Iranian J Publ Health, Vol. 38, No.4, 2009, pp.1-9 **Original Article**

Improving Efficiency of Disinfection of Water for Non-contact UV System

*AR Mesdaghinia [1], F Vaezi [2], *E Dehghanifard [2], AH Mahvi [1], K Naddafi [2], M Alimohammadi [2]*

[1] *Center for Environmental Research, Tehran University of Medical Sciences, Iran*
[2] *Dept. of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Iran*

(Received 3 Jan 2009; accepted 19 Jul 2009)

Abstract

Background: The goal was to upgrade and/or uprate the traditional non-contact array by producing few modifications in the configuration of this model in order to maximize light receiving of water from the UV lamp and a better disinfection.
Methods: An innovative non-contact model was made with a design based on irradiation of water, which was flowing as two thin waterfalls around a UV lamp in order to have direct germicidal rays from all positions of the lamp. By this water circulating and traditional water flow in an ordinary canal below the lamp, UV light would reach every drop of water effectively. Another model which had been studied was a simple stair type design in which a bare lamp was fixed over the shiny steel steps. Results of water disinfection in two flow rates of 12 and 24 L/min were compared with traditional design at exactly similar conditions.
Results: Disinfection in this new model produced more reduction in fecal coliforms concentration than the traditional array and the inactivation efficiency was specified to be 3.65 log reduction compared to 2.93 log, in the turbidity of 0.5 NTU. Besides, this new model was quite capable in disinfection of water with high turbidities up to 20 NTU.
Conclusion: The reduction in disinfection efficiency at higher flow rates for new model was much less than traditional array. Results of water disinfection in the simple stair type were not wonderful and even it was less satisfactory compared to traditional model. The reason is that the flow of water was not set parallel to the length of the lamp.

Keywords: *Ultraviolet radiation, Water disinfection, Non-contact UV system, Waterfall model, Stair type model*

Introduction

Disinfection is the most significant barrier to the transmission of waterborne diseases and thus it is of great importance to the public health. There are no exceptions to the requirement that all water sources had to be disinfected (1). Water disinfection by chlorine has many advantages but the facts that few parasitic cysts are highly resistant to chlorine and formation of dangerous DBPs (disinfection byproducts) have resulted in development of alternative disinfectants (2). In the case of ozone which is highly effective against all types of microorganisms, again toxic oxidations by products like bromates are formed in water. Besides, complexity of ozonation system and high O/M costs have resulted in limited use of ozone (2, 3).
Ultraviolet (UV) light has been used for many decades in disinfection of drinking water supplies worldwide. In North America, the use of UV was more widespread for wastewater disinfection in the last quarter-century, and only more recently has UV been considered for drinking water disinfection (4, 5). New researches have demonstrated that UV disinfection is capable of cost-effectively inactivating *Giardia* and *Cryptosporidium* oocysts (6, 7). Concurrently, new research has shown that much higher UV doses are needed for inactivation of adenovirus compared to other microbes (1, 8). However, the discovery of UV inactivation of those pathogens that other disinfectants can not kill them at conventional doses, points the way to a remarkable use of UV for drinking water treatment and a number of facilities including the largest water treatment plant in the world in New York have selected this technology (9, 10).

UV reaction chambers may be designed in two dif-

*Corresponding author: Tel: +98 912 6784800; Fax: +98 21 88950188, E-mail: dehghanifard@yahoo.com

ferent arrays: non-contact and submerged (4, 10). The non-contact array in which UV lamp is oriented above the free surface of flowing water has the advantage of simplicity of operation and maintenance. Besides, the costs of installation, operation and maintenance are much less than submerged systems, mainly because there would be no need to use expensive quartz sleeves (10, 11). In fact, this UV system is more favorable than all other water disinfection systems in terms of cost, labor and the need for trained personnel for operation and maintenance, thus non-contact array is more often adopted for water disinfection especially in developing countries (11). Compared to submerged arrays, however the disinfection efficiency is less and this drawback has confined the use of this special array for all communities (11, 12).

The goal of our project was to upgrade and/or uprate the traditional non-contact array by producing few modifications in the configuration of this model in order to maximize light receiving of water from the UV lamp and a better disinfection.

Materials and Methods

Water irradiation units

For this study, two independent non-contact units had been designed for irradiation of water and results of water disinfection in these units have been compared with traditional model of UV irradiation which is approved by WHO (11, 12). In traditional model as shown in Fig. 1, direct irradiation of water by the lamp is possible from solely an unimportant percentage of the lamp surface, which is about 50%, and a definite distance of 4 cm is adjusted between the UV lamp and the bottom of the underneath tray in which water can flow. The depth of water flow in this tray is adjusted to be not more than 1 cm.

For this project, innovative models were designed on the base of flowing water in a thin film stream and receiving more direct light from the UV lamp. In the first innovative model as shown in Fig. 2, water is flowed as two falls by overflowing water from the upper tray of the unit. The lamp is placed between these two falls and water is finally flowed beneath the lamp. This apparatus is made from polished steel of 2 mm thickness and an aluminum reflector is also used. Again, the water depth in the lower tray is adjusted to be not more than 1 cm. The UV lamp was installed beneath the upper tray. The disinfection experiments in this study had been accomplished mainly at the distance of 3 cm of the lamp from the water surface.

In the second unit of water disinfection as can be seen in Fig. 3, water was flowed down on the stairs, which had shiny surfaces, and a UV lamp was just inserted nearest to the two sides of the step. The width of this step was equal to the effective length of UV lamp which was about 85% of the total lamp length (35 cm).

The two water flow rates selected for disinfection tests were 0.2 and 0.4 L/s (12 and 24 L/min), thus the contact time had been maintained in the range recommended for UV irradiation (about 5 to 10 second for this study).

Specifications of UV lamps

The 50 cm long lamp used in disinfection units was 25-Watt low-pressure (LP) mercury vapor UV lamp, made by Osram Company. Table 1 shows the specifications of this lamp. It should be explained that the new lamps had worked for their burn-in period (100 h before starting the experiments and at the beginning of each test, the lamps had been used after 5 min which is the required time for initial warming.

Characteristics of water samples

Water samples were all gathered from the chanat (subterranean canal) of Tehran University and the required microbial population was supplied by addition of 10 mL/L of typical primary wastewater (after settling) to this water sample. In disinfection of water by UV light, the negative impacts of turbidity and iron in the water quality matrix were well documented and so these interfering parameters plus the value of UV transmittance (UVT of water) was being checked for all water samples (Table 2). Measuring UVT is important, since this parameter shows the overall negative impacts of suspended and dissolved solids of a water sample, and in fact the UV demand of water is depended to the value of its UVT (4).

Disinfection tests and analyses

Fecal coliform is widely preferred as an index of fecal contamination of drinking water. Thus, it has been used as an indicator of UV disinfection effectiveness. For this project, numeration of these coliforms in water samples leaving the disinfection units has been accomplished by membrane filtration method (13).

The effectiveness of disinfection has been determined by Chick-Watson relationship (14):

$Log\ N/N_0 = -\ kIt$ (Equation 1)

Where N_0 is the concentration of viable microorganisms before disinfection, N is the concentration after disinfection and N/N_0 is survived ratio. The UV radiation intensity (I) is measured as miliwatt per square centimeter and the UV dose (intensity×time) in mWs/cm^2. The range of UV dose for drinking water disinfection should be between 16-40 mWs/cm^2 and the exact amount is depended on the amount of UVT of water. According to equation 1, it should be noted that disinfectant doses equal to 99% inactivation (or 10% survival) would cause two logarithms reduction in the number of microorganisms.

Two synthetic turbid water samples having turbidities of 10 and 20 NTU had been examined for disinfection in our UV models. Preparation of high turbidity water samples for determination of maximum allowable turbidity level for disinfection in each model had been accomplished by mixing definite amounts of hydrazine sulphate and hexamethylen amin as described in Standard Methods (13). All the disinfection tests have been repeated twice and calculations have been performed on the geometric mean values.

Results

Results of water samples analyses for the main physicochemical parameters, which could affect disinfection efficiency, can be seen in Table 2. The temperature of water at the time of disinfection tests had been about 23 ^oC. Although electro conductivity of water samples were relatively high, total Fe concentrations of water samples were less than 1 mg/L, so could not affect UV disinfection process (6).

Comparisons between colony counts of fecal coliforms remained after irradiation in UV disinfection units and equivalent log removals in both flows of 0.2 and 0.4 L/s are shown in Fig. 4 and 5. As can be seen, logarithmic scale was used for better demonstrating colony counts of fecal coliforms. Finally, Fig. 6 shows the removal of fecal coliforms by UV irradiation in the waterfall model as a function of water turbidity.

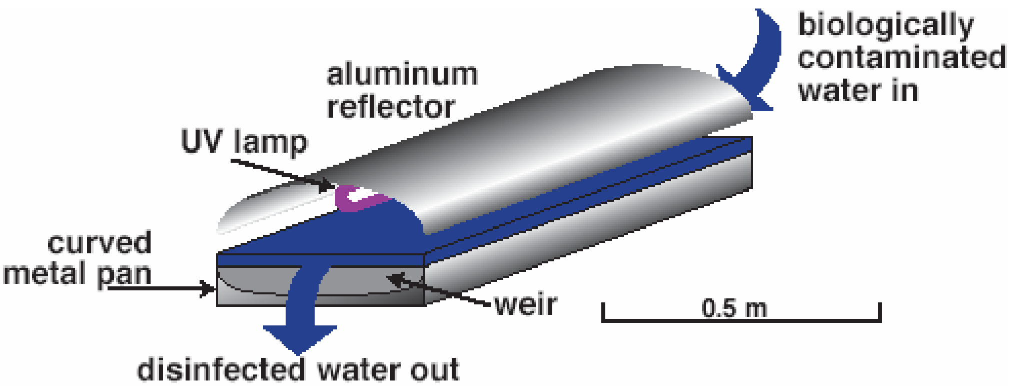


Fig. 1: Simplified schematic of the traditional non-contact model for UV disinfection of water

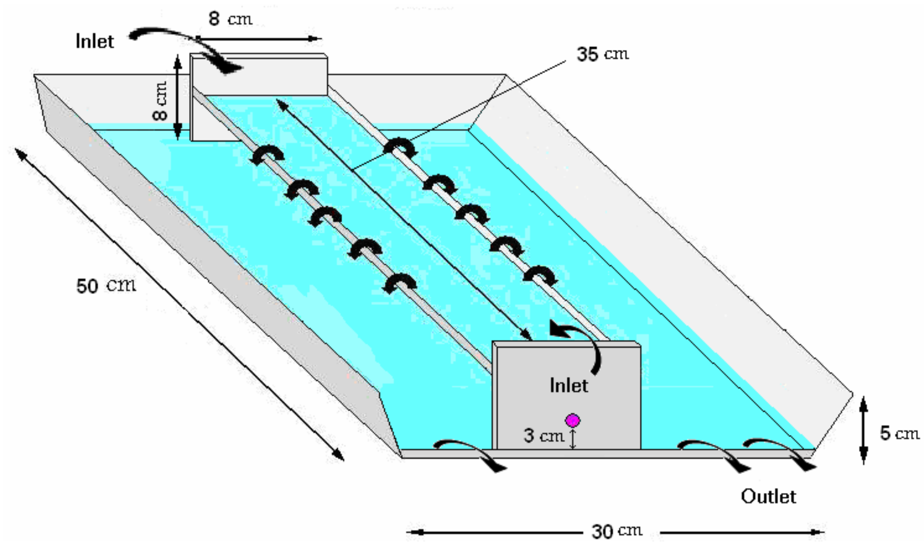


Fig. 2: Waterfall model designed for UV disinfection with lamp outside the water (A lamp is inserted beneath the above tray between two falls)

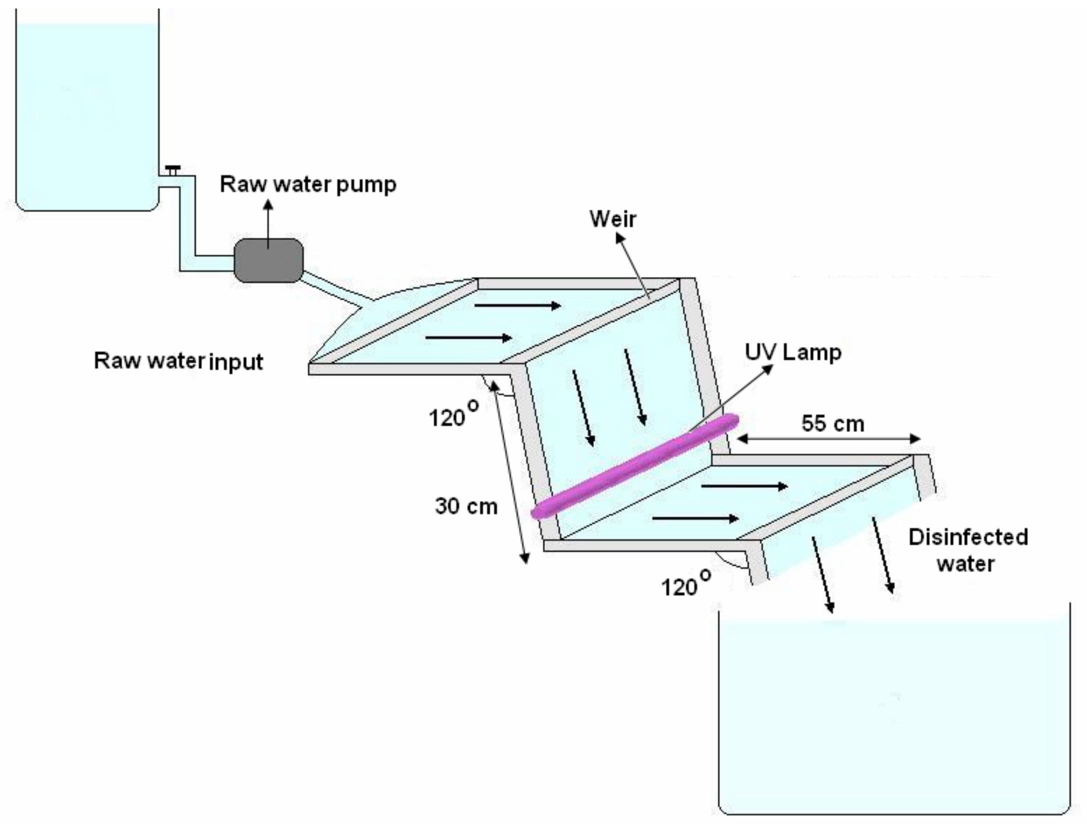


Fig. 3: Stair type model designed for UV disinfection with lamp outside the water

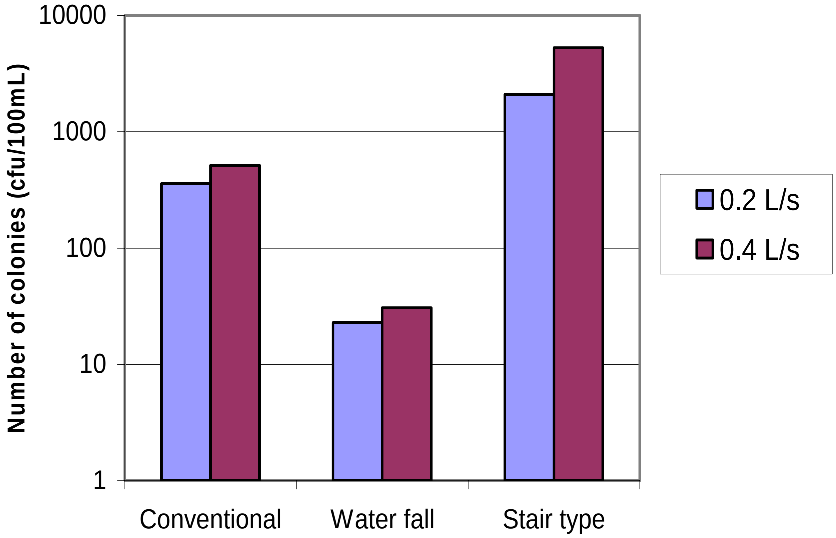
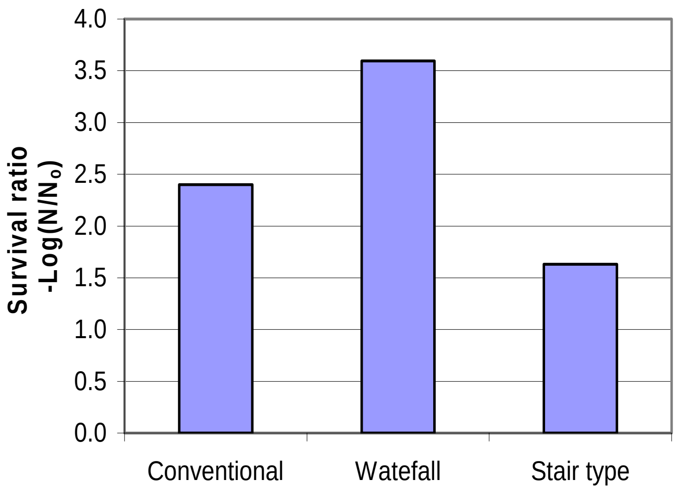
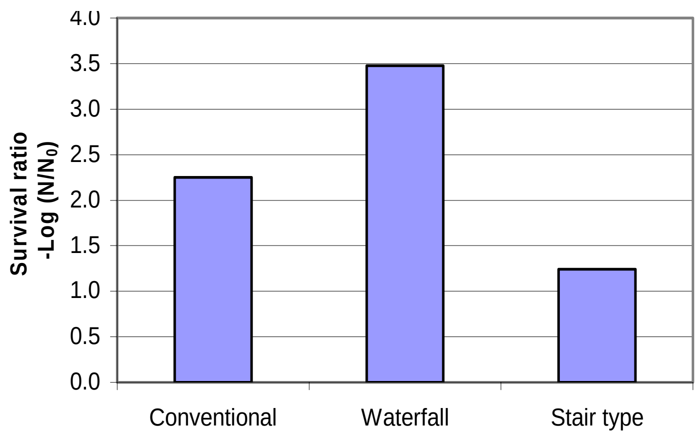


Fig. 4: Effect of irradiation of water samples in three non-contact models on survival of fecal coliforms in different water flows (0.2 and 0.4 L/s)



(a)



(b)

Fig. 5: Comparison between log removals of fecal coliforms after water disinfection in three non-contact models of irradiation by UV lamp [(a) for flow of 0.2 L/s and (b) for flow of 0.4 L/s]

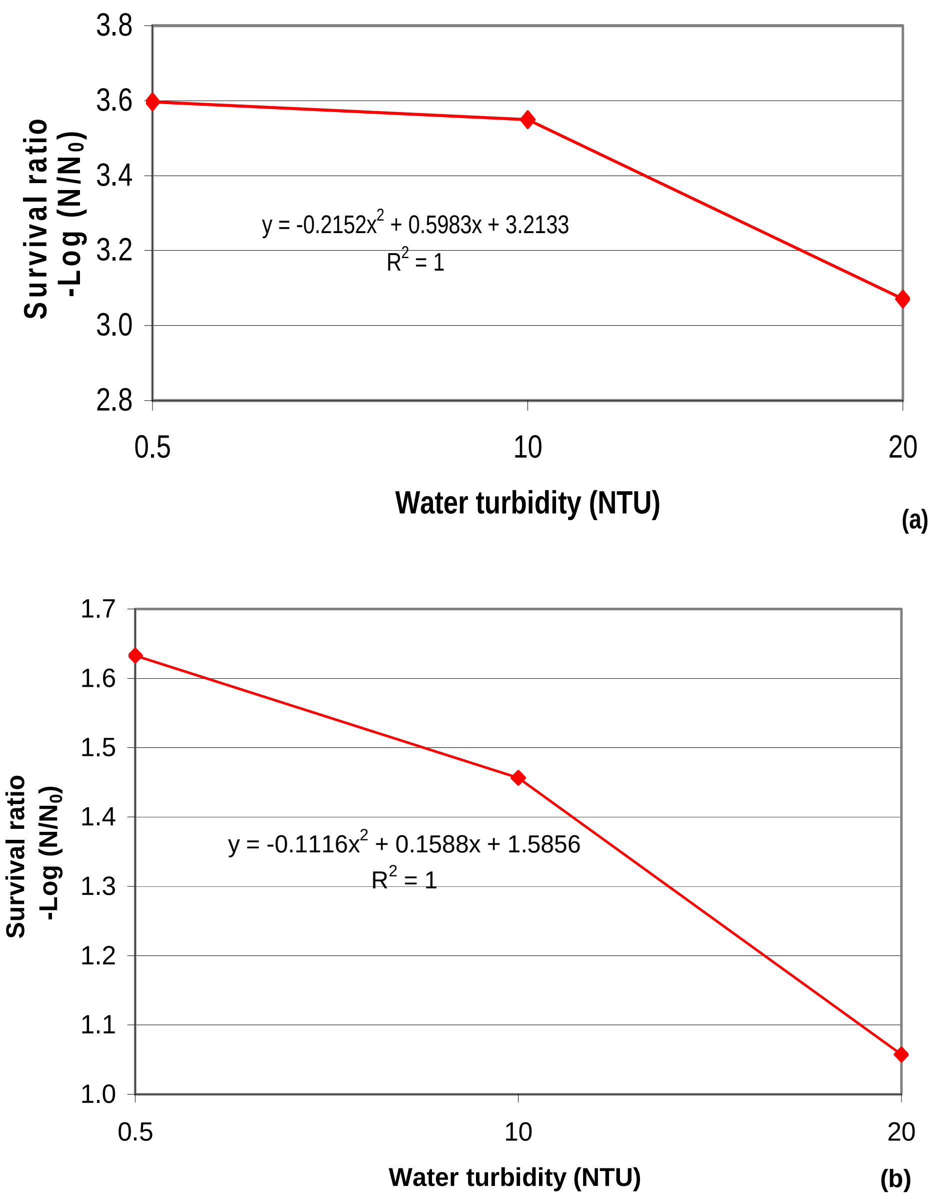


Fig. 6: Log removals of fecal coliforms obtained by disinfection of water samples with different turbidities in two innovative non-contact models of UV irradiation in the flow rate of 0.2 L/s [(a) Waterfall model (b) Stair type model]

Table 1: Specifications of low pressure UV lamp*

Lamp type	Main voltages (V)	Wattage (W)	Nominal current (A)	UVA radiation power 254nm (W)	Total length (mm)	Usable length (mm)	Total width (mm)
Osram-HNS 25 W OFR	230	25	0.6	6.9	436	351	25.5

*Data taken from Osram Co.

Table 2: Qualitative characteristics of water samples of subterranean canal of Tehran University

Sample \ Parameters	Total Fe (mg/L)	μs/cm (EC)	Turbidity (NTU)	UVT (%)
1	0.43	935	0.5	97
2	0.57	1067	0.5	99
3	0.49	993	0.5	99

Discussion

Non-contact array of water irradiation by UV is a common model for water disinfection in many developing countries. Although this design (Fig. 1) has the advantages of simplicity and low cost over the submerged arrays, the lesser disinfection efficiency is said to be a disadvantage. As reported by WHO, the maximum water flow which could be disinfected by this model is 30 liters per minute when a single 40 Watt LP lamp is used and the inactivation efficiency obtained is reported to be about 2 log removal of fecal coliforms, which is normally sufficient when groundwaters with low microbiological counts are treated. In the present research, 25 W lamp was used in this model and innovative units. The length of this lamp is about half the length of 40W lamp, thus disinfection systems installed for this work were less bulky, and it was possible to place them side by side in the laboratory for a better comparison.

Although the lamp used was shorter in length, direct irradiation of water in two innovative models had been accomplished by more than 50% of the total surface of the lamp. This view is more apparent in waterfall model (Fig. 2) since each molecule of water treated in this model may receive direct irradiation from about three forth (75%) of the lamp surface. Moreover, the water had flowed as two thin film falls (with about 1 mm thickness), thus the effect of irradiation could be increased even in low contact time. Increased receiving of direct irradiation from the lamp had resulted in much better disinfection of water in this special model compared to traditional non-contact array and this superiority is well described in Fig. 5. As shown, the inactivation efficiency was specified to be 3.65 log removal compared to 2.93 log removal of fecal coliforms achievable in traditional model at a similar turbidity of 0.5 NTU. Furthermore, as shown in Fig. 6(a), our system was quite capable in good disinfection of high turbid waters (with 20 NTU turbidity), whereas the maximum turbidity of water which has been claimed to be safe for a good disinfection in traditional model is less than 10 NTU. Indeed, the disinfection efficiency obtained for treatment of 20 NTU water in waterfall model was excellent (99.91% or 3 log fecal coliforms reduction). The equivalent UVT of this turbid water was 85%. It is important to remember that not only suspended solids but also some dissolved solids may reduce the UVT of water and interfere with UV disinfection. For this reason, groundwaters having high concentrations of iron would not be well disinfected in traditional model just like surface waters which are turbid. It is also noteworthy to say that as shown in Fig. 6(a), the reduction in disinfection efficiency of water for our model was less than that occurred in traditional system when the rate of water flow had been doubled. This means that disinfection of higher flows of water in waterfall model is feasible. Note that disinfection efficiencies obtained in flow rates of 0.2 and 0.4 L/s were 99.97% and 99.96% for waterfall model and 99.6% and 99.4% for traditional model. In other words, obtaining 3log disinfection was still possible by this new model.

In the case of stair type model (Fig. 3), the objective was again designing a disinfection unit by which receiving more than 50% of direct irradiation from the lamp could become possible. This model was designed similar to simple thin-film air-water contactors which are available in many water treatment plants for water aeration. In fact, by inserting a UV lamp over these stairs, we intended to provide both advantages of disinfection and aeration of water in a single unit. Nevertheless, the efficiency of this model in water disinfection was not very well and the maximum fecal coliforms removal as shown in Fig. 5 was 97.66% (about 1.6 log removal) which is less than traditional array, so this model should not be accepted as the main barrier for control of microorganisms in a community. The explanation is that in contrast to traditional array, the lamp in stair type model was not parallel to the flow of water.

Waterfall Model Compared to Other Water Disinfection Techniques

Since it was determined that UV treatment can provide an effective barrier to all types of pathogenic microorganisms, it has been targeted by many communities for drinking water disinfection. Limited studies however have been conducted for designing better irradiation chambers. We should refer to the most out-standing trial which is belonged to Atlantium Co. In 2005, this Israeli company developed an entirely new technology for non-contact irradiation of water by UV lamps. It used a big quartz tube as the main UV reactor and bombards the flowing water with homogenous dosages of radiation from medium pressure-high intensity UV lamps that were installed outside the water. According to Atlantium engineers, this system was able to inactivate waterborne organisms four order of magnitude more effectively than other existing systems and this superiority was combined with the ability to disinfect about 3300 L/min while consuming only 2.5 kW/h (15). Although this unique configuration which is called hydro-optic disinfection (HOD) could be considered even more efficient than a few submerged arrays, it may not be regarded as a suitable choice for developing countries because in comparison to less efficient traditional non-contact array it seems sophisticated. In fact, traditional non-contact array of water irradiation by LP lamps is very less efficient, but it has remained the selected model in developing countries, because of its low cost and simplicity.

This study indicates that waterfall model designed as a modern non-contact array has also the benefits of traditional model, namely it requires little space, little O/M and operator attention, and no on-site storage or use of potentially harmful chemicals compared with other disinfection technologies. Besides, although relatively more sophisticated than traditional UV array it is relatively easy to install.

Concluding Remarks

The authors conclude and recommend the following:

- Better results of water disinfection are expected by use of our waterfall model even in cases of increasing the turbidity and/or the UVT of water. In other words, it obtains good disinfection even for poor quality water sources.
- Better disinfection than traditional array is also expected in times of increasing the flow rate of water.
- Preliminary unit-cost estimates indicated that water fall model is more expensive than the traditional array for initial installation. However, progress is expected in analysis of costs for small system applications.

Finally, we recommend our cost-effective solution for supplying safe drinking water especially for developing countries and we hope that the findings of this study will encourage a variety of community systems to use or substitute their innovative model in order to have a better disinfection of water, since it proves to be more efficient than the traditional array.

Acknowledgements

This paper is based on the M.Sc. thesis of Mr Emad Dehghanifard carried out at the Dept. of Environmental Health Engineering of the School of Public Health, and the financial support was provided by Vice-chancellorship for Research Affairs of Tehran University of Medical Sciences (project No.5143). The authors declare that they have no conflicts of interest.

References

1. Lingireddy S (2002). *Control of Microorganisms in Drinking Water*. ASCE Inc, pp. 213-34.
2. Carins W, Wright HB (2000). *Is UV Disinfection the Best Available Technology?* IWA Yearbook.

3. Patourel GL, Smith F (2003). Implementation of Primary UV Disinfection at the Mannheim Water Treatment Plant. *J Am Water Work Assoc*, 95(10): 57-61.
4. AWWA (2005). *Water Treatment Plant Design*. 4th ed. McGraw Hill. New York.
5. Oppenlander T (2003). *Photochemical Purification of Water and Air*, VCH verlag Inc.
6. Masschelein WJ (2002). *Ultraviolet Light in Water and Wastewater Sanitation*. Lewis Pub.
7. McGuire MJ (2006). Eight Revolutions in the History of US Drinking Water Disinfection. *J Am Water Work Assoc*. 98(3): 123-149.
8. Yates MV, Malley J, Rochelle P, Hoffman R (2006). Effect of Adenovirus Resistance on UV Disinfection Requirements. *J Am Water Work Assoc*. 98(6):93-105.
9. Stedman L (2004). A Unanimous Vote of Confidence. *Water*, 21:31-32.
10. Carollo Engineers (2001). *Practical Aspects of UV Disinfection*. AWWA Pub.
11. Cotruvo JA, Craun GF, Hearne N (1999). *Providing Safe Drinking Water for Small Communities*. NSF, WHO, PAHO. Lewis Pub.
12. OECD, WHO (2003). *Assessing Microbial Safety of Drinking Water*. IWA pub: 47-64.
13. AWWA, APHA, WEF (2005). *Standard Methods for the Examination of Water and Wastewater*. 21st ed. American Public Health Association Inc.
14. Metcalf & Eddy (2003). *Wastewater Engineering, Treatment and Reuse*. 4th ed, McGraw Hill. New York.
15. http://www.isracast.com/articles/52.aspx, (Aug. 2005), new technology produces safer water.