

Wastewater ponds and subsequent UV disinfection - a lean cost option for agricultural wastewater reuse

T. Fuhrmann, K.-U. Rudolph

Institute of Environmental Engineering and Management at the University of Witten/Herdecke gGmbH (IEEM),
Alfred-Herrhausen-Straße 44, 58455 Witten, Germany
(E-mail: fuhrmann@uni-wh-utm.de, mail@uni-wh-utm.de)

Abstract Through their ability to significantly reduce pathogen levels of sewage, wastewater pond systems have to be taken into consideration as part of treatment concepts for reuse of sewage as irrigation water in agriculture, particularly in rural areas. But as pond effluent is seasonally variable and regularly does not fulfil relevant microbiological quality standards for wastewater reuse, there is a need for supplementary treatment of pond effluents, which means the use of subsequent disinfection systems. Among other options, UV irradiation has been identified as an appropriate method for this purpose. Although UV irradiation has so far been applied only for highly purified secondary effluents, tests with different pond effluents have shown UV disinfection as a reliable disinfection mean, even without further pre-treatment. In addition, low construction and operation costs in combination with limited demands regarding staff competence make pond systems with subsequent UV irradiation to be a promising option for efficient sewage treatment for reuse purposes, especially in non-industrialized countries and rural regions.

Keywords disinfection, ponds, reuse, UV irradiation

INTRODUCTION

Treatment of wastewater by pond systems is a proven and world-wide applied technology. The same is with UV irradiation, which has numerous applications for reclaimed water disinfection, especially at small and medium scale facilities. But the combination of pond systems with subsequent UV disinfection has so far only been rarely applied, due to doubts about low disinfection efficiency caused by supposed inadequate quality of pond effluents.

As knowledge about this issue is still limited, the authors conducted own lab scale tests on disinfection of different pond effluents by UV irradiation to assess the applicability of UV disinfection with reference to requirements for effluent reuse.

WASTEWATER TREATMENT FOR REUSE PURPOSES BY PONDS

Especially for rural areas in developing countries, wastewater ponds are often regarded as first choice in terms of wastewater treatment for reuse, because they are suitable for both small and large numbers of population equivalents (from <100 to >100.000). In addition, ponds are comparatively simple in operation and maintenance (as the principal of the system is a mainly natural method of wastewater treatment) and they are characterised by low capital and operational costs.

Pathogen reduction by wastewater ponds

When talking about agricultural wastewater reuse, appropriate wastewater disinfection is the main objective, unlike the reduction of nutrients, which can often be utilized as fertiliser. Pond systems offer excellent treatment features in terms of physical and biological reduction of pathogens in faecally-contaminated wastewater.

Even if not especially designed for pathogen reduction, waste stabilisation ponds typically may

achieve pathogen reductions of about 3 log units, as shown exemplarily in figure 1 with different pond steps and in figure 2 with a comparison of influents and effluents of different pond systems in Germany. The reduction rates of pond systems are varying within a range of about 1.5 to 4.5 log units, depending on different aspects like water depth, sedimentation effects, pH value and temperature.

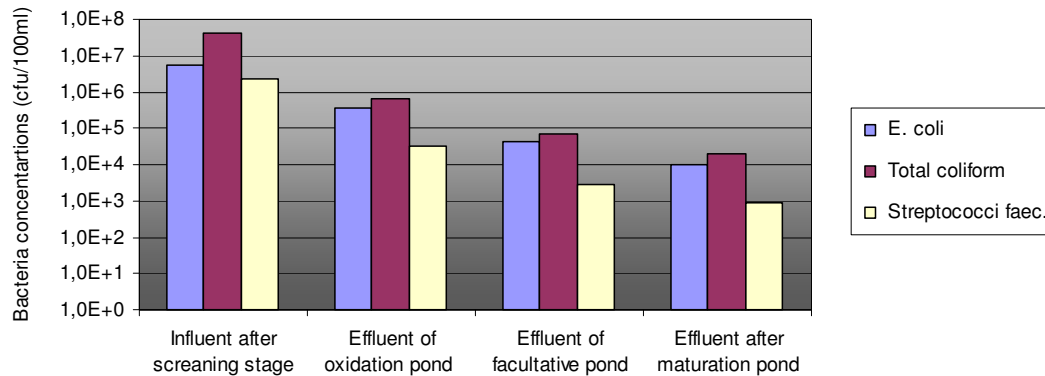


Figure 1 Example of pathogen reduction in a three-stage pond plant (average bacteria concentrations by each treatment step, WWTP Dorf Güll, Nov./Dec. 2005)

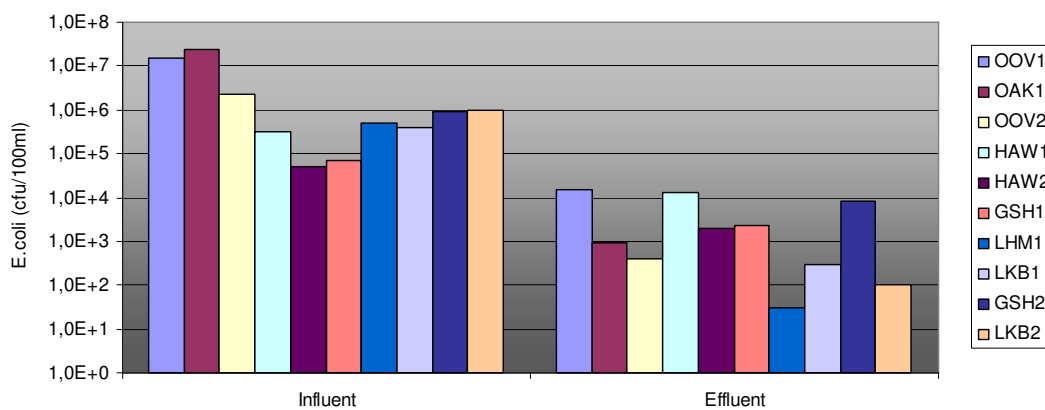


Figure 2 Escherichia coli concentrations in influent and effluent of different ponds in Germany (2006 / 2007)

Disinfection mechanisms

In pond systems pathogen levels are significantly lowered by the combination of both “removal” (by sedimentation of particle related pathogens as well as helminths) and “inactivation” (by insolation and biological processes). Due to density considerations, several pathogens like bacteria do not settle as individual cells or even colonies. But typically, bacteria can adsorb to particulate matter or floc particles, which settle during sedimentation and are later removed with the sludge (U.S. EPA, 2004). Especially regarding subsequent UV irradiation, the sedimentation effects are an ideal pre-treatment in terms of reduction of helminth eggs and disruptive particles.

Among others, three key mechanisms can be identified for disinfection in ponds:

- sedimentation, which leads to a significant reduction of helminths and particle-related pathogens by removal from the water body through settlement;
- high pH, especially in algae ponds, with inactivating effects when exceeding levels of above 9;
- sunlight, resulting in different effects like photobiological and photo-oxidative damage of DNA and external structures (e.g. Davies-Colley, 2005).

Several approaches exist to enhance the efficiency of pathogen reduction by modification of pond constructions or further developments of pond systems, as there are for example:

- specific constructions like buffers within the ponds or sequent arrangement of ponds to avoid short circuits and to make sure long retention times (e.g. Shilton and Mara, 2005);
- pond-specific filter systems, like rock filters (e.g. Johnson and Mara, 2005);
- algae ponds and systems with regular high pH values for biological inactivation of pathogens.

SUBSEQUENT DISINFECTION OF POND EFFLUENT

Despite the significant disinfection effects of pond systems (and partly independent from modifications for enhanced pathogen reduction), pond effluents are seasonally variable and regularly do not fulfil relevant microbiological quality requirements for wastewater reuse as sole treatment step (as other conventional mechanical and biological treatment systems, too).

Pathogen standards for irrigation

Especially regarding pathogen reduction, world-wide the definition of required levels for reclaimed water is very inhomogeneous, depending on the kind of reuse and regional constraints. Therefore, the microbiological standards vary greatly from country to country, as displayed in figure 3 with some examples of standards regarding the limitation of coliforms in water for irrigation purposes.

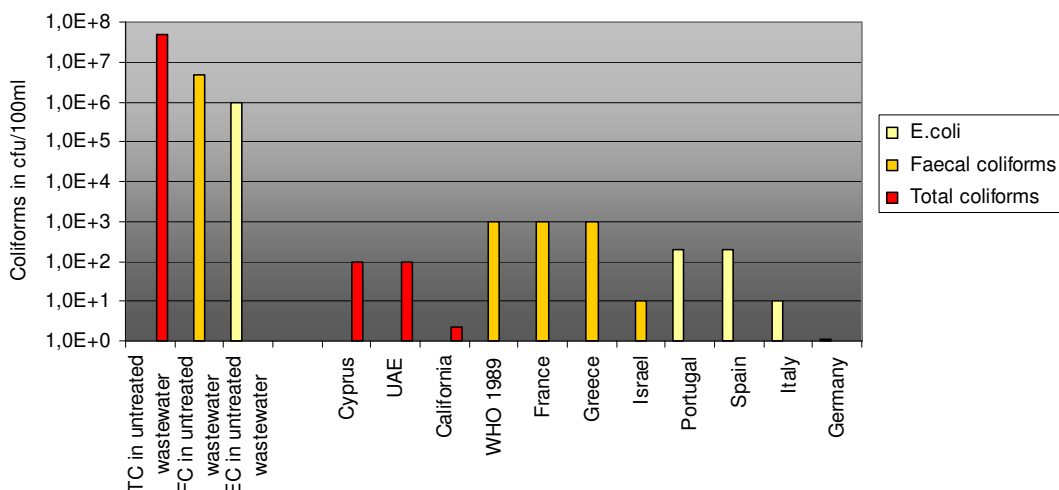


Figure 3 Standards for coliforms in irrigation water for unrestricted use in different countries (partly adopted from Bixio and Wintgens, 2006, and U.S. EPA, 2004) in comparison with average coliform concentrations in untreated wastewater (among others U.S. EPA (1986) and own measurements)

Compared with typical concentrations of pond effluent (e.g. in figure 1 and 2 for German plants) it is obvious that appropriate standards are not reachable only by pond treatment. This results in the need for supplementary disinfection of pond effluents by subsequent disinfection systems.

Comparison of subsequent disinfection methods

As for wastewater in general, there exist a number of options for disinfection of pond effluents. The most common ones are chlorine (Cl_2), chlorine dioxide (ClO_2), sodium hypochlorite (NaOCl), ozone (O_3), ultraviolet (UV) light, peracetic acid (PAA) and membrane filtration.

Table 1 Comparison of supplementary disinfection methods for pond effluent (partly from Bixio and Wintgens, 2006, and Rudolph, 2006)

Criteria	Cl ₂ / ClO ₂	NaOCl	UV	Ozone	PAA	Membrane
Safety	low	moderate	high	moderate	low	high
Bactericidal action	high	high	high	high	high	high
Virucidal action	moderate	moderate	moderate	mod. - high	moderate	mod. - high
Protozoa removal	low	low	high	high	low	high
Bacterial-regrowth	low	low	mod. - high	low	high	low
Residual toxicity	high	high	low	moderate	low	low
By-products	high	high	none	low	none	none
Operability	high	high	high	high	high	high
Full-scale experience	high	moderate	high	moderate	low	high
Operating costs	low	low	low	moderate	low	mod. - high
Investment costs	moderate	moderate	moderate	high	moderate	high

A comparison of the mentioned methods is displayed in table 1. Generally, the most inexpensive way to reduce pathogens is still chlorination, well experienced from potable water disinfection. But this method has evident disadvantages in terms of dangerous handling and formation of harmful chlorinated organic disinfection by-products, when reacting with wastewater constituents. Ozone and membrane systems both are characterised by comparatively difficult handling as they need specific technical devices. Particular membrane technology as the latest disinfection approach is still costly compared with the other methods and demands a high competence of the O&M staff, which especially conflicts with the advantage of limited operational efforts for pond plants.

Taking all aspects into consideration, UV irradiation has been identified as most appropriate disinfection method for pond effluents. It is a relatively simple method regarding operation and maintenance with moderate investment and operational expenditures.

Disinfection of wastewater ponds' effluent by UV irradiation

Because of the above mentioned advantages, nowadays the use of UV light as reclaimed water disinfectant has numerous applications, especially at small and medium scale facilities (Bixio and Wintgens, 2006). But so far, it also has been known as problematic in terms of high solid contents of pond effluents. Additionally, reactivation effects of pathogens like photo-reactivation and dark repair has to be reflected, which makes effluent disinfected by UV light only limited appropriate for long-term storage (photo-reactivation could be a problem, especially when using low-pressure UV lamps and if a minimum UV dose cannot be ensured).

Especially regarding limitations for UV disinfection caused by poor effluent quality, there is still little knowledge as literature reviews showed. Therefore, the authors carried out own tests with UV disinfection of pond effluents.

The performance of the germicidal effect of UV radiation generally depends on the UV dose applied to the pathogens (UV dose [J/m²] = Intensity or irradiance [W/m²] x Exposure time [s]), which is mainly influenced by the quality of the irradiated water. As UV light interacts with materials contained in the irradiated liquid through absorption, reflection, refraction and scattering, the remaining UV dose available for pathogen inactivation is very much depending on the water constituents. There are three key parameters often used to describe the influence of water constituents on the disinfection efficiency of UV irradiation:

- turbidity, stated in nephelometric turbidity units (NTU),
- suspended solids content (SS) and
- UV transmittance (or vice versa the UV absorption), as the share of light passing through a water sample over a specified distance, e.g. 1 cm.

Usually, for optimal UV-dose efficacy suspended solids contents of 5 mg SS/l, turbidity levels of 5 NTU and transmittance values above 60 % are recommended (Bixio and Wintgens, 2006).

Different authors researched the dependence between UV efficiency and turbidity respectively SS as well as particle size related aspects. In figures 4a and 4b examples of measurements with turbidity and SS are displayed. It is for sure that increased levels of turbidity and SS reduce the efficiency of UV light disinfection (a clear negative correlation, as shown in the figures), but until now, there could no general mathematically describable dependence be verified between UV efficiency and turbidity or SS, as the results were always been found to be highly site-specific. Therefore, when assessing water quality, UV transmittance (or UV absorbance) is the preferable parameter to clearly describe the behaviour of UV light in treated water.

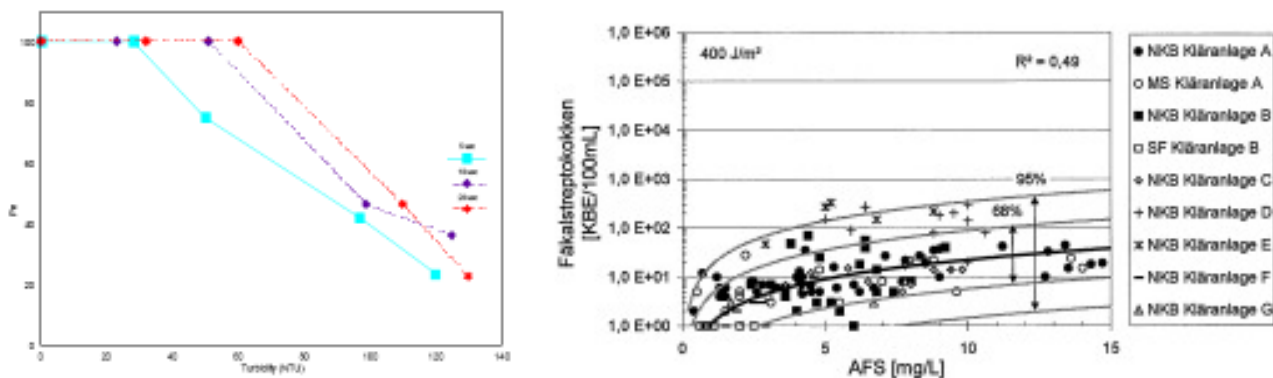


Figure 4a and 4b Examples for tests about the relationship between inactivation of *S. faecalis* with turbidity (Mbuya et al., 2003) and SS (= AFS) for different WWTPs (Schöler, 2004)

Wastewater treatment by ponds has a significant effect on the UV transmission values, as displayed in figure 5 with a comparison of influents and effluents of different pond systems in Germany. The range of UV transmittance is only slightly worse than that of typical secondarily treated WWTP effluents with about 45 to 70 % (Rudolph et al., 1992). For regions with high insolation, it has to be taken into consideration that, depending on pond operation, effluents might be loaded with algae, which may have a negative influence on the transmission values.

Wastewater treatment in ponds cannot ensure transmittance values over 80 % like fully purified secondary effluents after specific filtration for optimal UV disinfection efficiency. But laboratory scale tests with UV disinfection of pond-treated wastewater have shown that even for lower effluent qualities pathogen reductions, adequate for agricultural reuse, are feasible with cost-effective doses. As illustrated in figure 6 by examples of typical average dose-response curves from UV disinfection tests, the reduction rate for pond effluents can be found between mechanically and advanced biologically treated wastewater.

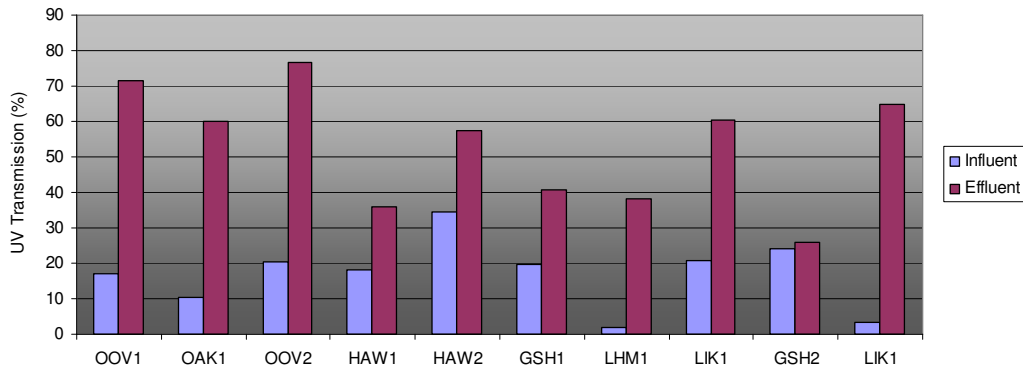


Figure 5 Exemplary comparison of UV transmittance (in %; for wavelength of 254 nm) of influents and effluents of different pond plants in Germany

For example, with UV doses of 500 J/m^2 ($= 50 \text{ mJ/cm}^2$), which are typically applied with filtrated secondary effluent to achieve a target of 10 total coliforms per 100 ml for unrestricted irrigation, a reduction to about 100 coliforms / 100 ml may be achieved with pond effluent. This means, the reduction is 1 log unit lower than with fully purified effluent. To ensure a reduction less than 10 coliforms / 100 ml, a UV dose of about 1500 J/m^2 ($= 150 \text{ mJ/cm}^2$) is necessary, so the dose has to be about three times higher, which is still a reliable value regarding energy consumption of the UV lamps.

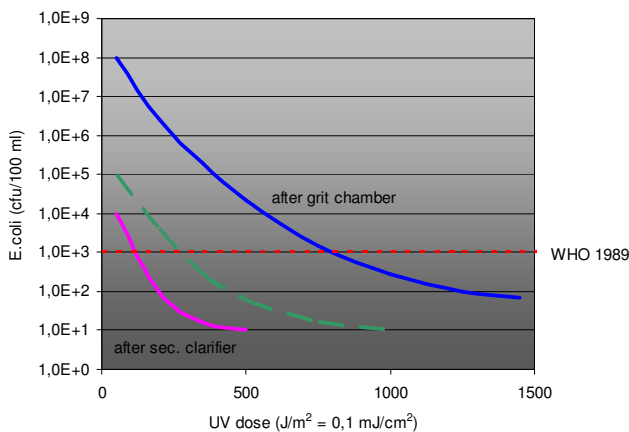


Figure 6 UV dose-response curves for different treated wastewater (laboratory tests were conducted with a collimated beam device according to U.S. EPA, 2002)

In total, the lab results being on the desk show that UV irradiation is technically possible and economically reasonable for disinfection of pond effluents to be reused, even without extended further purification.

Removal of helminth eggs

UV irradiation does not ensure adequate inactivation of helminth eggs. In fact, e.g. *Ascaris* eggs have proved to be the most UV-resistant water-related pathogen identified to date. Showing at UV doses of up to 1000 J/m^2 ($= 100 \text{ mJ/cm}^2$), which are used for typical UV applications, the inactivation may be less than 1 log unit (Brownell and Nelson, 2006). But applied as subsequent disinfection following a pre-treatment through ponds, this effect plays only a minor role, as pond plants provide high removal efficiencies of helminths up to 100 % by sedimentation and accumulation in the sludge (Sperling et al., 2003). By this, ponds are a most advantageous combination for UV disinfection, closing UV efficiency gap regarding helminth eggs removal.

Economic aspects

There are several kinds of sophisticated wastewater purification systems available, but most of them are too costly to provide feasible solutions for sewage treatment, particularly in rural areas or growing developing countries (Grau, 1994). Due to relatively low construction and operation costs, pond plants offer opportunities for low-cost treatment of municipal sewage. As comparisons of investment expenditures show, especially in rural areas the specific disadvantage of pond plants, the high place requirement per p.e., plays a minor role, because the prices for land are lower in comparison to that for necessary equipment of technical purification plants. Subsequent disinfection by UV applications requires investment costs to be found somewhere in the middle of costs for comparable disinfection methods, highly dependent from system scale and effluent quality. Summed up, the investment costs of ponds plus subsequent UV disinfection show values below the average of other treatment facilities with similar effluent quality.

As shown by above described test results, the subsequent disinfection of pond effluent for reuse purposes requires UV doses clearly adequate for practical applications. Depending on the required pathogen reduction, the energy consumption of the UV lamps, as the main part of the O&M efforts, is still in a feasible range, even without further pre-treatment. As the operational expenditures of pond plants are generally significantly lower than that of technical systems with higher requirements regarding maintenance and personnel competence, the arrangement of ponds with UV disinfection results in economically reliable cost levels.

Although tangible figures are difficult to name, as they are very much depending on several site-specific conditions, it can be stated that in total the combination of the near-to-nature treatment in ponds with subsequent disinfection by UV irradiation appears as an economically very promising solution.

CONCLUSIONS

Through their ability to significantly reduce pathogen levels of sewage, pond systems are a preferable part of treatment concepts for reuse of sewage for example as irrigation water in agriculture. But as effluent is seasonally variable and regularly does not fulfil relevant microbiological quality standards for wastewater reuse, there is a need for supplementary treatment of pond effluents, which means the use of subsequent disinfection systems. Among other options, UV irradiation has been identified as most appropriate disinfection method for pond effluents. Although UV irradiation has so far been applied only for highly purified effluents, investigations with different pond effluents show UV disinfection to be a technical reliable disinfection mean, even without extended pre-treatment. In addition, moderate construction and operation costs in combination with limited demands regarding staff competence make the arrangement of ponds systems with subsequent UV irradiation to be an interesting option of efficient sewage treatment for reuse purposes, especially in rural regions and non-industrialized countries. Treatment of wastewater for reuse purposes by pond systems with effluent disinfection by UV irradiation presents itself as an excellent example for the efficient combination of natural reclamation and high-tech (but easy to handle) technology.

ACKNOWLEDGEMENT

Most commendable, the investigations about UV disinfection of pond effluents have been granted by the German Federal Ministry of Research (BMBF, project no. 02WD0543) and additionally supported by WEDECO AG (Germany).

REFERENCES

- Bixio, D.; Wintgens, T. (2006). *Water reuse system management manual*. AQUAREC, EVK1-CT-2002-00130, May 2006, European Commission, Edited by Bixio, D. and Wintgens, T., European Communities Publishing Services, ISBN: 92-79-01934-1
- Brownell S.A.; Nelson, K.L. (2006). *Inactivation of Single-celled Ascaris suum eggs by low-pressure UV radiation*. Applied and Environm. Microbiology, vol. 72, no. 3, pp. 2178-2184
- Davies-Colley, R. (2005). Pond disinfection. In: *Pond treatment technology*. Shilton, A. (Ed.), IWA Publishing, London, UK, pp. 100-136
- Grau, P. (1994). *What's next*. Water Quality International, no. 4, pp. 29-32
- Johnson, M.; Mara, D.D. (2005). Aerated rock filters for enhanced nitrogen and faecal coliform removal from facultative waste stabilization pond effluents. *Water Science and Technology*, vol. 51, no. 12, pp. 99-102
- Mbuya, O.S.; Mankazana, J.B.; Latinwo, L.K.; Gardner, C.S. (2003). *The Use of Ultraviolet Light to Disinfect Drinking Water - An Alternative to Chlorination*. Presentation, Center for Water Quality, Florida A&M University Tallahassee, 2003. <http://www.usawaterquality.org/conferences/2003/presentations/MbuyaUVLight.pdf> (accessed June 2007)
- Schöler, A. (2003). *Untersuchungen zum Einfluss der suspendierten Stoffen auf die UV-Desinfektion von Kläranlagenabläufen (Studies into the influence of suspended solids on UV disinfection of Sewage works effluents)*. KA, vol. 51, no. 4, April 2003, pp. 382-389
- Rudolph, K.-U.; Nelle, T.; Oberg, C. (1992). *Desinfection of wastewater by ultraviolet-irradiation and ozonation*. Proceedings, Joint German-Israeli Workshop on Water Technology, BMFT, Kernforschungszentrum Karlsruhe, 15.-16. Sept. 1992, Karlsruhe, Germany
- Rudolph, K.-U. (2006). *Decentralised wastewater stations*. Presentation on 1st WEDECO Technological Symposium, 27 April 2006, Bielefeld, Germany
- Shilton, A.N.; Mara, D.D. (2005). *CFD modelling of baffles for optimizing tropical waste stabilization pond systems*. *Water Science and Technology*, vol. 51, no. 12, pp. 103-106
- Sperling, M.; Chernicharo, C.A.L.; Soares, A.M.E.; Zerbini, A.M. (2003). *Evaluation and modelling of helminth eggs removal in baffled and unbaffled ponds treating anaerobic effluent*. *Water Science and Technology*, vol. 48, no. 2, pp. 113-120
- U.S. Environmental Protection Agency (1986). *Design Manual - Municipal Wastewater Disinfection*. EPA/625/1-86/021, 1986, United States Environmental Protection Agency (U.S. EPA), Washington, USA
- U.S. Environmental Protection Agency (2002). *Ultraviolet Disinfection Guidance Manual*. Proposal Draft June 2003, EPA 815-D-03-007, United States Environmental Protection Agency (U.S. EPA), Washington, USA
- U.S. Environmental Protection Agency (2004). *Guidelines for Water Reuse*. EPA/625/R-04/108, Sept. 2004, Produced by Camp Dresser & McKee Inc. for U.S. Environmental Protection Agency (U.S. EPA), Washington, USA