNIQUES

By CHRISTIAN PLATZER*

The closing of the natural cycle is the aim of optimal sludge treatment. Reuse in agriculture and landscaping are a priority goal. Deposit of sludge on dumping grounds can only be a temporary solution.

Nature-orientated sludge treatment techniques can save energy for pumping of sludge and leachate and limit the use of chemicals.

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Sludge treatment reed beds (STRB) have been successfully used in Europe for more than 10 years. An alternative nature-oriented procedure is the raw wastewater application to constructed wetlands. Reed bed filters for raw domestic wastewater combine waste water purification and sludge treatment in one system. This may well be a key solution for wastewater and sludge treatment in warm climates without freezing.

Both systems combine the following advantages: Low investment and operation costs, easy maintenance and plant management, low or modest level of mechanisation, a minimum of external energy input and high reliability.

The drying of sewage sludge in a reed bed means dewatering, volume reduction and the stabilisation of the sludge without additional energy input. The sludge is accumulated over an average of 10 years and achieves a sludge residue with a dry matter content of approx. 30 - 40%. After an operating period of 10 years the beds are emptied, for hygienic reasons the sludge has a resting period of six months after the last application of raw wastewater or sludge.

SLUDGE TREATMENT REED BEDS

The sludge treatment reed beds are systems particularly designed for the treatment of sludge and resemble the conventional drying beds with a filter layer of sand and gravel and a drainage. The leachate is led back to the treatment plant by the drainage system. The second function of the drainage system is the aeration of the filter and the sludge residue.

The decomposition mechanisms in a sludge drying reed bed are very complex and result from the co-operation between reed, micro-organisms, sludge and filter material. In the planted beds, the reeds create a large drying and aeration network along the stems, rhizomes and roots. Following these paths, the water percolates to the bottom of the beds.

Due to dewatering, decomposition and compaction of the material the volume of the sludge is reduced by 85% in the reed bed during the operation cycle. The total nitrogen content is reduced by nearly 50%. Potassium, calcium, magnesium and sodium show only a slight decrease in relation to the original mineral content.

The final product "mineralised sludge" is a crumbly, light brown-coloured material with a typical earthy smell. After 10 years of treatment, organic components and pathogenic micro-organisms are reduced and the final product is suitable for agricultural use. Pollution with heavy metals should be avoided from the beginning. Sensitisation and information campaigns have been very successful in achieving this.

Dimensioning of the sludge treatment reed bed is based on sludge quantity, quality and climate. When the STRB is used for secondary sludge (i.e. after an activated sludge plant in extended aeration for the treatment of domestic wastewater) the total required surface is 0,25 m²/per population equivalent (pe). This

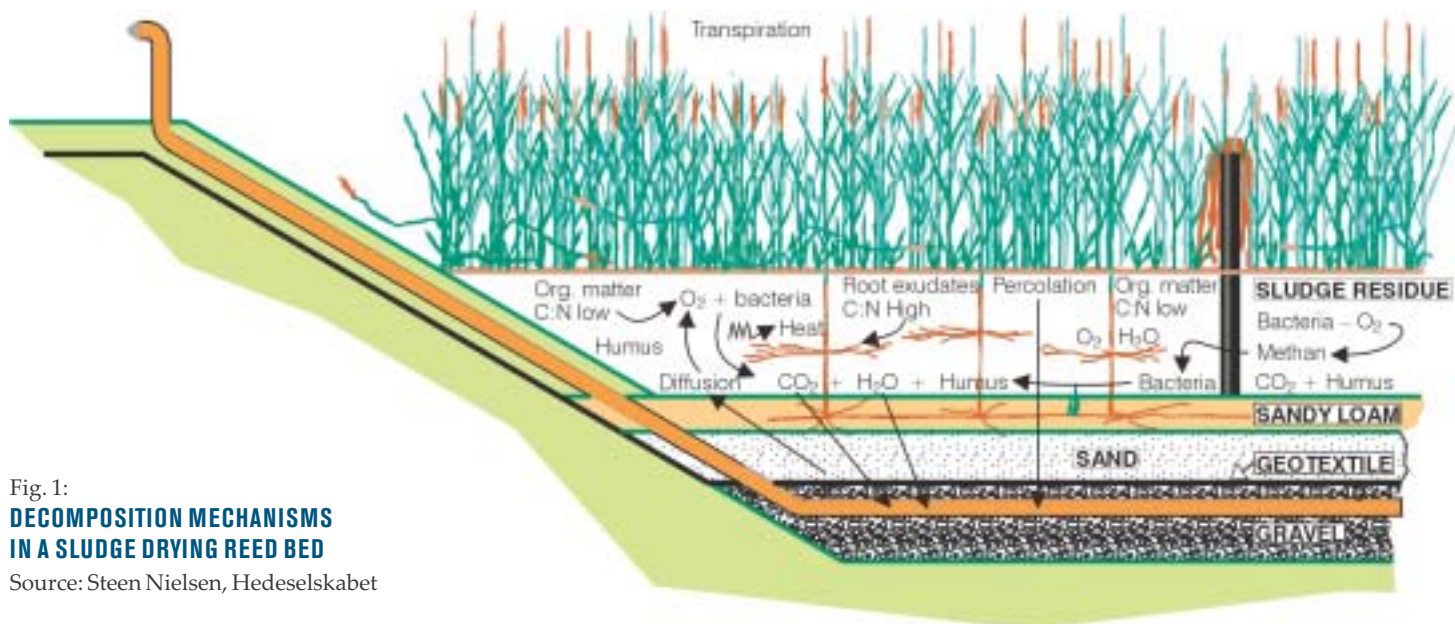


Fig. 1:
**DECOMPOSITION MECHANISMS
IN A SLUDGE DRYING REED BED**

Source: Steen Nielsen, Hedeselskabet

means a specific load of 50 - 70 kg DM/(m².y). For operation in climates having periods without vegetation (winter) an increase of the surface up to 0,5 m²/pe is recommended. At least four separate beds shall be provided which are alimented in rotation.

When the STRB is used for primary sludge after a pretreatment (i.e. imhofftank or 3-chamber septic tanks) combined with an reed bed treatment system (RBTS) an area of 0,4 - 0,5 m²/pe is needed. At such dimensioning, the bed should not be fed during winter (in times without vegetation) with primary sludge (e.g. under Austrian conditions with frost in the winter). It must be possible to store the accruing

sludge during the winter months in the pretreatment.

At least two beds are required to allow a switch for the emptying process. A drying and resting period without addition of new material for six months to one year should be respected. During this period only one bed is fed with fresh sludge, whereas the second bed is resting.

The STRB for a one family house consists of a pre-fabricated concrete bottom slab and rings of 2,5 m diameter as they are used for a 3-chamber septic tank (see fig. 2). Once a year, the sludge is withdrawn from the septic tank with a vacuum cistern or pump and spread onto the surface of the filter bed. The bed is lo-



Fig. 2:
SLUDGE TREATMENT REED BEDS (STRB) FOR A ONE FAMILY HOUSE



Fig. 3: **SLUDGE TREATMENT REED BEDS (STRB) FOR PRIMARY SLUDGE FROM A 3-CHAMBER SEPTIC TANK OF A 50 PE CONSTRUCTED WETLAND PLANT**

Fig. 4: **KOLDING SLUDGE REED BED SYSTEM (DENMARK)**



Fig. 4 shows the Kolding Sludge Reed Bed System (Denmark) which was established in connection with the Kolding Wastewater Treatment Plant for a load of 125.000 pe and started operation in 2000. The sludge comprises of excess sludge from biological removal of phosphorous (65%) and sludge from the sludge digester (35%). The system has 13 planted basins and covers an area of approximately 62.000 m² (Steen Nielsen: Sludge treatment and drying in reed bed systems, AEE journal *erneuerbare energie* 2/2004)

RAW WASTEWATER APPLICATION

Research has been carried out in France about raw wastewater application to constructed wetlands, i.e. treatment of sludge and wastewater on the same constructed wetland without prior primary treatment. The following information of this research is courtesy of Alain Liénard, CEMAGREF, Lyon.

GENERAL CONFIGURATION OF THE SYSTEM

A typical plant consists of two stages of filters: a primary stage of vertical flow reed beds is fed with raw wastewater. Only a bar screen has to be installed for pre-treatment at the inlet of the 1st stage. The sludge accumulates on the surface and is decomposed. The wastewater infiltrates into the filter. This primary stage is followed by a secondary stage with vertical flow filters, for further treatment of the wastewater. Coarse grained filter medium (gravel) is used in the primary stage. The secondary stage filter beds are filled with two layers of sand and gravel. Both stages have a drainage layer of pebbles or drainage bricks at the bottom. The treatment of the sludge occurs in the first stage only which is described in detail below.

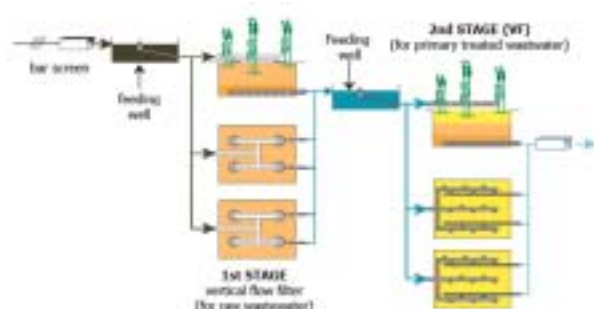
Each stage is divided into three units that operate independently. Each of the primary stage units (type A

cated on the slope above the septic tank so the leachate can easily be conducted back into the septic tank.

Fig. 3 shows an STRB for primary sludge from a 3-chamber septic tank of a 50 pe constructed wetland plant. The bed is fed with a vacuum cistern. The leachate returns to the septic tank by gravity flow. At the background the vertical flow constructed wetland is visible. Shortly after construction, the reed was still very small.

Fig. 5: **GENERAL CONFIGURATION OF THE SYSTEM**

Source:
Alain Liénard,
CEMAGREF



filter) receives the full organic load during the feeding period which lasts three to four days and then undergoes a resting period twice as long. For very small plants, ≤ 100 pe, the investment cost per capita can be reduced if only two units per stage are implemented.

Fig. 6 shows a 1st stage bed just after completion and before reed planting. The feeding system with outlets and the top ends of the drainage pipes which are also used for ventilation of the beds from the bottom are well visible. The filter below the outlets is protected by a concrete slab to prevent erosion.

Wastewater is supplied to the filters in hydraulic batches by a high capacity feeding system (pumps or self-priming siphon if topography allows it). This ensures a distribution of wastewater over the available infiltration area and improves oxygen renewal between the feedings due to convection induced by the water movement. The alternating phases of feed and rest are important for microbial growth on the filter material (sand, gravel or rhizomes), to maintain aerobic conditions within the filter bed and to mineralise the organic deposits.

SIGNIFICANCE OF THE REED

The free space around the reed stems probably assists in preventing clogging. The ring space around the stems always forms again due to the movement of the plants in the wind. Roots and rhizomes are supposed to be symbiotic media for attached bacteria. Plants give shade to the surface that prevents drying and favours the biological decomposition.

DIMENSIONING

The dimensioning is based on experience. The first stage filters receive the larger part of organic load and suspended solids and require a larger surface total of 1.2 - 1.3 m² per pe, divided into three identical, alternately fed units of 0.4 - 0.45 m² per pe (global organic load of 100 g COD/(m².d)). This dimensioning allows



Fig. 6: 1st STAGE BED AFTER COMPLETION AND BEFORE REED PLANTING

Source:
Alain Liénard

a reduction of more than 80% of COD and 85% of TSS as well as a beginning of nitrogen oxidation. The dimensioning of the second stage filter surface depends mostly on the hydraulic load that is applied and the distribution on the surface. The minimum is 1 m² per pe (Boutin et al., 1997, 2000).

CONCLUSION

It can be assumed that both systems, the sludge treatment reed bed and the reed bed filter for raw wastewater, will be more effective with higher treatment rates and final dry matter content in warm and dry climates without freezing periods.

After 10 years of treatment, hazardous organic compounds and pathogenic micro-organisms are extensively reduced and the end product is suitable as a high-quality fertiliser in the agriculture.

Therefore pollution with heavy metals should be avoided from the beginning. Sensitisation and information campaigns have been very successful in achieving this.



Fig. 7: 1st STAGE FILTER THREE AND 10 WEEKS AFTER SLUDGE WITHDRAWAL, FRENCH PLANT

Source:
Alain Liénard



◀ Fig. 1: COMPACT VACUUM STATION WITH TANK, VACUUM PUMPS, DISCHARGE PUMPS AND CONTROL PANEL AT A SOLAR PANEL FACTORY AT BRAUNSCHWEIG, GERMANY.

Foto: Wach

Installing a pipe-based water network must be accompanied by a robust water metering and a social system that ensures that customers pay according to their water consumption. If this has been guaranteed then all these simply to install water saving devices for households like tap restrictors or water saving shower heads get a value for the clients.

PRECONDITIONS

Although clients will always agree that water saving is environmental friendly and they will support this approach and install some efficient devices in the beginning in the long run only financial aspects will convince people to take care that all economical devices will function well. There will be no questions about an efficient use of water if people have to carry the water to their dwellings or when they have to pay for every litre which is brought to their house. Using a network rises the question how to control the individual water consumption, how to meter it and how to charge money for it. Mostly the maintenance of the network is the most expensive part of the water supply (around 80% of the total costs), so water saving will not lead to a large decrease of costs for every household, but it will minimize the costs for the society and save the water sources for a sustainable development. Charging money according to the water consumption has mainly an upbringing effect for everyone to take care of his water use.

SANITARY FACILITIES

By FRIEDRICH GERHARD WACH*

Efficient use of drinking water especially in regions of water scarcity will get great importance in the next decades. On one side people are longing for comfortable tap water which provides the customer at any time with water only by opening and shutting the faucets at the walls in their house on the other side this advantage will lead automatically to a not economical use of water.

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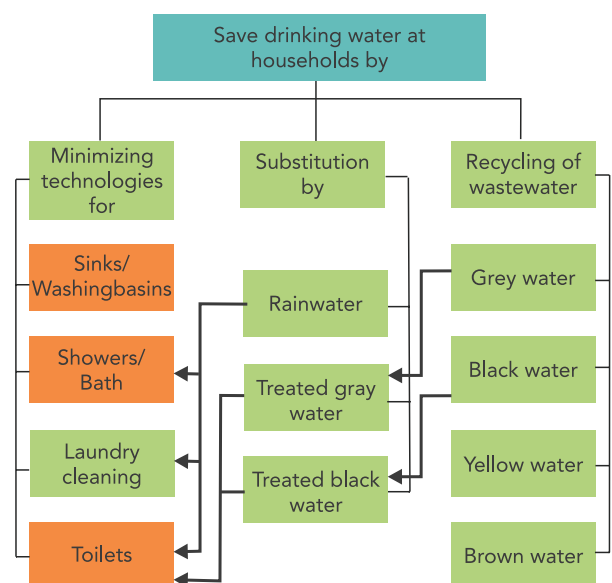


Fig. 2: WATER SAVING MEASURES AT HOUSEHOLDS

POSSIBILITIES FOR AN EFFICIENT USE OF WATER AT HOUSEHOLDS

Fig. 2 shows the possibilities for water saving measures at households. Besides water consumption minimizing technologies for some purposes like body cleaning tap water of drinking water quality can be substituted by water of a less standard to serve tasks like toilet flushing or to do the washing. Substitution and reuse will not be highlighted here, we will look at the red boxes of fig. 2: Minimizing technologies for sinks, washing basins, showers and for toilets.

WATER SAVING TECHNOLOGIES FOR FAUCETS

Faucets at sinks and washing basins are widely used to wash hands or to fill small cups of water for teeth brushing or other tasks like dish washing. For such purposes a water flux of 4 till 5 litres/minute is absolutely sufficient. The easiest way to reduce the water stream is to ask the plumber to fix the faucet to this amount. If this is not possible flow regulators in combination with aerators can be screwed at the outlet of the faucet. These appliances will first stabilize the water flux so it will be independent from the water pressure and second add air to it and then this will work like a water jet pump. You will get "soft" water and the amount will be reduced from 12 till 5 - 7 litres/minute.

These appliances cost about some Euro and will be paid back in months depending on the water price. For further information please visit the homepages of the producers: www.rst-wassersparer.de/eng_akt/default_e.htm or www.neoperl.de or from other providers.

Comfortable faucets provide hot and cold water. Two handle mixers are not comfortable and are wasting water during searching the right temperature. A single lever mixer is more comfortable, but will lead you to use more hot water. For this reason the sanitary industry is offering faucets where cold water is running when the lever is also in the central position. Alternatively an installed thermostat will always serve the chosen temperature. It is important to remind that every saved litre of hot water will also save energy and money.

WATER SAVING TECHNOLOGIES FOR SHOWER HEADS

There are a lot of shower heads on the market and the water flux differs from 8 till 20 litres/minute. There are also shower heads available where you can change the jet and the water volume by turning at a small lever at the head. Interesting is again the water jet pump principle which will reduce the water flux and soften the jet. When buying a shower head you have to ask for its water consumption and to test the jet if it fits your expectations. The firms mentioned above for water saving devices are offering special water saving shower heads.

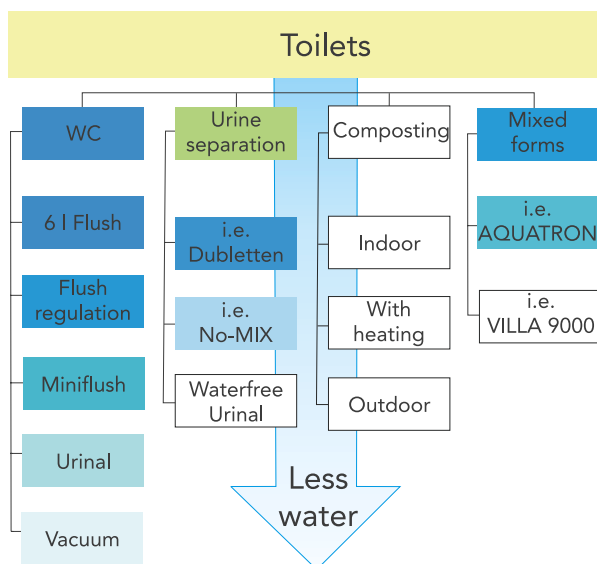


Fig. 3: AVAILABLE TOILET SYSTEMS ON THE EUROPEAN MARKET

WATER SAVING TOILETS

Fig. 3 gives a rough overview about available toilet systems on the European market. Mainly they can be divided by using water for flushing or not. A special group are the urine separation toilets which can work with flushing or without flushing. Composting toilets are characterised for working without water and there are groups of toilets summarized as mixed forms where flushing is combined with composting or urine separation with composting (other arrangements are also possible).

WC: 6-LITRES-FLUSH AND FLUSH REGULATION

The standard for WC selling is nowadays the 6-litres flushing cistern very often combined with a stop button or alternatively with a double button for flushing 6 or 3 litres of water (GEBERIT 2003). That means a water reduction for flushing has taken place from the former 11 or 9 litres cistern to about 50%. Investigations show that a toilet is used five times a day (one time for faeces, four times for urine), that means in former times 45 till 55 litres a day and today 18 litres (using the flush regulation) till 30 litres. Many WC with larger cisterns in the actual stock can be upgraded by installing a metal heft in the overflow pipe of the cistern. Then water is flushing only as long as the button is pressed down. Such appliances can be ordered by www.rst-wassersparer.de/eng_akt/default_e.htm or organized and manufactured by the owner himself.

MINIFLUSH: 1 LITRE WC

The toilet uses pressure from the water pipe, provided with a conical valve that flushes one litre of water each use. Excrements and paper are falling on a trap, which is filled with water and gives a seal against smell. After pushing the button for flushing, the trap

opens by means of water pressure. Several jets of water transport excrements and paper down to the pipe and clean the bowl. The high pressure of water prevents bad smell coming out of the pipe system. Finally the trap closes again, providing a seal with water. The toilet has to be connected to a vertical waste pipe, which leads to the down pipe using a slope of 2% and 45°-bends. The pipe length may be up to 20 meters without having any other waste water input from shower or washing machine before. The amount of water for flushing can be increased up to 1.6 litres, if there is an insufficient slope. For more information look at www.berger-biotechnik.de/downloads/miniflush_englisch.pdf

VACUUM TOILETS

Vacuum toilets are well known from airplanes, high speed trains, ferries and other passenger ships. By using also only 1 litre of water for flushing the amount of wastewater to carry to the next station or harbour can be reduced drastically in comparison to a normal WC. Vacuum toilets are also used in large buildings, hotels and offices where many toilet seats can be connected to one vacuum unit, which provides a vacuum of about 500 milli bar to suck faeces and water to the central unit. In reality water and the materials are transported by air in the pipes. The main advantages are small pipe diameters, flexible pipe installations, independent from natural slope evacuation devices for all waste water inlets and the possibility of separate collection of black and grey water. Due to the necessary vacuum unit run by electricity the investment for a single house is too large, but it can be used for multi-family houses. The acceptance for such a solution is growing although provisos exists because the pipes can be blocked if other materials like paper is thrown into the toilet bowls, also the toilet system itself is a little noisier than a WC. For more information have a look i.e. at www.roevac.com/html/english/supply-sub2.htm (see also fig. 1).

WATER FREE URINALS

Urinals are very common at restaurants and in public buildings, but they can use 2 till 5 litres of water for one flush. Especially at public toilets with an automatic flushing regime the water consumption can be very high. Nowadays three different systems of water free urinals are entering the public toilet scene. The most established system is using an organic liquid filling up the siphon and because this is lighter than water it prevents that the smell of the urine under the liquid will spoil the air of the toilet room. The second uses a magnet and an electrical sensor for opening and closing a sealing lid in the trap, so that no smell out of the drain pipe will occur. The third one uses a urinal bowl of china with a very glossy surface and for the trap a special membrane which lets pass the urine but afterwards the pores of the membrane close so that no

smell from the drain pipe comes up. The advantage of all systems is that no water for flushing is necessary and for this reason also no water supply installation. Additionally pure urine can be collected that can be used as a fertilizer if necessary. For detailed information a visit of these sites are useful:

www.ernstsystems.com/en/system.html,
www.urimat.com/homepage_gb/, www.keramag.de/Wasserlos_neue_Urinal-Generat.948.0.html

COMPOSTING TOILETS

Composting toilets are often called dry toilets because they don't need water for flushing. An additional advantage is its absence of smell and their better restroom climate if the toilet is equipped with a fan. Faeces and urine stay in the house or in the house area, the users have to learn how to deal with the process of composting and the compost itself. Very often a composting toilet is equipped with an urine separation bowl. The reason is that our urine is nitrogen dominated and for an optimal ratio of 30:1 (C:N) carbon sources like straw or leaves have to be added. The better way is to take away the urine so the faeces will be composted by itself and the large amount of liquid from urine will not disturb the composting process. There are two approaches for composting our excreta. The first one is to collect all organic material of a household in one large bin and to organize the composting in the bin until a mature compost will be received. The other one is to collect the faeces and the urine in a small bin or bag (latter preferably made of an organic material that can be degraded by microorganisms) and emptying or putting it time by time on a composting heap in the garden to finalize the process outside. The latter one becomes more and more popular because large investments and also a room of at least 1 m³ is not necessary for installing a composting toilet in the house.

The composting toilet VILLA 9000 (www.separett.com) is made of polypropylene plastic and in its body is a bucket for collecting the faeces. If the bucket is full it has to be emptied on a compost heap and covered by other organic material in the garden or replaced by a by a second bin and the material will be composted in the original bin. The bucket inside the toilet is covered by two lids. The first is for opening the toilet, the second will be opened only when the user will sit down on the toilet. The toilet is equipped with a fan, which is sucking air through the toilet out of the toilet room to outdoors. Additionally the toilet has an urine separation device, to collect the urine separately outdoors.

The above presented composting toilet is used for single family houses or vacation houses and it is combined with an urine separation bowl. The next system is also for single family houses. It is an example for a continual process system with a constant state of composting. „Deposits“ are put into the system, composting reduces the volume and moves it downward where it is harvested after 6-12 months or more depending on the climate conditions as fully composted

material. There are two large projects in Germany where such systems are installed in multi family houses.

The system TERRA NOVA (www.berger-biotechnik.de) consists of a 1 m³ large fibre plastic container, situated in the basement of a building and receives faeces and urine as well as organic materials from the kitchen. Two toilet seats (on different floors) can be connected. A fan is sucking air through the material and transports moisture and gases by a pipe to the chimney. Every year about 10 - 40 litres of mature compost/person can be taken out of the container and can be used for trees and ornamental plants in the garden. The installation costs are about 7.000 € for an entity which serves four persons the whole year round.

COSTS

The simplest odourless composting toilet costs—only for the toilet itself—about 300 €, for larger ones and more comfortable ones the costs can go up to 10.000 € for a composting bin. Additional costs for the installation of ventilation pipes, a fan and an urine tank will increase the investments. Running costs will be electricity for the fan which can reach about 30 € (500 Wh/d x 365 d x 0,15 €/kWh = 27 €) a year, if the fan will work every day the whole year. Other running costs are difficult to calculate like emptying the faeces bin or taking out the compost and distributing it in the garden. Using a composting toilet a client will save 100 litres of flushing water a day for a four person family. That could mean for German conditions about 100 € a year (100 litres x d x 3 €/m³).

The simplest composting toilet is a bucket with a lid and the faeces will be bestrewed by sand, earth or peat and carried it outside time by time. The more comfort is asked for the more installation (ventilation, urine separation) is needed.

Composting toilets have to be considered under an economic view with such results:

- To organize artificial aeration like at wastewater treatment plants to oxidise our faeces to carbon dioxide it is not necessary anymore. To provide activated sludge with oxygen is the most expensive part of a normal WWTP.
- Human beings will not be anymore the source for nitrogen and phosphorus eutrophication lakes, rivers and seas. These nutrients and others like potassium will go back to the soil.
- Composting toilets are saving flushing water. This water amount has not to be abstracted.
- The fertilising equivalent of excreta is, in theory at least, nearly sufficient for a person to grow its own food (Drangert, J.O. (1998). The use of composting toilets can minimize world hunger problems and protect the resources of nutrients, especially of phosphorus.

The positive economic facts will only become reality if people are educated to deal with their excreta, especially their faeces in a better way as they do today—

flushing it away. Also to learn what composting means and how it works will be a precondition for a larger acceptance of composting toilets.

COMBINED TOILET SYSTEMS

Inventions are made to combine the comfort of flushing with the environmental friendly technologies of urine separation and composting. In a multi family house in Norrköping, Sweden the AQUATRON technology was installed in 1998 as a self-sufficient system producing compost by the help of earthworms, diverting urine and transporting it to an agriculture farm using it as a fertilizer. The water is treated in a small constructed wetland on the spot and infiltrated afterwards into the ground. This technology is also available for single houses.

Aquatron (www.aquatron.se) uses standard WC (flushing volume 3 – 6 litres) or special models where the urine is mechanically diverted from the flushing water and the solid waste in the bowl itself. When the toilet is flushed, the contents of the bowl are transported to the Aquatron separator where approx. 98% of the liquid fraction is separated by using the momentum of the flushing water, centrifugal force and gravity. The solid waste (paper and faeces) falls down into the biological chamber where it is composted by bacteria and, if desired, by worms. If worms are used, the volume of the solid waste is reduced by approx. 95%. The need for emptying and handling the waste is therefore reduced to a minimum. Optimal temperature for the composting is 12 - 25°C. Freezing temperatures will kill the worms.

OUTLOOK

There are a lot of possibilities and technologies available to save water, energy and nutrients and not to spoil the environment by flushing away or discharging our excreta somewhere. The industrialised countries have developed water network and wastewater collection and treatment as a well organised though expensive procedure. Doubts about the sustainability of the system, however, arise and alternatives are discussed, especially under water scarcity conditions. The demand DON'T MIX, DON'T FLUSH, DON'T WASTE can show the right way.

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- Drangert, J. O. (1998): Fighting the Urine Blindness to Provide More Sanitation Options. Water South Africa, Vol. 24, No. 2, April.

MEDA WATER PROJECTS

www.emwis.org/meda/projects.htm

PROJECT TITLE / ACRONYM	Countries involved	COORDINATION	INFORMATION
Autonomous desalination system concepts for sea water and brackish water in rural areas with renewable energies – Potentials, Technologies, Field Experience, Socio-technical and Socio-economic impacts / ADIRA	DE, EG, ES, GR, JO, MA, TR	Fraunhofer-Institut für Solare Energiesysteme (DE)	www.adira.info
Development of tools and guidelines for the promotion of the sustainable urban wastewater treatment and reuse in the agricultural production in the Mediterranean countries / MEDAWARE	CY, GR, JO, LB, MA, PS, SP, TR	National Technical University Athens, School of chemical Engineering, Unit of Environmental Sciences (GR)	147.102.83.100/projects/meda/meda.htm
Efficient Management of Wastewater, its Treatment and Re-Use in the Mediterranean Countries / EMWATER	DE, IT, JO, LB, PS, TR	InWent - Carl Duisberg Gesellschaft (DE)	www.emwater.org
Euro-Med Participatory Water Resources Scenarios / EMPOWERS	EG, JO, NL, PS, UK	CARE International (UK)	www.empowers.info
Improvement of irrigation water management in Lebanon and Jordan / IRWA	ES, IT, JO, LB	Istituto per la Cooperazione Universitaria (IT)	www.irwaproject.com
Institutional and social innovations in irrigation mediterranean management / ISIIMM	EG, ES, FR, IT, LB, MA	Agropolis (FR)	www.isiimm.agropolis.fr
Mediterranean Drought Preparedness and Mitigation Planning / MEDROPLAN	CY, ES, GR, IT, MA, TN	Mediterranean Agronomic Institute of Zaragoza (ES)	www.iamz.ciheam.org/medroplan
Stakeholder Participatory Sustainable Water Management at Farm Level MEDWA	AT, ES, JO, PS	HWA – Hilfswerk Austria (AT)	www.hilfswerk-austria.at
Sustainable concepts towards a zero outflow municipality / Zer0-M	AT, EG, GE, GR, IT, MA, TN, TR	Institute for sustainable technologies (AT)	www.zero-m.org



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