

Decentralized raw sewage utilization for irrigation of green areas in arid cities

K.-U. Rudolph*, T. Fuhrmann*, R. Soud**

* Institute of Environmental Engineering and Management at the University of Witten/Herdecke gGmbH (IEEM), Alfred-Herrhausen-Straße 44, 58455 Witten, Germany

(E-mail: *mail@uni-wh-utm.de*, *fuhrmann@uni-wh-utm.de*)

** Unterhof 69, App. 1003, 35392 Gießen, Germany

(E-mail: *rimsoud@hotmail.com*)

Abstract To reduce the use of potable water for irrigation of public green areas in urban arid regions, a specific decentralized approach has been developed. As part of a multi-barrier concept, a compact and simplified treatment system was designed for efficient utilization of wastewater from existing sewage systems. The treatment system consists of only two purification steps: a mechanical pre-treatment and a subsequent disinfection by UV irradiation. Departed from the mainstream opinion, preparatory laboratory scale tests indicate that the disinfection of only mechanically purified wastewater by UV irradiation is a feasible solution with acceptable levels of UV doses and resulting power consumption. Especially according to the requirements for irrigation water, disinfection by UV light is an appropriate option for point-of-use systems, which makes it preferable for decentralized wastewater treatment systems.

Keywords compact wastewater treatment system; disinfection; sewage reuse; UV irradiation

INTRODUCTION

Public green areas like parks or green stripes along traffic lines are essential for life in urban areas, especially in arid regions. They positively influence city's local climate and reduce the appearance of dust. To keep green areas in a proper condition despite arid climate with little rainfall and high evaporation, they have to be intensively irrigated.

Even in regions with scarce water resources, potable water from public water supply systems is used for this purpose, resulting in an increasing lack of water for higher-valuable uses like water supply for the population and industrial purposes. On the other hand, particularly in arid developing countries, completely uncontrolled use of raw wastewater for irrigation purposes is widely spread, with all the hygienic problems linked to this.

Facing these challenges and based on a general multi-barrier concept, within an ongoing research project a decentralized system for controlled utilisation of sewage as irrigation water in public green areas has been developed to reduce the demand of water from public supply systems as well as ensuring reasonably secure conditions for the application of sewage for irrigation purposes. Aim of the project has not been to offer a costly full purification facility for sewage but a comparatively efficient system with partial treatment and disinfection of raw wastewater, only as far as it is necessary for the specific use in public green areas.

DEVELOPMENT OF A CONCEPT FOR DECENTRALIZED SEWAGE UTILISATION

The key demand: wastewater disinfection

The main task of sewage treatment plants, the reduction of organics and nutrients etc., is usually not required, if the treated water is used for irrigation purposes, as the contained nutrients are often needed as useful fertiliser. Therefore, when talking about wastewater reuse for irrigation of green

areas, appropriate wastewater disinfection is the overall key issue.

To protect workers conducting irrigation activities and population passing irrigated areas as well as protecting the environment from possible contamination, microbial pathogens have to be reduced to levels being suitable for irrigation water. Seen from a strict technical point of view, purification of wastewater including disinfection can be performed to any wished level, up to a total sterilisation of wastewater. Taking treatment costs and often limited competence of operational staff into consideration, performance of purification systems should be limited to real required levels. But it has to be paid emphasis on the demand that partial treatment of wastewater is generally only adequate, if it is combined with other measures like restricted irrigation, human exposure control etc. (as it is for example fully described in the new WHO guidelines (WHO, 2006)).

Independent from current discussions to tighten up the restrictions (especially in context with the revision of the WHO guidelines), the design of site-specific irrigation concepts will always be a compromise between desirable low levels of harmful water constituents like pathogens on the one hand and the limitations by local economical and knowledge resources on the other hand. This is also reflected by the variety of standards, regulations and guidelines existing for wastewater to be utilized for irrigation purposes, exemplarily shown by the authors in another paper presented on the WRRS 2007 (Fuhrmann and Rudolph, 2007).

Multi-barrier strategy

To cope with the specific constraints regarding the utilization of sewage for irrigation purposes an investigation of all relevant criteria has been conducted, considering the specific purification and disinfection demands, as well as practicable technologies applicable to surroundings of urban green areas (like gardening and aesthetic related aspects). As result, a multi-barrier strategy for hygienic risk management regarding irrigation of public areas with wastewater has been outlined, taking into consideration three key issues:

- (1) water reutilization suitable for the site conditions
(like geological situation, kind of plantings, etc.),
- (2) way of handling suitable for the water reutilization
(e.g. regarding distribution and application of the irrigation water),
- (3) treatment suitable to the way of handling of raw sewage
(especially regarding pathogen reduction).

The mentioned issues are dependent from each other in both ways (what is often ignored in practical applications). For example, sewage treatment with only limited reduction of pathogens urgently requires a suitable handling like drip irrigation instead of sprinkling as well as adequate instructions for workers and operational staff.

Development of a pilot treatment system

The design of a suitable treatment system according to above mentioned issue (3) has to fulfil several demands regarding its treatment concept and construction. To make it reliable especially for decentralised applications, the complete treatment unit should be as compact as possible and most flexible regarding the conditions of the application locality. As the removal of nutrients from the wastewater is not relevant in this case, the treatment concept can be focused on two main steps, which have been identified to be sufficient to produce irrigation water of the required quality:

- mechanical purification of the influent
(to remove grit and organic matter in order to avoid odorous and aesthetic problems with the

- irrigation and as pre-treatment for the subsequent disinfection),
- appropriate wastewater disinfection
(in order to avoid health risks through pathogens contained in the irrigation water).

Funded by the German Federal Ministry of Research (BMBF, project no. 02WD0417 and 02WD0757), in co-operation with Huber AG and supported by WEDECO AG (Germany), a specific pilot system has been developed, fulfilling these demands (IEEM et al., 2005). The principal layout is displayed in figure 1. Essentially, the system consists of only four key parts described in table 1.

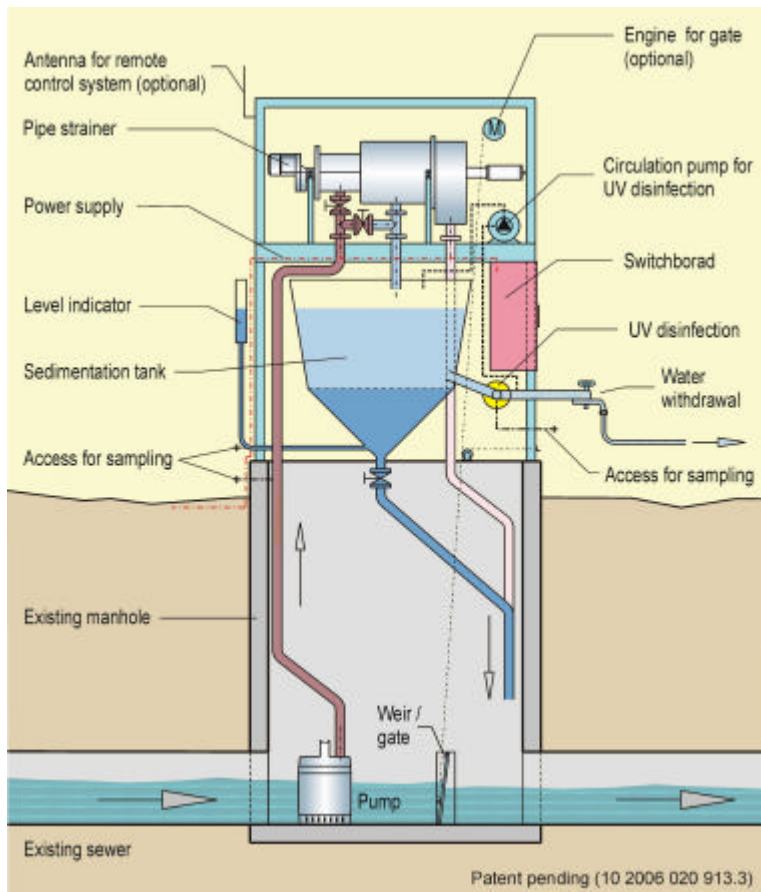


Figure 1 Schematic layout of the pilot treatment system

The construction of the system allows a placement on or next to an existing manhole of the sewage system. Due to the limited size, it can be moved to other locations, if needed. The system combines removal of pathogens sticking to particles as well as helminths by settlement with subsequent inactivation of pathogens contained in the effluent by UV light. The mechanical treatment also results in a significant reduction of COD loads.

The whole technical concept will be demonstrated over a two years period by a pilot scheme in the Middle East, accompanied by a measurement programme to validate the disinfection efficiency.

Table 1 Key parts of the pilot treatment system for sewage utilization

Part	Description
Feeding pump	A pump to feed the system with raw sewage from existing sewage systems, protected by a screen against coarse matter.
Pipe strainer	The mechanical separation of solid wastes and organic matter including removal of hair, fibres and fine suspended material is done by fine screening through a pipe strainer with a screen of 0.2 to 1.0 mm slot width. The pipe strainer consists of a horizontal screw which rotates inside a pipe-shaped screen basket and transports the solids retained on the screen surface up to the screenings' discharge. The wastewater to be treated flows through the screen from inside to outside and is then discharged vertically downwards through an outlet pipe connection (see fig. 1). The screen basket can be equipped with different screening elements and thus adapted to suit specific requirements, with the screen surface mechanically cleaned by brushes, which are fitted to the screw. Backwashing with water is not required.
Settlement tank	The sedimentation tank has two functions: settlement of suspended solids and buffer volume for flow variations as well as for recirculation from the disinfection unit. Sediment can periodically be removed from the tank through valves downwards back into sewage system.
UV irradiation reactor	Disinfection of the wastewater to the required level is ensured by a subsequent disinfection reactor with UV irradiation. By recirculation, the UV dose can be increased, resulting in higher disinfection efficiency.

DISINFECTION OF PARTLY PURIFIED WASTEWATER BY UV IRRADIATION

Within the project, the application of different disinfection technologies like chlorine, ozone, UV light and membrane filtration has been compared. Carefully considering the relevant criterions as there are investment costs, operation and maintenance efforts, demanded staff competence and nascent of harmful by-products, disinfection by UV light has been identified as the most appropriate disinfection technology in this context. Especially because of low demands regarding operational efforts and competence of operational staff as well as no need for regular use of harmful chemicals (like chlorine), UV light disinfection suggests itself for decentralized and small scale systems in rural areas and non-industrialized countries.

Ultraviolet light as an energy-rich light with a wavelength of about 200 to 400 nm has a germicidal effect on micro-organisms by damaging deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). The effect is particularly efficient with a wavelength of about 254 nm (see figure 2). This goes together with the emission maximum of low-pressure mercury lamps, used as UV light source. The performance of the germicidal effect depends on the UV dose applied to the pathogens, which is limited by the output of the used UV lamps (UV dose = lamp intensity x exposure time) and by the quality of the water to be disinfected.

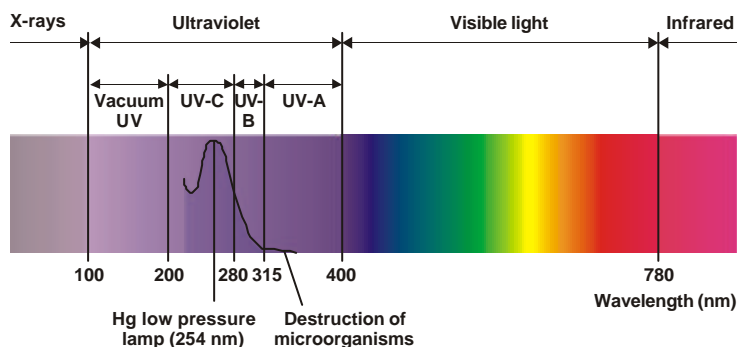


Figure 2 Identification of the UV radiation portion of the electromagnetic spectrum (WEDECO)

Experimental validation of the effect of low UV transmittance

UV light interacts with the materials it encounters through absorption, reflection, refraction and scattering. In disinfection applications, these phenomena result from interactions between the emitted UV light and the UV reactor components and especially the water being treated. Therefore optimal UV disinfection efficiency of typical systems applied after biological treatment steps of conventional sewage plants requires secondary effluent with high UV transmission values, indicated by low SS concentration and turbidity and little colour. Often filtration (e.g. by sand filters) is used prior to UV disinfection, which might add on cost when reduction of suspended solids and turbidity is not required for other reasons.

In contrast to fully purified wastewater, literature review shows that there is still little knowledge about disinfection of only partly purified sewage (see for example Rudolph et al., 1992; Emerick et al., 1999; Rott and Schöler, 2001; Frank et al., 2002). Currently, there are ongoing tests of the authors with UV disinfection of wastewater conducted in combination with limited pre-treatment by fine screening and sedimentation on laboratory scale. First results indicate UV irradiation to be feasible for disinfection of poorly purified sewage with acceptable levels of UV doses and resulting power consumption.

Without extended pre-treatment it is not possible to reach pathogens concentrations near zero with UV doses being reasonable for practical applications. For example, to reduce the often used indicator bacteria *Escherichia coli* from levels of about 10^7 cfu/100ml in raw sewage to values of about 10^1 cfu/100ml after irradiation, UV doses of several thousand J/m^2 are necessary, in comparison to only 300 to 500 J/m^2 (= 30 to 50 mJ/cm^2) necessary for fully purified secondary effluent.

Applying means of mechanical pre-treatment improves the disinfection efficiency significantly. In figure 3 typical results of laboratory scale tests regarding inactivation of *E. coli* in screened (6 mm) sewage after different short-time sedimentation periods (15 to 90 min) are displayed. To reach for example a reduction of about three to four log units to levels of maximum 10^3 cfu/100ml (analogues to the former WHO guidelines), UV doses of 500 to less than 1.500 J/m^2 (= 150 mJ/cm^2) are necessary, depending on the settlement time. This shows that even with relatively small settlement times adequate disinfection efficiencies can be achieved with reasonable UV doses.

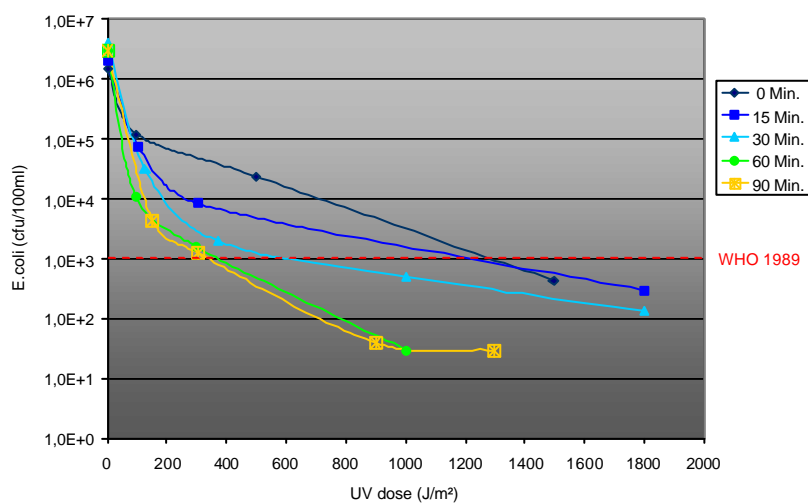


Figure 3 Example for inactivation of *Escherichia coli* by UV light in screened sewage after different settlement times (laboratory tests conducted with a collimated beam device according to U.S. EPA, 2002)

The major effect on the disinfection efficiency is caused by the level of UV transmission, indicating the ability of UV light to pass through the water to be irradiated. In combination with other mechanical treatments, e.g. micro sieving, the transmission may be further improved. Even only by extension of settlement time without any further treatment, a significant improvement can be measured, as displayed in figure 4 for sewage with worse initial values.

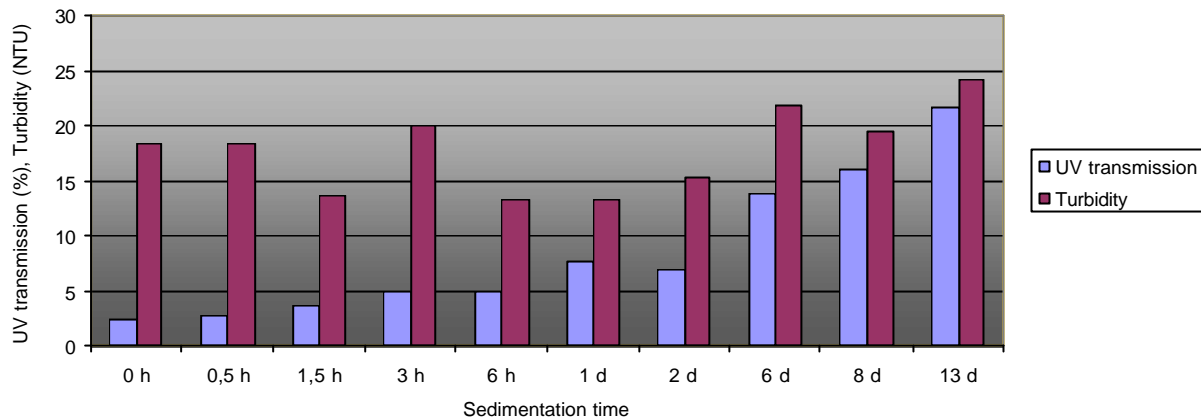


Figure 4 Development of UV transmission and turbidity over settlement time

The conducted tests prove the ranges of necessary UV doses after mechanical pre-treatment to be economically applicable for practical use. Therefore, the preliminary results of the lab-scale tests support the implementation of UV irradiation for the above described treatment system.

Reactivation of pathogens

When disinfecting wastewater by UV light, it has to be taken into consideration that the pathogen reduction can be reversed when storing the water for some time. In contrast to disinfection by chlorine, there is no residual disinfection dose left from the UV irradiation and, in addition, repair mechanisms like photo-reactivation and dark repair of irradiated cells may let the numbers of pathogens increase again some time after the application of UV light.

Photo-reactivation becomes significantly evident not before some hours of visible light exposure on disinfected water. Data of different authors show a wide range of exposure time, e.g. varying for reactivation of coliforms of about 1.0 to 2.0 log units from 2 to 6 h light exposure (Whitby et al., 1984; Harris et al., 1987; Chrték and Popp, 1991; Thyen et al., 1993, Oberg, 1995). Photo-reactivation as well as dark repair effects are highly depending on the site conditions (temperature, light exposure, surfaces etc.). The repair effects become more evident when adequate UV doses can not be ensured during irradiation, which is given with disinfection of not fully purified wastewater (Lindenauer and Darby, 1994).

Because of reactivation effects, wastewater disinfected by UV light is only restricted appropriate for long-term storage. In the case of a point-of-use disinfection, as proposed with the above described system, the reactivation effects are minor relevant. They have to be taken into consideration, if disinfected water should be stored for irrigation at later occasions.

CONCLUSIONS

Treatment of sewage to be reused as irrigation water for green areas in arid urban regions is first of all a question of disinfection. As part of a multi-barrier concept to utilize wastewater from existing sewage systems, UV irradiation has been identified as most appropriate disinfection method within a compact and simplified treatment system. Departed from the mainstream opinion that disinfection of wastewater is only feasible with fully purified effluents of wastewater treatment plants with secondary treatment, a system has been designed with only two purification steps: a mechanical pre-treatment and a subsequent disinfection reactor with UV irradiation.

Preparatory laboratory scale tests of the authors clearly indicate that even with only mechanical treatment of raw sewage the disinfection by UV light is reasonable according to irrigation requirements. The disinfection to usual standards for irrigation water demands levels of UV doses allowing economical applications for practical use.

Taking into consideration reactivation processes of wastewater disinfected by UV light, UV irradiation is preferably appropriate for point-of-use systems, like the described decentralized treatment system.

Because of their limited demands regarding operational efforts and competence of operational staff, UV irradiation systems are applicable for decentralized and small scale wastewater treatment systems (like the described one) in urban areas as well as in rural areas and non-industrialized countries.

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