APPLICATION OF FLAT PLATE SOLAR COLLECTOR FOR THERMAL DISINFECTION OF WASTEWATER EFFLUENTS

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ABSTRACT
Application of solar energy for wastewater treatment has shown to have the least negative effects and costs. This experimental research was carried out in pilot-scale on the effluent of the extended aeration activated sludge wastewater treatment system in Kashan. The plant is located at the Kashan University of Medical Sciences campus and receives about 100 m^3/d sewage from official and residential building blocks. In this study thermal disinfection of the effluent in 55 ºC for 2 hours using flat plat solar collector (FPSC) was investigated. During the study in the beginning of every week, one day was selected randomly and the pilot was run. The pilot influent temperature was the same as ambient air throughout the day. If the liquid temperature within the pilot increased above 55 ºC, a thermostatic valve opened. Passed liquid was maintained for 2 hours in this temperature. Whenever the volume of disinfected effluent was measurable fecal MPN test and Nemathoda eggs count-up were done according to the Standard Methods and Leeds-II directions, respectively. In 200 days from April to November the geometric mean of fecal coliform never exceeded the WHO guideline (1000 MPN/100mL), but in 5 days (21%) it exceeded the Iranian standard (400/100mL). Mathematical mean of Nemathoda eggs was less than 1 per liter (Engelberg Index) persistently. The mean of hydraulic loading rates was calculated 83.25 L/d m^2 while it decreased to 41.85L/d.m^2 in the days without thermal reclamation.

Key words: Wastewater; Solar energy; Engelberg index; Fecal coliform; MPN

INTRODUCTION
Wastewater disinfection is necessary for public health and protects water and soil against contaminants. Disinfection is defined as careful inactivation of pathogens in water resources. It primarily takes place by means of physical, radiological or chemical methods (Qasim, 1999). Nowadays, some other new methods have been developed for water and wastewater disinfection; however, chlorine is still widely used for this purpose, due to its economical benefits and suitable operation and maintenance of facilities. Chlorine disinfection has some limitations and defects, for example it destroys enteric pathogens (e.g. bacteria and viruses) particularly in the absence of suspended and colloidal matters. In addition, wastewater requires higher residual chlorine than clear water (Tchobanoglous, 2003; Salvato, 2003; Nabi Bidhendi *et al*., 2006; Hammer, 2008). Furthermore, protozoa cysts and helminthes eggs are resistant to chlorine. Also adding chlorine to drinking water can cause some adverse impacts on the residential users since chlorination of contaminated water and wastewaters can produce some disinfection byproducts. Humic substances mainly humic acids constitute the major fraction of natural organic matter in water supplies. They

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play an important role in the formation of harmful disinfection by products (Mahvi *et al.*, 2009). Disinfection byproducts include trihalometans (THMs), haloacetic acids and halocetonitriles that are mutagens/carcinogens and tratogens. (Bitton, 2005; Nabi Bidhendi *et al*, 2006).

Thermal disinfection is identified as a preferred alternative technique to the water and wastewater chlorination, but it requires a great deal of energy consumption. Thermal disinfection of sludge has been performed successfully as sludge pasteurization. Although energy-intensive, pasteurization destroys effectively helminthes eggs and most bacteria and viral pathogens. Pasteurization at 70 ºC for 30 min destroys more than 99% of Taenia Saginata ova, moreover a complete inactivation of Salmonella and Enteroviruses may be achieved. Simlar consequences have been reported for heating sludge at a lower temperature for a longer period of time (55º C for 2 h) (Bitton, 2005).

Today, world activities require agreat deal of energy, up to 10 billion tons of oil per year. Following effects of this energy consumption are environmental problems such as enhanced CO_2 concentration in the ambient air and acidic precipitates. Hence renewable sources of energy have received a lot of attention in the past decade. Fortunately, a vast part of Iran is located in the first degree of solar energy in the world. However, fossil fuel ratio in Iran is about 99% and it is increasing (World Council of Energy, 1996; Iranian Solar Energy Association, 1997; Iranian Ministry of Energy, 1997).

In many countries such as Japan, Australia and some other countries, flat plate solar collectors are used as geyser; also, some researches have shown that the solar choker box could be used for water pasteurization (McKinney, 1998; Rlla, 1998; Saitch, 1999).

Fortunately, in Iran, many projects have been designed for application of renewable energy sources, but a few of them are in the water and wastewater fields. Unlike fossil fuels, application of solar energy in every field, such as wastewater treatment processes has no negative problems. Hence this study was conducted to evaluate the efficiency of flat plate solar collectors for thermal disinfection of wastewater effluents.

MATERIALS AND METHODS

This experimental research was carried out in pilot scale on extended is activated sludge effluents in Kashan's as a desert district. The wastewater treatment plant located at Kashan University of Medical Sciences and receives 100 m^3/d sewage collected from some official and residential building blocks at the university. The initial mean values for TSS, COD, BOD, and pH in applied activated sludge effluent were 69.05 mg/L, 88.88 mg/L, 41.57 mg/L and pH=6.56, respectively.

It was supposed that the most probable number of coliforms in activated sludge effluent are 107 per 100mL and the helminthes eggs are103 per 100 mL, based on previous studies, that had stated the most probable number of coliforms is 10^4-10^9 per 100mL of raw domestic wastewater and number of helminthes eggs up to 10^3; furthermore, bacteria and helminthes eggs removal efficiencies by activated sludge process had been reported as 2-3 log10 units (99-99.9%) and 1-2 log10 units (90-99%) respectively. Also removal of helminthes ova by biological process had been obtained up to 76 percent. These figures have been used as a basis for determining efficiencies in this research (Arceivala, 1986; Donald, 1995; Mattheus, 2000). Fig. 1 shows the schematic of the pilot and its components.

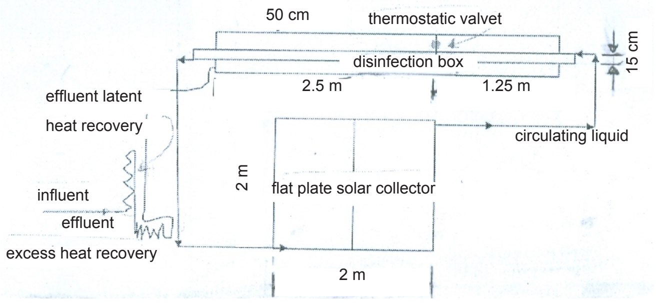

Fig. 1: Schematic diagram of designed pilot and its components

The pilot was designed by the following formula for the worst weather conditions for a day in the winter and other criteria, as bellow:

$$E = (A * \cos 45^{\circ} * R * C_w * C_e * (1 - C_t)) / (E_d)$$

Where:
E = Expected effluent (140 m^3/d)
A = Total Flat Plate Solar Collector (FPSC) surface area (4m^2)
45° = Install FPSC angel
R = Solar radiation (17mJ/m^2)
C_w = winter radiation coefficient (0.05)
C_e = Collector efficiency (30%)
C_t = Thermal energy waste coefficient (0.3)
E_d =Energy demand for rising the water temperature up to its boiling point (3600K J/m^3)
The pilot had several main parts; two units of FPSC which had a total surface area 4 m2, a feeding tank, an elevated pressure tank with enough height (2.5m) and a disinfection box. The elevated pressure tank was designed for providing enough head force to circulate FPSC liquid. Disinfection box was isolated for energy saving. It was divided in 2 compartments. The wastewater treatment plant effluent entered the pilot by the first compartment and left it by the next. The temperature of influent was increased to 55 ºC in the first compartment and was retained in this temperature for 2 hours in the second. These compartments were established longitudinally and a 55ºC thermostatic valve was placed between them. A galvanized pipe was placed among these compartments as heating exchanger tube (HET). The influent passed through the disinfection box outside the HET and the FPSC closed circulation liquid in it. A counter current heat exchanger was designed in order to achieve maximum efficiency. In order to achieve heat reclamation and more efficiency, the hot effluent from disinfection box was discharged to a secondary isolated box. The pilot influent was entered the disinfection box through a pipe which was placed in this secondary isolated box, in this way the influent was preheated with a countercurrent flow.
During the study, in the beginning of every week, a day was selected for sampling, randomly. In the early morning of each selected day, the feeding tank was filled with activated sludge effluent. Throughout these days liquid temperature was about ambient air. At any time which the liquid temperature was increased to above 55ºC the thermostatic valve was opened and the heated liquid discharged to second box. Passed liquid maintained for 2 hours in this temp for disinfection. After sunset the volume of disinfected effluent was measured and samples were taken for fecal MPN and Nemathoda eggs count up. Pearson's correlation was done to determine the association between volume of disinfected effluent and weather conditions. Nemathoda eggs count up was performed by Leeds II direction (Gharavi, 1999)

Table 1: Weather conditions of Kashan on selected days with thermal reclamation

Weather conditions	Statistical indices	Daily lowest temperature (ºC)	Daily highest temperature (ºC)	Mean of daily temperatures (ºC)	Sunny hours number (h/d)
Spring(n=7)	mean	19.1	23.0	26.1	8.8
	S.D.	2.9	2.8	2.7	1.9
Summer(n=13)	mean	24.6	39.8	31.8	11.0
	S.D.	2.7	2.6	3.3	0.9
Autumn(n=4)	mean	10.8	30.9	23.9	8.8
	S.D.	2.0	0.8	1.4	1.4

and the other examinations took place according to the 21st Edition of Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Besides, for assessment of reclamation efficiency in the middle of each month a day was selected randomly and activated sludge effluent was fed directly to disinfection box (without heat reclamation) then the volume of disinfected liquid was measured.

RESULTS

In the winter, solar energy alone could not increase the effluent temperature above 55 ºC as needed level for disinfection purpose hence; as had been suspected the pilot effluent wasn't measurable. The weather conditions of Kashan on selected days during the study when the pilot had some effluent are shown in Table 1.

In the period of April to November, the pilot produced expected results. Table 2 shows the findings in the seasons which the pilot had effluent. The liquid volumes of disinfected effluent as a function of weather conditions of area on selected days without heat reclamation (once in a month) are shown in Table 3.

On the selected days with heat reclamation (once a week from April to November), hydraulic loading rates were in the range of 70.75 - 98.25 L/dm^2. Regarding to Fig. 2 it is revealed that the mean of hydraulic loadings were about 78.25, 90.25 and 73.75 L/dm^2 for the Spring, Summer and Autumn, respectively and the mean during the whole period was calculated as 83.25 L/dm^2. The mean of hydraulic loading rates was 41.85 L/dm^2 on the selected days without heat reclamation (once a month from April to November).

Table 2: Findings of pilot study on selected days with thermal reclamation

Parameter	Statistical indices	Mean of influent temperature (ºC)	Volume of disinfected liquid (L/d)	Geometric mean of fecal coliforms (MPN/100mL)	Mathematical mean of Nematoda eggs (number/L)
Spring(n=7)	mean	26.07	313.00	325.50	0.29
	S.D.	2.69	20.39	108.00	0.49
Summer (n=13)	mean	31.83	361.15	369.63	0.38
	S.D.	3.29	19.77	130.00	0.65
Autumn(n=4)	mean	13.88	295.33	268.33	0.33
	S.D.	12	8.55	46.66	0.84

Table 3: Weather conditions of area and findings of the pilot on selected days without heat reclamation

Weather conditions	Statistical indices	Daily lowest temperature (ºC)	Daily highest temperature (ºC)	Mean of daily temperature (ºC)	Mean of sunny hours (h/d)	Mean of disinfected liquid volumes (L/d)
(n=7)	mean	20.4	36.1	28.2	9.9	167.4
	S.D.	3.3	3.7	3.2	2.3	16.6

The geometric means of fecal MPN per 100 mL of disinfected effluent were 325.50, 369.63, 268.33 and 337.84 for Spring, Summer, Autumn and during the whole period, respectively. The removal efficiencies corresponding to these results were calculated in percentage and are shown in Fig. 3.

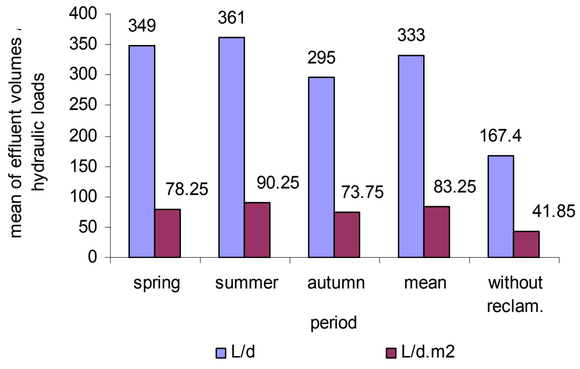

Fig. 2: mean of disinfected effluent volumes and hydraulic loads

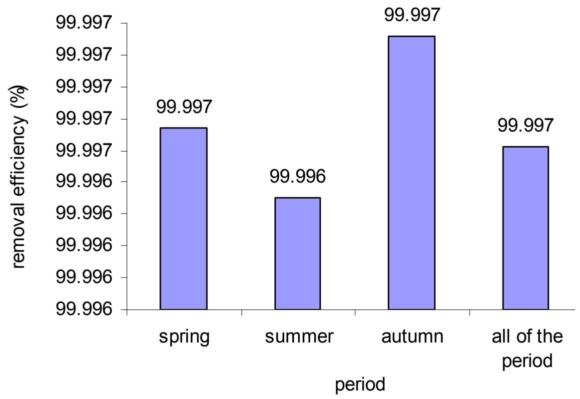

Fig. 3: the removal efficiencies of fecal coliforms per 100 mL of disinfected effluent

DISCUSSION

The findings of this study showed that FPSC is applicable for successful thermal disinfection of activated sludge effluent without other supplementary sources of energy in 200 days of the year (55%). The minimum hydraulic loading rate for this purpose was about 71 L/dm^2 of FPSC surface area. The greatest association was observed for the volume of pilot effluent and daily maximum ambient air temperature (R^2=0.997). In addition, there was a significant correlation between the volume of purified effluent and daily average ambient air temp. (R^2=0.862). The least correlation was observed between the effluent volume and sunny hours per day (R^2=0.332). A comparable study was not found by the Internet searches.

The geometric mean of fecal MPN were 325.50, 369.63and 268.33 per 100 mL, in the Spring, Summer and Autumn as respectively and for the whole period (April to November) was calculated 337.84 per 100 mL. All of these values were less than 400 per 100 mL that has been recommended by Department of Environmental of Iran (Research Deputy of Iranian Environmental Protection Organization, 1998). The fecal MPN was more than 400 per 100 mL, one day in the Spring and four days in the Summer only. However, it was not more than 1000 per 100 mL that has been recommended by WHO as Engelberg criteria for irrigation with no restriction (Mara, 2003). These results implicate that thermal disinfection is more effective than complex of hydrogen peroxide and silver on thermotolerant coliforms in disinfection of swimming pool water which has not shown significant change in it (Nabizadeh *et al.*, 2008).

According to WHO guideline and the Iranian standard, the mathematical mean of Nemathoda eggs in purified effluent should be less than one per litter (Mara, 2003, Environmental Protection Organization of Iran, 2001). Consequently by the solar energy technique alone, we could maintain both the Iranian standard and Engelberg criteria, for 200 days between April to November. It is clear that, for other days it can be used as a supplementary source of energy.

The mean volume of disinfected effluent was about 333 L/d and 167.4 L/d with and without thermal reclamation, respectively (Table 2). Therefore heat reclamation increased the efficiency up to 200%. However It is less than 400% that has been reported by Rlla,Trudy C (Rlla, 1998). The difference between our findings and those reported by Rlla,Trudy C can be related to some factors such as special features of the design and operation of the pilots besides other dissimilarities and so on.

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