Decentralized and centralized wastewater management: a challenge for technology developers

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Abstract The traditional wastewater management concept (urban wastewater collection system plus treatment of the wastewater in a central treatment plant) has been successfully applied over many decades in densely populated areas of industrialized countries. Whether this technology is of ultimate wisdom must be questioned, especially considering the urgent need for improved sanitary infrastructures in developing countries. The problem is that the costs for implementing a centralized system in mega-cities, in particular the investment costs for the sewer system, are exorbitant. Decentralized wastewater management systems, with the wastewater treated close to where it is generated, are being considered by various researchers and institutions including the World Bank as an alternative to the traditional centralized system. The degree of technological sophistication that should be applied is under dispute, however. In this paper, we advocate development and application of high-tech on-site treatment plants, designed and fabricated by modern industrial methods. When mass produced, the costs for manufacturing such package plants can presumably be kept at a relatively low level. The plants should be delivered in a "user ready" state. Local plumbers may connect toilet bowls and sinks and washing machines, but may not be involved in the manufacturing of the treatment system. The plant should produce an effluent which is hygienically safe and can subsequently be utilized for toilet flushing, washing clothes, cleaning floors or watering lawns. In order to keep the plants operating properly, they should controlled by remote sensing, and maintained by specialized service enterprises. The conceptual design of such a compact plant is discussed in the form of a case study.

Keywords compact wastewater treatment plants; decentralized sanitation; developing countries; industrial scale manufacturing; wastewater management

Introduction

In the middle of the past century, engineers and natural scientists discovered that the outbreak of fatal diseases such as typhus, cholera and diarrhoea was caused by the direct contact of human beings with their own excreta, and by the spread of pathogenic microorganisms contained in the excreta. To protect the human population from getting infected, the central sewer system was invented – or , more accurately, re-invented, since sewer systems had been widely used centuries ago already, for instance by the Romans and other ancient civilizations. Technical means were developed to collect the sewage generated in households and to transport it, together with wastewater from industry and storm water runoff, away from the human settlement. Simultaneously, the flushing toilet was invented, and has been praised ever since as a most important civilization gain disregarding the fact that high quality (and often scarce) drinking water is required for flushing and transport of wastes to the treatment plant. In industrialized countries a huge amount of money has been spent over the past decades to build up and maintain such sewer systems, with drinking water as a transport medium. Gradually, the cities, villages and rural areas in Europe and elsewhere have been provided with sewers. In Germany, for instance, more than 95 per cent of the population are currently connected to sewer systems.

As more and more sewage was discharged into surface waters a subsequent problem became evident. Large numbers of pathogenic organisms created health risks to the population living downstream. Oxygen depletion as a result of bacterial growth and respiration led to fish kill. Due to increased levels of nutrients algae and water plants started to proliferate. Suddenly, surface water could no longer be used as a source for drinking water supply. Intensive and costly purification became necessary, wastewater treatment technology had to be developed, and huge investments had to be made to improve surface water quality including that of estuaries and marine water bodies.

The wastewater treatment system which evolved is illustrated in Figure 1. This system became a standard tool of environmental protection and control in industrialized countries. It can be described as "centralized wastewater collection and treatment system". Literally, it is to be considered as an "end of the pipe" technology. The costs for the development and implementation were to be covered by the local economies. Since implementation was gradually accomplished over a rather long period of time, however, the financial loading per unit of time remained reasonable. The economic benefits, on the other hand, were significant, both with respect to the infrastructural gains and the long-term business opportunities provided to the building sector. The rise of the economic status of the State of Singapore over the recent years can be viewed as a good example for how closely related economic growth and achievements in water quality control are.

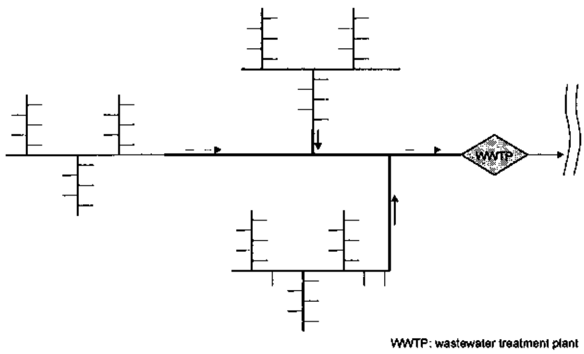

Figure 1 Representation of the centralized wastewater collection and treatment system as it has been developed and successfully applied over the past decades in the industrialized countries

As the situation in most of the industrialized states has reached a fairly high standard, severe problems with respect to water supply and wastewater management became apparent in the developing countries. There sewer systems do not exist or exist only in a rather rudimentary form, and the wastewater generated in the settlements and cities is often not treated at all. The situation resembles in a way that of Central Europe and England in the 19th century, but is not entirely comparable, nevertheless. The difference is that in the municipal areas of developing countries sanitary systems coexist differing in technological level from "zero" (pit latrine) to "highly sophisticated" (high rate biological wastewater treatment). Squatters and residential areas of rather wealthy families are often in close neighborhood. New settlements spring up, sometimes virtually overnight, and are removed and replaced by commercial establishments soon after. No matter how inhomogeneous the situation may be, sanitary infrastructure is needed urgently, and the time yet available for getting wastewater management to be effective is nearly zero. The instantaneous demand for investment money to build up centralized wastewater collection and treatment systems is very high, and can hardly be covered, certainly not by the local economy.

At this point the question should be raised whether the centralized wastewater collection and treatment system is indeed the optimal and ultimate solution. What could be the alternative, and how quickly could the alternative method be made available? In the following, answers to this question will be investigated and critically discussed.

Definitions

In the context of this paper, the term "centralized wastewater treatment" is used to describe systems consisting of a sewer system that collects wastewater from households, small enterprises, industrial plants and institutions, even storm water runoff, and transports this ever changing mixture to a wastewater treatment plant located outside of the limits of the city or the village (Figure 1). The sewer system consists of two major parts, the collection and the transport sub-systems. The wastewater treatment plant also consists of two sub-systems, the one designed to eliminate pollutants from the wastewater, the other one to convert the eliminated substances and their derivatives (waste sludge in summary) into a form suitable of any further use (e.g., as a soil conditioner in agriculture). The treated wastewater is discharged into the closest water body (river, estuary, ocean) where natural physical, chemical and biological processes are expected to be effective, leading to final polishing of the water.

In contrast, the wastewater that is generated in a settlement served by "decentralized systems" is treated rather close to the point of origin (Figure 2). Still, the wastewater has to be collected by means of a piping system, but the length of sewers is comparatively short.

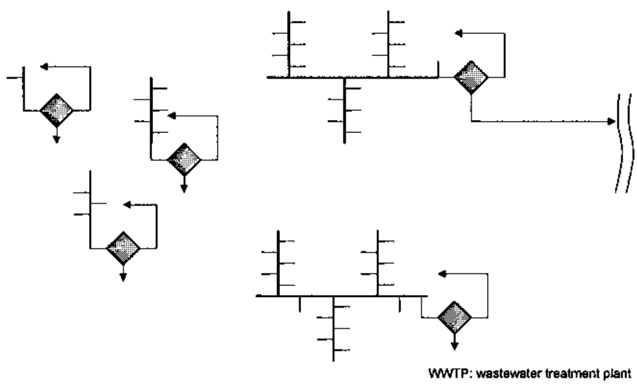

Figure 2 Schematic representation of a decentralized wastewater collection and treatment system

The collected wastewater flows to small on-site treatment plants, where wastewater and sludge treatment processes are executed. The treated water may be used for groundwater recharge, and polished by physical, chemical and biological processes during soil passage. Alternatively, the treated water may be sent to a nearby surface water body, or used for flushing toilets, washing clothes, for irrigation or fire fighting. The sludge is converted into a compost that can be used, on site, as a soil conditioner and as a fertilizer source in gardening or landscaping.

Pro and contra

Centralized and decentralized systems have coexisted over the past years, but water authorities of industrialized countries were hardly fond of the decentralized alternative. The reason for that is obvious when taking into account the low purification level achieved by most of the treatment facilities that are on the market (septic tanks, ponds, wetlands etc.), and the poor and mostly non-professional attention on-site facilities receive during operation.

Usually, the owners of the houses, and persons in charge of small enterprises and industries are expected to supervise and maintain the plants. They almost never have any in-depth knowledge of the processes on which a successful operation of the treatment system depends, nor are they motivated to take care of the system.

A further argument against decentralization of wastewater collection and treatment systems is based on financial concerns. Building and operating a great number of small on-site systems is assumed to be far more expensive than one large central wastewater collection and treatment system.

All these arguments have to be taken seriously. A decentralized system can only become competitive, when the following conditions are satisfactorily met.

1 Small wastewater treatment systems for decentralized application must provide advanced wastewater treatment; they must be highly effective, robust, easy to operate, and low in costs.
2 Operation and control of the treatment systems must be accomplished by people who are especially trained for the job to be accomplished.

Only then can the decentralized version of wastewater collection and treatment systems be considered as a viable alternative, both for industrialized and developing countries. The latter could greatly profit from such a technology since the components of such a modular system can be implemented in a stepwise approach. For instance, as a new settlement or a new industrial estate is build the water management system can be implemented and taken into operation irrespectively of the sanitation standards in the adjacent areas.

If – by contrast – a centralized approach is chosen, a sewer system has to be built with wastewater to be transported over long distances, and finally treated at the end of the pipe. The transport and treatment system is mostly designed for a situation which is anticipated to develop over the upcoming years. Until this situation is established, the capacity of the system is far higher than actually needed. Subsequently, the operation costs are high, and the treatment plant works way below under sub-optimal conditions. The investment costs have to be spent within a relatively short period of time, and the burden on the local economy would be very high.

A new road to be travelled

In the following, a concept is presented which may not find unanimous support, and may stir up a controversial discussion, but needs to be discussed, nevertheless. In particular, the question must be raised whether pit latrines, composting toilets, septic tanks, intermittent sand filters are really “the” alternative to combined sewer systems and treatment plants at the end of the pipe?

First, it should be realized that water is a valuable material, especially in water shortage areas. Wasting of water by first polluting it, providing some purification thereafter, then discharging the partially treated water into either surface water bodies or into the ground is a method that has its merits but needs to be questioned in the light of the “Agenda 21”. Shouldn’t it be the primary goal to treat the polluted water to a degree that enables reuse of the water, even for no other purpose than for flushing toilets, cleaning and/or watering lawns?

It should be realized that wastewater that is generated in households, enterprises and in industrial plants consists of various fractions each specific with respect to flow, composition and concentration, patterns of flow and patterns of mass fluxes. There are fractions which require sophisticated action, and others which can be treated with a minimum of effort.

With respect to household wastewater, sewage from toilets and kitchen sinks, in the following referred to as “black water”, contains organic substances in high concentration, including pathogenic organisms, and needs special care, therefore. Black water contains dissolved and particulate materials including large numbers of active bacteria which are capable of hydrolyzing particulate substances. As a result, a significant fraction of particulate material is transformed into dissolved substances, as long as both fractions of pollutants are kept in close contact. Separation of particulate material from the bulk liquid at the earliest point of time is a means to avoid the concentration of soluble organics in the bulk liquid to increase above the original level. It is a means to minimize the need for subsequent treatment.

In contrast to black water, wastewater from showers, washing machines and cleaning, in the following referred to as "gray water'', can be considered being rather low in pollution. It contains comparatively little nitrogen and phosphorus compounds. Treatment of this type of wastewater is considered to be relatively easy. When fixed bed biofilm reactors are chosen for biological treatment, extensive biomass growth is not to be expected, and a high hydraulic conductivity of the bed can be maintained without the need of back-washing (Netter *et al*., 1993). As a conclusion, black water and gray water require different treatment efforts. Fractionation should be applied, and the fractions should be treated separately.

Manufacturers of small wastewater treatment plants are presumably experts in getting together the parts which a plant consists of, but have mostly only limited understanding of the complexity of the physical, chemical and microbiological processes taking place in wastewater treatment plants. In analogy, manufacturers of engines may be able to put together a motor for a lawn mower, but are certainly not capable of manufacturing the engine of a BMW. Modern car engines are highly complex systems which cannot be designed and produced by any single manufacturer but only by specifically trained and well equipped teams of experts. Why do we leave the manufacturing of highly complex wastewater treatment plants to constructors experienced in not much more than building up tanks of concrete? It is a basic mistake of wastewater engineering today to keep relying on the capabilities of plumbers and tank manufacturers.

To stay with the example of car manufacturing, the engines of modern motor vehicles are highly complex but easy to operate also by people with relatively low technical skills. Cars are also available in a price range reasonable for people with a relatively low income. Mass production of engines and cars on the basis of modern computer aided design and manufacturing made it possible to achieve this status. Why shouldn't mass production of wastewater treatment "engines" be possible when using the same degree of sophistication in design and manufacturing? Why shouldn't that lead to acceptable results with respect to convenience, reliability and compliance in operating the system, and with respect to price? There is supposedly a market for mass-produced treatment systems when considering the problems in developing countries and the urgent need for solutions.

Applicants of decentralized treatment plants (the so called "man in the street") cannot be expected to be experienced in operating a highly complex bio-technological system, and being motivated to provide any kind of serious supervision. Using the same example as above, service and repair of modern automobiles is not something which can be accomplished by the owners of a car, nor by a simple mechanic. Highly qualified service needs to be provided also for complex wastewater treatment systems. Here is an excellent job opportunity for a whole generation of well educated young engineers with a background in chemical engineering, chemistry and microbiology. Remote sensing and monitoring systems combined with modern devices for data transfer allow simultaneous supervision of a multitude of small plants in municipal areas. This has to be realised by society.

Previously proposed solutions

The technologies which are currently applied to treat small quantities of wastewater, in particular septic tanks, do not meet the requirements described above. Septic tanks provide only partial purification of wastewater. One may argue that the combination of septic tanks and intermittent sand filters offer specific advantages because of the inherent stability which that system provides due to the many trophic levels of organisms living in the filter bed (Venhuizen, 1997). Combinations of septic tanks and ponds or constructed wetlands may also be judged as alternatives. The problem is that these systems require a considerable area of land which may be available in rural areas or at the outskirts of big cities but certainly not within densely populated metropolitan areas where the urgency of solving environmental problems is particularly great.

In Japan, attempts were already made years ago to treat wastewater from housing complexes and use the effluent for toilet flushing and irrigation. The treatment plants were installed in the basement or in the close neighborhood of the buildings. A fairly high acceptance rate for this technology has been reported (Asano, 1996).

In Europe, the development of novel sanitation concepts started only recently. Ingerle (1998) designed several innovative systems for huts in remote Alpine regions. Otterpohl *et al.*, (1997, 1998) suggested replacement of the traditional flushing toilets by vacuum toilet systems, similar to those used in ships and aircrafts. The collected black water is transported into a tank where it is anaerobically digested. The gray water flows to constructed wetlands and is treated there. Currently, this concept is the subject of two field trials. Larsen and Gujer (1996, 1997) proposed separation of faeces and urine at the earliest stage to facilitate treatment of black water. A highly compact system to treat black water in running railroad cars was developed by Bleicher and Winter (1998). The latter system is probably the first one considered for mass production under modern industrial scale measures.

Concept of a novel compact treatment system

In the following, the concept for a treatment system is outlined, and the planned procedure of getting the system ready for mass production is summarized. The proposed flow schematic is presented in Figure 3.

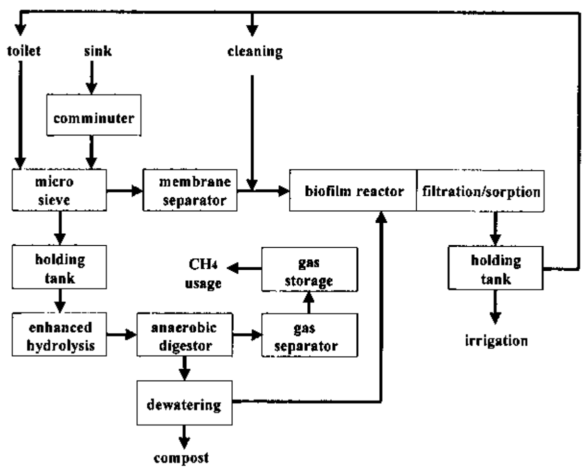

Figure 3 Flow schematic of the proposed treatment system

The basic ideas which led to the development of the concept are summarized in the following.

- Separate collection of black water (including biodegradable kitchen wastes comminuted in a sink disposal), and gray water.
- Solid-liquid separation immediately after reception of the black water to keep the concentration of the liquid fraction of the black water as low as possible. Application of micro-sieve and membrane separation technology to keep pathogenic organisms away from the liquid fraction of the black water (Günder und Krauth, 1998).
- Anaerobic treatment of the solid fraction of the black water with the aim to produce a hygienically safe compost.

- Combined treatment of the liquid fraction of the black water (filtrate of membrane separator) and the gray water in a horizontal flow fixed bed biofilm reactor. Segments of the reactor are aerated to achieve nitrification. Other sections are not aerated. By bubble free transfer of methane into the reactor fluid as electron donors to drive denitrification processes (Mason, 1977, Wisotzky and Bardtke, 1992). In the final section of the reactor the water passes a sand filter with the sand coated with iron to eliminate phosphorus in the form of iron-phosphate (Ngo and Vigneswaran, 1996).
- Development of a monitoring concept that allows on-line control of the performance of the system from distant locations.
- Development of the system in close collaboration with the design shop of a competent industrial manufacturer, and with the marketing department of the same company to make sure that the technology development process keeps in line with the demands of the international market.
- Application of computer aided design and development of computer aided manufacturing methods to enable mass production.
- Field trials and advertisement of the new product, worldwide.

Two application scenarios are sketched in Figure 4 and 5. If a single house (dwelling, high rise building, industrial plant) is to be served, treatment of both fractions, solid and liquid, has to be combined in one physical unit. For cost reasons, the anaerobic treatment of the solid fraction should be provided in a separate semi-central unit, however, if a condominium, a cluster of high rise buildings or an industrial estate is in focus.

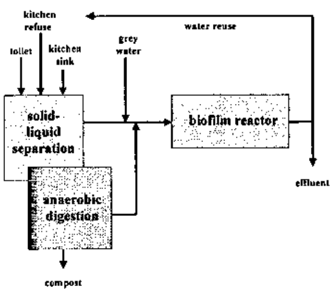

Figure 4 Application of the treatment concept when the wastewater of single houses is to be treated

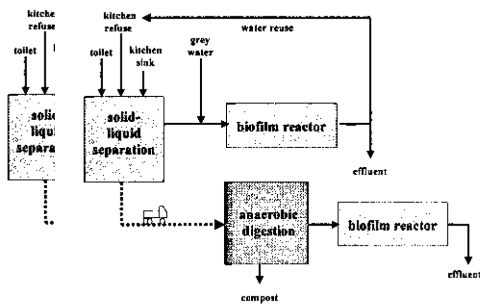

Figure 5 Proposal for a system serving small communities and industrial estates

Since the major components of the system have already been tested in full scale, and have proved to be applicable, the chances to succeed in the development of the concept are considered to be quite high. Close collaboration between university researchers, engineers specialized in industrial manufacturing, and marketing people is assumed to be essential for making the proposed technology competitive on the international market. The authors advocate the combination of forces inherent in the university system and in industry in order to make progress in developing a novel package plant, but also to establish sustainable wastewater management systems.

Conclusions

The traditional wastewater management concept needs to be complemented with an equally powerful tool that serves areas of low population density of industrialized countries, and of developing countries as a whole.

Decentralization of municipal sanitation can be considered as an economically and ecologically interesting alternative to the traditional concept provided the individual treatment systems produce a high quality effluent reliably and for a reasonable price.

There are three main advantages decentralized sanitation systems provide. First, transport sewers including lifting stations and storage facilities to handle combined sewage flow are not needed; that results in significant cost savings. Second, a large number of opportunities are granted for on-site water reuse and groundwater recharge. Third, failures of single units do not cause the collapse of the whole system.

A new generation of highly efficient, compact, user friendly and low-priced treatment systems is to be developed, urgently, in order to serve the needs of developing countries.

A new approach in designing, fabricating, and operating decentralized package plants is necessary. Mass production using modern industrial methods provides best chances to serve the public with reliable, effective, robust and reasonably priced treatment plants.

Close collaboration between university researchers and industrial designers, manufacturers and marketing people is necessary to keep research and development of novel wastewater treatment methods in line with the actual field requirements.

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