THE PROMOTION UV DISINFECTION EFFICIENCY IN TREATING SECONDARY EFFLUENT BY EXPANDEDPERLITE FILTER

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Introduction

Wastewater treatment plants (WTPs) remove primarily the organic matters and in some WTPs, nitrogen and phosphorus. Conventional WTPs reduce the numbers of coliforms, but effluents still contain high numbers of fecal microorganisms [1, 2]. Wastewater treatment plants should minimize the discharge of pathogens to environment, to limit the infection cycles of pathogenic microorganisms. Most countries follow the World Health Organization (WHO) and United States

Environmental Protection Agency (US-EPA) standards for irrigation of food that can be eaten raw and landscape irrigation. In addition, many European countries are adopting themselves to microbial guidelines in the European Union (EU) bathing water directive (Table 1).

Table 1. Coliform limit values according to different authorities and laws [3-5].

	WHO(a)	US-EPA(b,c)	EU(d)	Turkey(e)	Greece(a)	Cyprus(a)
Fecal coliform /100 ml	<1000	< 200	< 100	< 200	< 200	< 250
Total coliform /100 ml	-	-	< 500	< 1000		

(a) Limit value for restricted irrigation of crops likely to be eaten uncooked, sports fields and public parks.

(b) Limit value for domestic wastewater being discharged standards in to lakes

(c) Limit value for agricultural reuse after secondary disinfection.

(d) Limit value for quality of bathing water.

(e) Limit values for recreational use and deep sea discharge.

As counts of indicator organisms such as fecal coliforms are usually not reduced to tolerable levels in a conventional treatment process, additional subsequent disinfection step is unavoidable. Types of disinfection techniques are various, which include physical, chemical and biological methods [6].

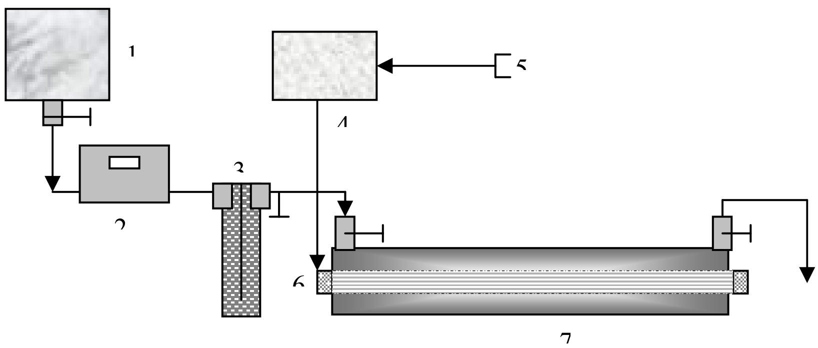
UV disinfection is characterized by a short contact time and a more efficient bacterial action. Many factors (such as lamp envelope, lamp ageing, turbidity, concentration of suspended solids and micro-organisms, and fluid thickness) affect the efficiency of UV irradiation [7, 8]. Efficiency of UV disinfection depends also on the UV dose and the aggregation state of bacteria in water [9].

The aims of this study were (I) to investigate the disinfection of municipal WTPs effluents by UV system, (II) to determine the removal of solid matter, turbidity, total coliform, fecal coliform and *Escherichia coli* in a UV unit combined with the expanded perlite filter (EPF).

Material and methods

The study took placed in wastewater laboratory (Department of Environmental Engineering, Firat University) using monolamp UV pilot equipment supplied by Arbiol (Istanbul, Turkey). The UV reactor has a useful volume of 4.2 l. A low-pressure mercury vapor discharge lamp has length of 900 mm, diameter of 13 mm, wavelength of 254 nm and power of 65 W. A quartz sleeve were used to mechanically protect and seal the lamp. For protect of UV lamp and energy saving, a filter was added to the UV system (Fig. 1). Expanded perlite was used as filter packing material. The properties of expanded perlite were given in Table 2. To ensure optimal particle sizes, the expanded perlite was screened using a mechanical shaker with sieves. The fraction of expanded perlite remaining on the 1 mm sieves was used as the filter packing material.

The EPF has an effective volume of 2.7 l and medium porosity of 0.313. Filtration velocity was kept to be 5.75 x 10^{-3} m/s. To investigate the performance of EPF on disinfection, experiments were run with and without EPF for same samples. Flow rate was kept to be 0.035 l/s.



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1. Feed Tank	5. Electrical input
2. Flow meter	6. UV lamb
3. Expanded Perlite filter	7. UV reactor
4. Ballast	8. Disinfected effluent

Figure 1. Schematic view of EPF-UV combined system [10].

Table 2. Physical and chemical properties of expanded perlite [11].

Physical properties		**Chemical properties**			
Color	White	pH	6.6 – 8.0	Na_2O %	2.9-4.0
Melting point, °C	1300	SiO_2 %	71 – 75	TiO_2 %	0.03-0.2
Thermal conductivity, Kcal/Mh °C	0,034 – 0,045	Fe_2O_3 %	0.5 – 1.45	K_2O %	4-5
Density, kg/m^3	32 – 200	Al_2O_3 %	12 – 16	CaO %	0.2-0.5
Sound absorbing, db (125 Hz)	18	MgO : %	0.03 – 0.5		

Wastewater characterization was assessed by total solids (TS), total suspended solids (TSS), volatile suspended solids (VSS), total coliform (TC), fecal coliform (FC), *Escherichia coli*, total hardness, total alkalinity, pH, conductivity, and turbidity. Conductivity, pH and turbidity were measured WTF–LF 330, Orion-SA 720 and Torbidimetro Velp–115, respectively. Total nitrogen (TN) and total phosphorus (TP) were measured with spectrophotometer (Nova 60). Transmittance at 253.7 nm measured in a spectrophotometer (Shimadzu UV160U) equipped with a 1 cm rectangular cell. Other parameters were analyzed according to Standard Methods [12]. The samples were collected from secondary effluent of biological (activated sludge system) municipal WTP located in Elazig (Turkey), during 15 weeks. The characterization of the WTP effluent was summarized in Table 3.

Table 3. The characterization of secondary effluent.

Parameters	N	Minimum	Maximum	Mean values	SE
pH	24	7.60	8.11	7.80	0.02
Temperature, °C	24	22	28	24,9	0.39
TCOD, mg/l	15	80	176	123.07	7.60
TN, mg/l	15	10.10	34.27	20.90	1.89
TP, mg/l	15	0.80	2.24	1.37	0.12
Alkalinity, mg $CaCO_3$/L	24	480	520	498.75	3.42
Total hardness, mg $CaCO_3$/L	24	324	668	504.50	23.36
Conductivity, μS/cm	24	1117	1345	1221.29	13.99
TS, mg/l	17	670	790	717.33	7.33
VSS, mg/l	17	490	660	525.33	10.41
TSS, mg/l	17	20	80	51.66	4.72
Turbidity, NTU	17	1.80	8.40	5.37	0.59
TC, MPN/100 ml	17	110,000	260,000	192,000	11159.49
FC, MPN/100 ml	17	62,000	150,000	95333.33	7687.33

N= Number of samples and SE= Standard error

Bacteriological analysis included the estimation of total coliform, fecal coliform and *Escherichia coli*. The estimation of numbers of the coliform group was carried out with the Multiple Tube Dilution (MTD) methods by lactose broth. *E. coli* was determined by EMB agar according to Standard Methods [12] by confirmed test. The calculation of MPN of coliforms was done by combination of positive and negative results in the multiple tube tests [12]. The corrected MPN tables proposed by Man (1983) were used [13]. It was used a statistic program (SPSS 12.0, Microsoft Corporation Inc.) for calculations of means, standard errors and t-test values.

UV doses in the irradiation chamber were evaluated using the empirical method recommended by Qualls et al. (1989) [14]. This method considers the UV incident intensity, measured on the surface of the quartz sleeve, and the depth of the water layer crossed by UV radiation. Thus, the dose at the area ***e*** of 1 cm^2 in the irradiation chamber is defined as follows:

$$D_e = I_m \cdot t_c \cdot T_{(l)} \qquad (1)$$

Where, D*e* is calculated UV dose at the area of 1cm^2, mWs/cm^2;

I_m, the average UV incident intensity measured on the surface of quartz tube, mW/cm^2;

t_c = exposure time, s. [t_c = irradiation chamber volume (l) / flow rate (l/s)];

$T_{(l)}$ is the value of UV transmittance determined in the laboratory using a spectrophotometer (UV-visible) with different length quartz vessels and wastewater.

The incident intensities at the liquid surface, at 254 nm, were measured with an International Light Radiometer (Model 14000A) with a SEL 240 sensor. The exposure time was calculated based on approximate plug-flow conditions. Transmittance was determined on one each sample (TSS=76 mg/l) in the WWP effluent and (TSS=32 mg/l) in the EPF effluent (Fig. 2). A 20 ml aliquot of the wastewater sample was placed in sterile Petri dishes (90 mm ID). The layer of water crossed with UV rays was 3 mm deep. Each experiment was repeated at least three times. The concentration of total coliform before and after exposure to UV light was determined. Dose expressed in mWs/cm^2 was calculated using (1).

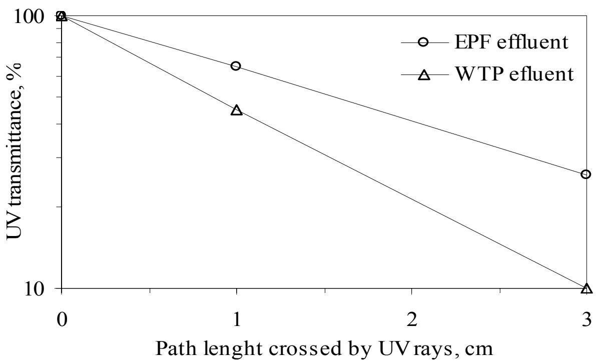

Figure 2. Transmittance UV according to the optical way of UV rays.

Results and Discussion

Disinfection with only UV

Effective UV doses in the UV system are variable. Three types of doses were defined: (i) the minimal dose determined inside the irradiation chamber, which is relative to a layer of water with 3.0 cm deep, (ii) the maximal dose calculated at the exterior surface of the quartz sleeve, and (iii) the median dose corresponding to the middle (1.5 cm) depth of the irradiation chamber. Effective UV doses were calculated in the UV system (Table 4). The doses in the irradiation chamber changed between 96 and 820 (median 164) mWs/cm^2 at an exposure time of 120 s.

Table 4. Estimation of the UV radiation at different exposure times.

	I_m (a), mW/cm^2	Path length crossed by UV, cm	$T_{(l)}$ (b), %	Exposure time(c), s			
				30	60	120	180
				UV Doses, mWs/cm^2			
Minimal	-	3	10	24	48	96	144
Median	8	1.5	17	41	82	164	245
Maximal	-	0	100	240	460	820	1230

(a) Mean of UV incident intensity measured on the surface of the tube of quartz and expressed in mW /cm^2.

(b) UV transmittance calculated according to abacus in Fig. 2.

(c) Exposure time (s) = flow, l/s / Volume of the irradiation chamber, l.

For UV doses of 82 and 164 mWs/cm^2, it was respectively found to be total coliform of 300 – 600 MPN/100 ml and 95 – 310 MPN/100 ml, and fecal coliform of 100 – 430 MPN/100 ml and 54 – 150 MPN/100 ml. Total coliform was less than 350 MPN/100 ml, and fecal coliform was less than 150 MPN/100 ml at exposure time of 120 s and UV dose of 164 mWs/cm^2 (Fig. 3).

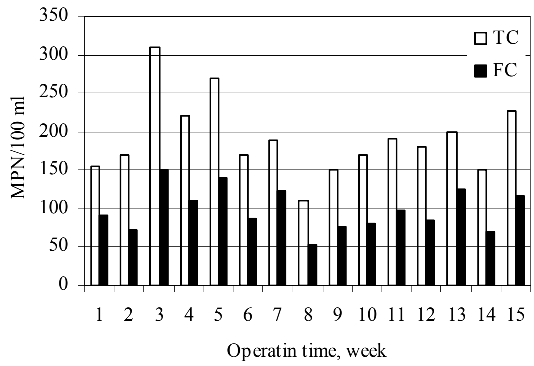

Figure 3. The changes of coliforms in the effluent of UV system at exposure time of 120 s and UV dose of 164 mWs/cm^2.

The results showed that with the UV dose of 164 mWs/cm^2, the average reduction of total and fecal coliforms was in the range of 2.9 – 3.3 log units. Hassen *et al.* (2000) achieved about 3 log unit reductions in order to attain a minimum disinfection value of 10^3 fecal bacteria/100 ml at the outlet of the UV pilot system for average reduction of fecal coliform at UV dose of 108 mWs/cm^2 [8]. In general, UV dose prescribed in water disinfection is a function of the characteristics of installation, exposure time and the UV absorption of water. According to study by Moreno *et al.* (1997), a dose of 27 mWs/cm^2 was sufficient to reach the fixed limit of 10^3 fecal coliform /100 ml for a secondary effluent with a low bacterial load, and the dose had to be increased to 32 mWs/cm^2 with an increase in the contamination [15]. Loge *et al.* (1996) used a dose of approximately 140 mWs/cm^2 to meet a permitted effluent coliform concentration of 23 MPN/100 [1], having similar to characteristics in the present study. Paraskeva and Graham (2005) were able to achieve total coliform reduction to point of 100 – 200 CFU/100 ml with dose of average 300 mWs/cm^2 [16].

There was a linear relationship between TSS and coliform, and a strong correlation between turbidity and coliforms in samples passed through only UV (Fig. 4). It was shown that the number of total coliforms was less than 300 MPN/100 ml when turbidity value was 7 NTU.

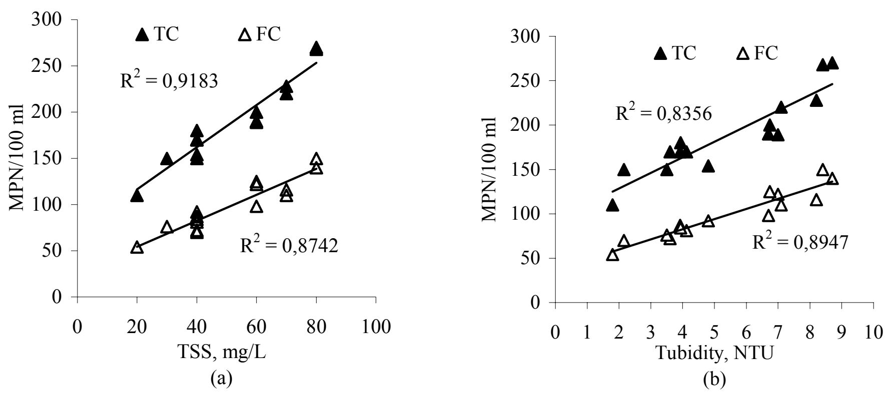

Figure 4. The Correlations a) between TSS and coliforms, and b) between turbidity and coliforms in the UV effluent.

Disinfection with EPF-UV

Several studies showed that the disinfection performance was highly influenced TSS concentration [6, 17 – 21], due to the fact that TSS could protect bacteria and viruses [1, 8]. It was shown that the expanded perlite filtration increased the disinfection capacity. TSS and turbidity were respectively reduced in the levels of 33 – 67% and 19 – 67% by using only perlite filter. Lubello *et al.* (2004) stated that the reductions of TSS and turbidity received up to 89% and 59%, respectively, by dualmedia pressurized filters [19]. Hamoda *et al.* (2004) indicated suspended solids removal at 95% and volatile suspended solids removal at 99% by sand filtration [21]. On the other hand, Hassen *et al.* (2000) emphasized that sand filtration did not change the efficacy of the disinfection and the increase of UV dose, beyond the mean of 108 mWs/cm^2, did not seem to have a significant effect on the efficacy of the disinfection [8]. In the current study, TSS concentrations reduced less than 40 mg/l by using the expanded perlite filter (Fig. 5). According to results, optimum removals were achieved at TSS of 20 mg/l and turbidity of 1.8 NTU. The differences in total suspended solid ($P<0.01$) and turbidity ($P<0.05$) values between UV and EPF-UV effluents were statistically found significant.

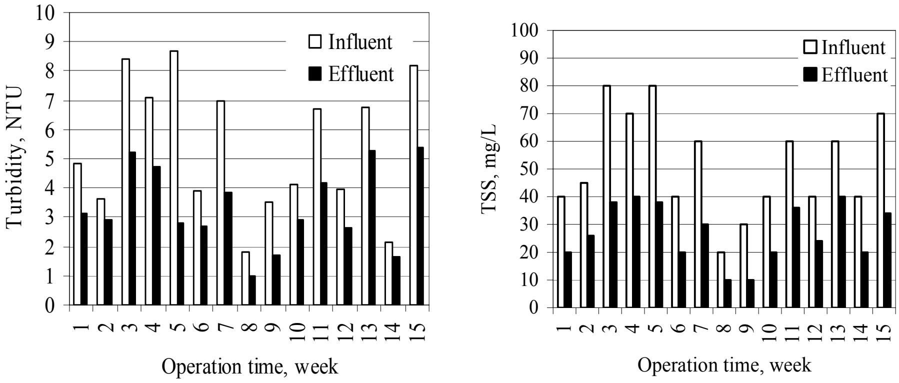

Figure 5. Turbidity and TSS concentrations in the influent and effluent of EPF-UV system.

It was found that total coliform and fecal coliform in the EPF-UV effluents were 62 – 196 MPN/100 ml and 24 – 100 MPN/100 ml with removals of 99.70 – 99.93% and 97.72 – 99.94%, respectively (Fig. 6).

It was proved that the EPF-UV system reduced of total coliform and fecal coliform, because of reduction effectively in TSS and turbidity. Mann and Cramer (1992) emphasized that TSS concentration had to be less than 30 mg/l in effluent before disinfection [22].

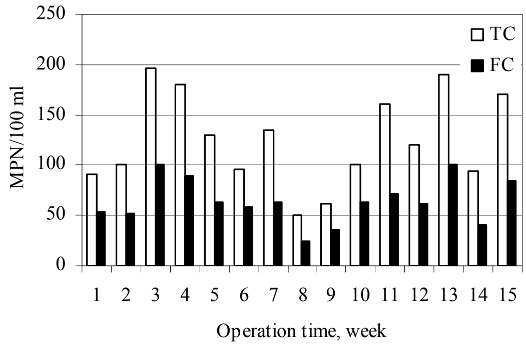

Figure 6. The coliform changes in the effluent of EPF-UV system.

The numbers of total coliform in the effluent of EPF-UV system were less then that in the effluent of UV and the differences were statistically significant ($P<0.001$). This showed that some microorganisms adhered in solid matter were eliminated. The turbidity was less than 5.4 NTU with the addition of EPF to the system and as a result better elimination of coliforms was optained. A strong correlation ($R > 0.94$) was found between turbidity and total coliform number (Fig. 7). The effluent characterization of EPF-UV combined system is given in Table 5.

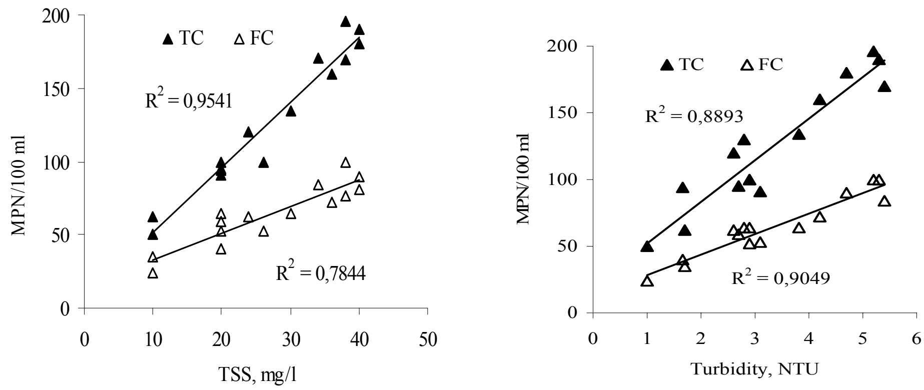

Figure 7. The Correlations a) between TSS and coliforms, and b) between turbidity and coliforms in EPF-UV combined system.

The elimination of *Escherichia Coli* increased with the reduction of turbidity and TSS by using EPF-UV combined system in wastewater samples with TSS of 20 mg/l and turbidity of 3 NTU. In particular, the results obtained by EPF-UV showed that an effective removal of *E .coli* occurred in TSS concentration less than 30 mg/l (Table 6).

Table 5. Characteristics of the EPF-UV effluent.

Parameters	N	Minimum	Maximum	Mean	SE
TS, mg/l	15	220.00	410.00	298.00	14.28
VS, mg/l	15	90.00	240.00	177.33	10.58
TSS, mg/l	15	10.00	40.00	26.00	3.05
Turbidity, NTU	15	1.00	5.20	3.33	0.36
TC, MPN/100 ml	15	62.00	196.00	124.80	11.85
FC, MPN/100 ml	15	24.00	100.00	64.20	5.79

Table 6. The presence of *E. coli* according to results in the multiple tube tests.

Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
UV	*E .coli*	-	+	+	+	+	-	+	-	+	+	+	+	+	-	+
	TSS, mg/l	40	45	80	70	80	40	60	20	30	40	60	40	60	40	70
EPF-UV	*E. coli*	-	+	-	+	+	-	+	-	-	-	-	-	+	-	+
	TSS, mg/l	20	26	38	40	38	20	30	10	10	16	20	24	40	20	34

Distinction should be made between restricted and unrestricted irrigation, on the basis of irrigated crops and modes of operation. Crops for restricted irrigation include forests and areas where access to the public is not expected, fodder, industrial crops, pastures, trees, seed crops and products which are processed before consumption. With respect to irrigation methods the spraying is not allowed. For restricted irrigation, the minimum treatment required is secondary biological treatment and disinfection producing an effluent with SS concentrations below 35 mg/l and fecal coliforms concentration below 200 FC/100 ml. For unrestricted irrigation, the treatment is a secondary biological treatment followed by a tertiary treatment (normally coagulation, flocculation, sedimentation, filtration) and disinfection producing an effluent with SS concentrations below 10 mg/l and turbidities below 2 NTU as an average value. Fecal coliform concentrations should be also below 5 FC/100 ml and not exceeding 100 FC/100 ml in any sample [3, 23]. The unrestricted irrigation includes all other crops such as vegetables, vineyards, crops, with products that are consumed raw, greenhouses. UV disinfection studies carried out after usage of EPF as a unit of tertiary treatment in the current study ensured the restricted irrigation criterions, but not ensure the unrestricted irrigation criterions, proposed by EU directive and Greece Standards.

Conclusions

Experimental results with only UV indicated major limitations for the use of the effluent as an irrigation source in plants. The results showed that filtration was most effective for removal of TSS, but slightly effective for coliforms. The value of fecal coliform (<100 MPN/100 ml) was constantly satisfied according to the criterions of restricted irrigation. The effluents obtained by UV and EPF can be used for irrigations in only forests and areas where access to the public is not expected, fodder, industrial crops, pastures, trees, seed crops which are processed before consumption. Spray irrigation should not be practiced. It was shown that UV and EPF effluents were not effective for unrestricted irrigation.

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