# Greywater Disinfection by SolarReactor in Baghdad

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## Abstract

Solar disinfection is an efficient method for greywater treatment where it is exposed to solar radiation to inactivate pathogenic organisms.Solar disinfection is affected by numerous variables which include the wavelengths of solar radiation, water temperature, turbidity, and reactor selection. A Laborotary model of solar reacter has been designed and constructed at Environmental Hydraulic in Mustansiriya University/College of Engineering. The model consists of four independent Acrylic reactors of 100mm diameter and 1300mm length, filled with different materials for filtration and disinfection including (sand, Black granite, Granular activated carbón, and Mixture of granular activated carbonated black granite).

Thesolardisinfectiontreatmentwas experimented bya8 L multistage contiuous flow with recycling ratio 4 .The treatmentprocesses still incomplete wherethe tertiarytreatmentisnotapplied in many treatment plants in Iraq.Thissituationcouldcompromisetheplannedwastewater reuseregardingespecially themicrobialquality.

**KeyWord:** Solar Energy, Disinfection, Greywater, Multi Stage reactor

## 1-Introduction

Greywater can be contaminated by activities such as bathing and clothes washing. Disease-causing organisms in greywater are principally transmitted through ingestion of greywater via contaminated hands, aerosols from spray irrigation (usually only allowed for use with suitably treated greywater), or indirectly through contact with contaminated items such as grass, soil, toys and garden implements. (Dheyaa et. al, 2013)

Inaridareas of Baghdad, water conservation and reuse are issues that receive a great deal of public attention in the last decade. The search for way store sponsibly use and reuse water is vital to the sustainability of the water supply and thus the future of the seregions Treated grey water in house scanbere used fortoilet flushing, outdoor irrigationandspraying water evaporation cooling of selected apartments building located in Baghdad. Treated wastewateralsocanbeusedforirrigationandstreetscleaningbymunicipalinstitutes.Several experiments in Baghdad have been achieved for small scale to reuse greywaterfor toilet flushing, irrigation, outside housecleaning and evaporative cooling. Baghdad's Water demand is estimated to 3.2Millionm$^3$/sec, the quantity of produce dwateris (66%)of the required needs (Dheyaa et.al, 2014)

Untreated greywater is not considered suitable for spray irrigation and human contact should be avoided if bucketing or maintaining greywater diversion or irrigation systems ( Table 1 ). (Dheyaa et.al, 2014)

Table 1: International Criteria for Reuse, Surendran and Wheatley, 1998

| | Faecal coliforms cfu/100ml | Total coliforms cfu/100 ml | BOD mg/l | Turbidity NTU | TSS (mg/l) | DO% % saturation | PH | $Cl_2$ Residual mg/l |
|---|---|---|---|---|---|---|---|---|
| US EPA (g) | 14 for any sample<br>0 for 90% samples | | 10 | 2 | | | 6-9 | 1 |
| Florida (m) | 25 for any sample<br>0 for 75% samples | | 20 | | 5 | | | 1 |
| Texas (m) | 75 (m) | | 5 | 3 | | | | |
| Germany (g) | 100 (g) | 500 (g) | 20 (g) | 1-2 (m) | 30 | 80-120 | 6-9 | |
| Japan (m) | 10 for any sample | 10 | 10 | 5 | | | 6-9 | |
| South Africa (g) | 0 (g) | | | | | | | |
| WHO Iawn irrigation | 200 (g)<br>1000 (m) | | | | | | | |
| EC bathing water | 100 (g)<br>2000 (m) | 500 (g)<br>10000 (m) | 2 m (g)<br>1 m (m) | | | 80-120 | 6-9 | |
| UK (BSRIA) Proposed (g) | 14 for any sample<br>0 for 90% | | | | | | | |

A study which aimed at evaluating the amount of grey water generation in the city of Baghdad has been carried out by Dheyaaetal.(2009). The study showed that the water consumption in Baghdad in August averaged 138

Liters per capita per day (120-200Lpcd); while the water consumption in Baghdad in December averaged 75 Liters per capita per day (58-100Lpcd).

Greywaterrepresenta an incontestable release source of many chemicals, physical and biological compounds which may havean impact on the environment and human health. Water disinfection methods can be divided into two categories. The first category is chemical disinfection. Which includes methods such as chlorination and iodine treatment.However. The other catogary physical treatment methods such as boiling water and UV treatment which is only effective for low turbid water and therefore pretreatment such as filtering is required for poor water quality sources

Solar water disinfection is a type of portable water purification that uses solar energy, in one or more ways, to make contaminated water safe to drink by ridding it of infectious disease-causing biological agents such as bacteria, viruses, protozoa and worms. However, disinfection may not make all kinds of water safe to drink due to non-biological agents such as toxic chemicals or heavy metals. Consequently, additional steps beyond disinfection may be necessary to make water clean to drink. .

Solar thermal water disinfection uses heat from the sun to heat water to 70C-100$^{o}$C for a short period of time. A number of approaches exist here. Solar heat collectors can have lenses in front of them, or use reflectors. They may also use varying levels of insulation or glazing. In addition, some solar thermal water disinfection processes are batch-based, while others (through-flow solar thermal disinfection) operate almost continuously while the sun shines. Water heated to temperatures below 100C is generally referred to as Pasteurized water (SANDEC, 2010). .

UV radiation is subdivided into UVA (400–320nm)which constitutes94%'sUV radiation. The rest is constitutes by UVB(320–290nm) and UVC (290–200nm) (Meierhofer R, 2002).

In the disinfection technologies, UV radiation is used because it induces harmful photo biological effects. The researches improvement all owed their successful application against all water borne pathogens (Hijnenet al. (2006).

Comparatively to UVB and UVC, UVA radiation is more abundant in the solar spectrum but induces the lower photo biological effects. The wave lengths radiations inferior to 320 nmare more active which induces the subdivision of UVA into UVAI (400–340nm) and UVAII (340–320 nm) (Meierhofer R, 2002)

Direct UV radiation use (photolysis) remains less effective by themselves, the combination of UV and semi-conductors metals (photocatalysis) as $TiO_2$;ZnO, Ag…records better results in water-and air-purification and several antibacterial products (Fujishima et al.(2000)

Many several studies advised UV disinfection for its efficiency and safe use especially for the wastewater treatment intended for the reuse (Adam Jokerst , 2012).

The objective of this research is to test the inactivation of different bacteria by solar disinfection using multi stage of Solar Reacter. The variables tested have to be water , turbidity, and exposure time. The inactivation of E. coli in the samples is quantified over time.

## 2- Material and Methodlogy

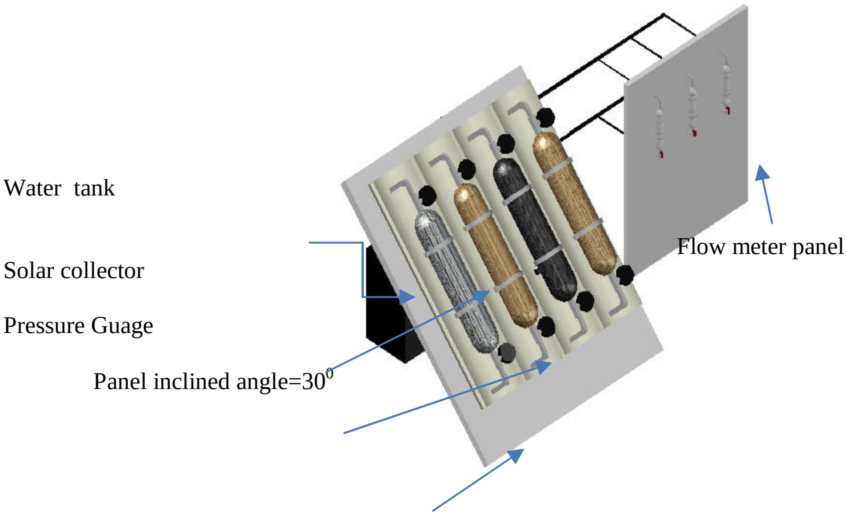
A Laborotary Models of Solar Reacter has been designed and constructed at Environmental Hydraulic in Mustansiriya University/College of Engineering as shown in plate (1) and fig.(1) The model consists of four independent acrylic reactors of 100mm diameter and 1300mm length ,filled with different materials biofiltration and disinfection, as shown in table (1).

Measurments were achieved during period from Febreuary to December 2013 in Baghdad

Table (1 ) Types of reactors and media used

| Type of reactor | Type of media | effective size mm | Uniformity factor |
|---|---|---|---|
| 1st reactor | Sand of effective grain size | 0.7 | 1.4 |
| 2nd reactor | Black granite | 1.2 | 1.8 |
| 3rd reactor | Granular activated carbon | 2.2 | 2.4 |
| 4th reactor | Mixture of granular activated carbonated black granite | 1.2 | 2.4 |

Tests includ : PH,TDS,TSS,BOD5,COD,Cl, E. Coli, Faecal Coliforms.



fig(1 ) plate (1)

## 3. Results

### *3.1. Metrology Measurements*:

Efficiency oftheSolar Reactor process is dependent on theamountofsunlightavailable and solarradiation, however, is unevenly distributed and varies in intensity from one geographical location to another depending on latitude, season and the time of the day Baghdad forSolar Collector which is locatedLatitude33 Over 90% of the sunlight touch the earth as direct radiation due to the limited cloud cover and rainfall (less than 250mm rain and usually more than 3350 hours of sunshine annually). The date of hourly solar energy, air temperatura, relative humidity, wind speed are graphed in figuers (2) to (7) can therefore rely as an energy source for solar disinfection of drinking water

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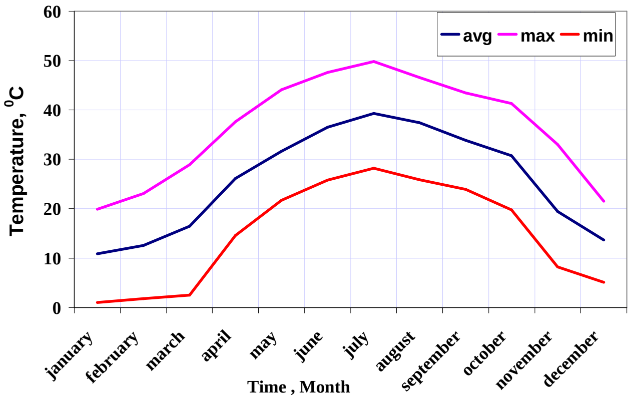


Fig. (2): The Monthly variation of air temperature in Baghdad city

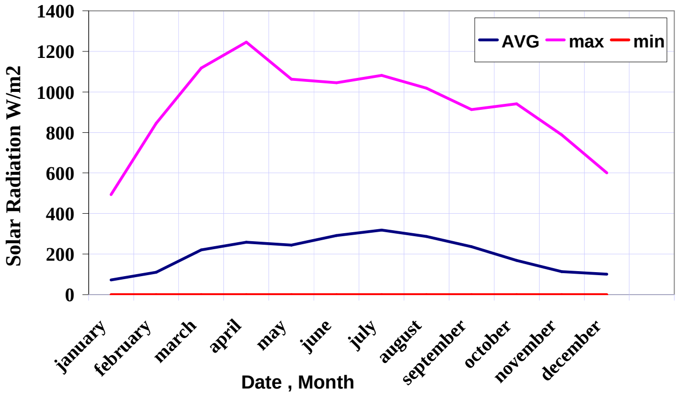


Fig. (3): The Monthly variation of solar radiation in Baghdad city

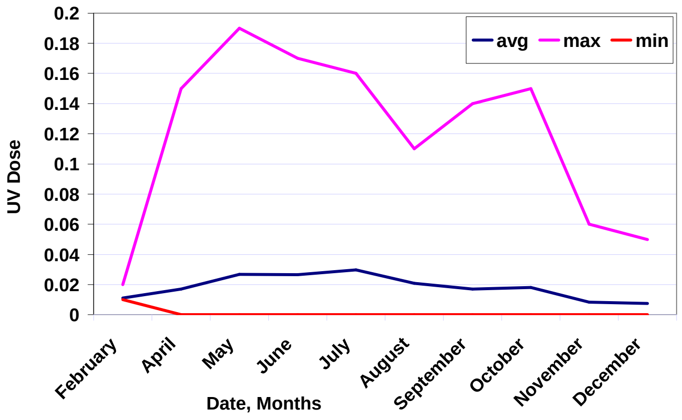


Fig (4) : The Monthly UV dose in Baghdad city

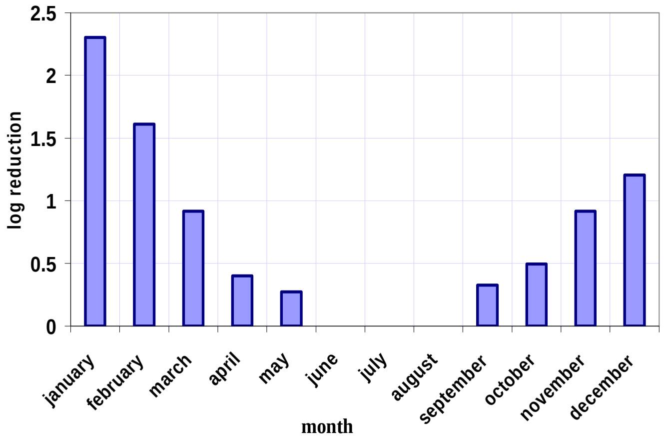


Fig (5) : The Monthly UV dose exposure in Baghdad city

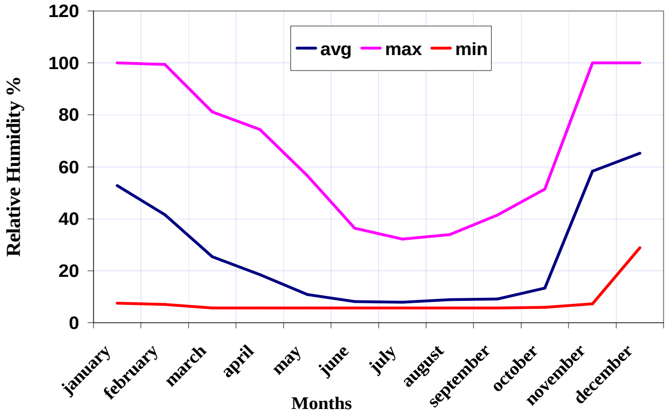


Fig.(6): The monthly variation of relative humidity in Baghdad city

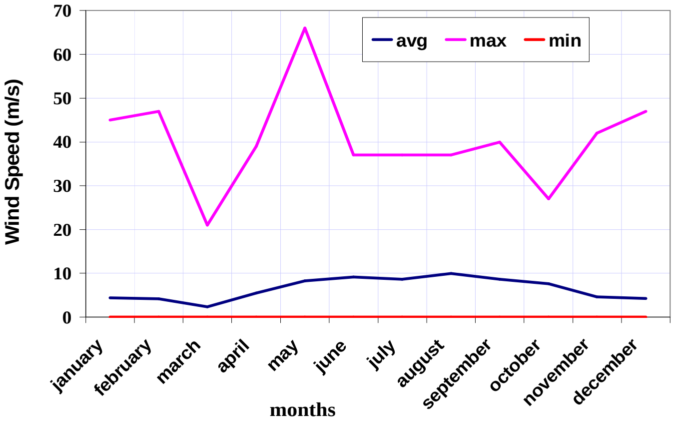
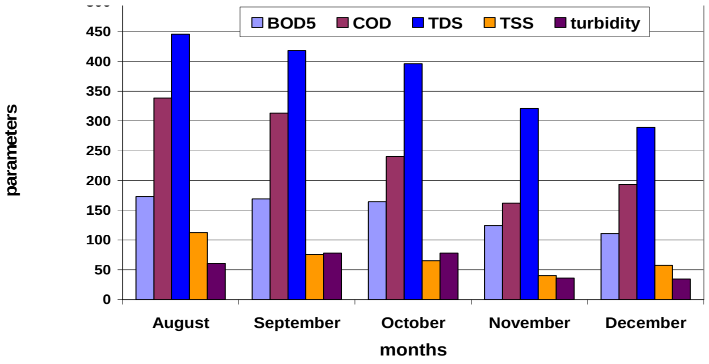


Fig.(7): The monthly variation of wind speed in Baghdad city

BOD5 mg/L-COD mg/L- TDS mg/L-Tss mg/L – Turbidity NTU



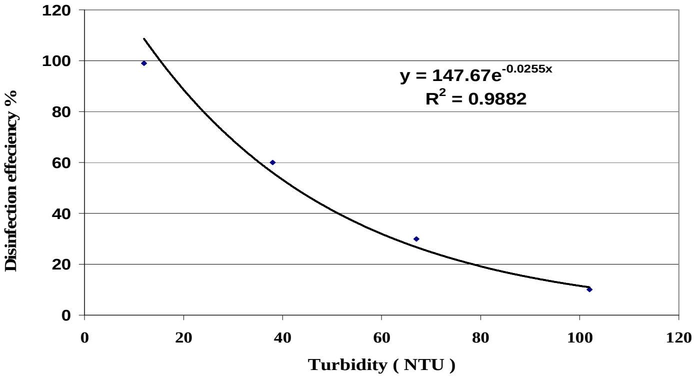


Fig (8 ): Different average parameters with time in Baghdad city

Fig (9): Disinfection Effeciency with turbidity

### 3.2. Physiochemical Properties of Greywater

The physical and chemical properties of Greywater are highly variable depending on the source, and are influenced by many factors including the number of household occupants, types of cleaners and personal care products used, grooming and hygiene habits, and sink waste disposal practices (Eriksson et al., 2002). Concentration ranges for common water quality constituents compiled from three studies are listed in Table (2) to (3). The values presented Eriksson et al. are for low-load Greywater only derived from bathroom sinks, showers, and baths. The values 8 from Rose et al. (1991) are in reference to Greywater not including kitchen sources composited in a storage tank. The values from Gross et al. (2007b) refer to Greywater mixed artificially

to replicate Greywater from mixed sources.
To study the effects of solar radiation and heating on the inactivation of E. coli, experiments are conducted from Febreuary to December 2013. For each experiment, the test reactors are prepared and spiked with E. coli in the laboratory. The initial temperature and turbidity of each test is recorded and samples must be taken to enumerate the starting concentration of bacteria. The test are then exposes to sunlight and samples have to be collected at predetermined intervals to determine the bacteria concentration. During each sampling time, air temperature, water temperature, and solar irradiance are measured and the log inactivation of bacteria is calculated over time. The results of the solar radiation and heating experiments are then analyzed and compared to the results of the heating only experiments.
The greywater characteristics in this study were measured in table( 2) figure (8 )
Table(2) :Quantity of Pollutants Loading (minimum and maximum value ) Measure dinmgper Liter for sixty one samples for period from August to December 2010.

| Parameter | August | September | October | November | December |
|---|---|---|---|---|---|
| BOD5(mg/l) | 158-187 | 119-169 | 105-164 | 91-158 | 89-132 |
| COD(mg/l) | 287-390 | 267-313 | 123-240 | 144-180 | 156-230 |
| pH | 8.6-9.5 | 7.7-7.9 | 7.9-8.3 | 7.6-8.2 | 7.4-7.8 |
| SuspendedSolid(mg/l) | 88-137 | 42-76 | 37-65 | 36-45 | 39-76 |
| TotalSolid(mg/l) | 345-546 | 322-418 | 296-396 | 287-354 | 234-344 |
| TotalPhosphorus(mg/l) | 7-9 | 8-11 | 7-13 | 9-12 | 9-13 |
| PresumptiveFaecal | 2.50E+05 | 8.00E+05 | 8.00E+03 | 6.00E+03 | 5.00E+03 |
| Coliforms | 0.6 | 0.3 | 0.3 | 0.4 | 0.4 |
| NitrateN(mg/l) | 0.07 | 0.03 | 0.02 | 0.008 | 0.03 |
| Nitrite N(mg/l) | 23 | 36 | 34 | 27 | 28 |
| TurbidityNTU | 44-78 | 34-62 | 28-47 | 29-43 | 23-46 |
| Lead(mg/l) | 4 | 11 | 7 | 15 | 16 |
| Zinc(mg/l) | 67 | 76 | 43 | 56 | 81 |
| Copper(mg/l) | 97 | 112 | 108 | 132 | 107 |

The basic treatment has been achieved using biological treatment for 6 hrs to make dissolved oxygen of 3 to 4 mg/l

Table(3): Average Values of Composition of grey water from different sources in Baghdad households based on measurements of 50 to 118 for each parameter compared to the concentration of domestic black water.

| | Greywater from bathtubs,showers and hand basins | Greywater from bathtubs, showers, hand basins and washing machine (including baby diaper) | Greywater from bathtubs, showers, hand basins, washing machines and kitchen | Domestic wastewater (black water) |
|---|---|---|---|---|
| $BOD_5$ (mg/l) | 113 | 193 | 372 | 281 |
| COD (mg/l) | 234 | 354 | 546 | 567 |
| TSS (mg/l) | 46 | n/a | n/a | 224 |
| $P_{total}$ | 1.8 | n/a | 6.2 | 17 |
| $N_{total}$ | 11.8 | n/a | 15.6 | 73 |
| Total coliforms (MPN/ml) | $10^5$ | $10^4$ | $10^4$ | $10^6$ |
| E. coli (MPN/ml) | $10^4$ | $10^4$ | $10^5$ | $10^6$ |
| pH | 7, 7 | n/a | 7.4 | 6.7 |

### *3.3.Microbiologic analysis*

The UV disinfection efficiency was evaluated by the enumeration of the live pathogenic colonies after each experiment. The MPN method (most probable number) was followed to enumerate total and fecalcoliforms, streptococci, staphylococci, sulphite-reducing sporesand fungi. Thesampleswerefilteredby0.45micrometerthenseedinginselectiveculturemediaduring 48hours. The number of microorganisms was plotted as CFU(Colony forming units)/100ml and the disinfection result is plotted in Logreduction as follows:

$$\text{Log reduction} = \log \frac{C_0}{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \ (1)$$

where:

$C_0$: number of survival pathogenic before treatment.
C: number of survival pathogenic after treatment.

For grey water with turbidity less than 30 NTU the disinfection resultsachieved2.5 Log-reduction of total coliforms,3.4 Log reduction off ecalcoliforms, where 2.72-Logreductionofstreptococci,3.2-Logreductionofstaphylococci,0.07-logreduction of yeasts, 0.18- Log reduction of molds and 1.17-logreduction of sulphite-reducing spores.

The disinfection effeciency reduced extremely when grey water turbidity is more tan( 60 NTU ).

### 3.3.1. Effect of Solar reactor on pathogens

Human pathogens are adapted to live in the human intestines, where they find a dark, humid environment and temperatures ranging between 36°C and 37°C. Once the pathogens are discharged into the environment, they are very sensitive to the harsh conditions outside the human body. They are not able to resist increased temperatures and they do not have any protection mechanisms against UV radiation. Therefore, temperature and UV radiation can be used to inactivate the pathogens.

The solar energy required will vary according to type and concentration of pathogen and greywatercharacterstics such as turbidity fig.(9), and pH fig ( ), oxygen content, mineral salts, humic substances, colour, and other factors, solar reaction design such as the diameter (depth) of water, type of backing (reflective, absorptive), shape of container, material composition, etc. Bacteria and most viruses are relatively easy to destroy, while bacterial spores, and parasitic eggs, cysts or oocysts, are relatively difficult. The most UV resistant organism is the Ascaris egg, which, due likely to the protein cost, requires a fluence of 8 KJ/m$^2$. However, this pathogen is not normally water borne. The most difficult water borne organism to destroy is the Bacillus subtilis spore[15], which required a fluence of 2.22 KJ/cm$^2$These energies refer to UVC radiation, typically at 253.7 nm, which is not available in natural solar radiation.

Natural solar radiation available at ground level includes: UVA (280-320nm) , UVB (320-400nm), Visible light (400-700nm), and Infrared (700-14,000nm)

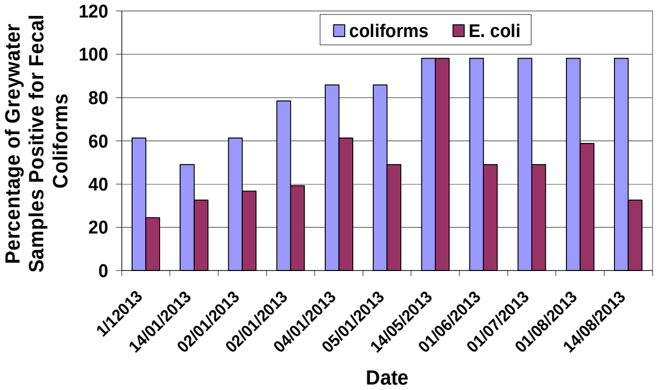


Fig.(10): Monthly Percentage of Graywater Samples Positive for Fecal Coliforms and E. coli

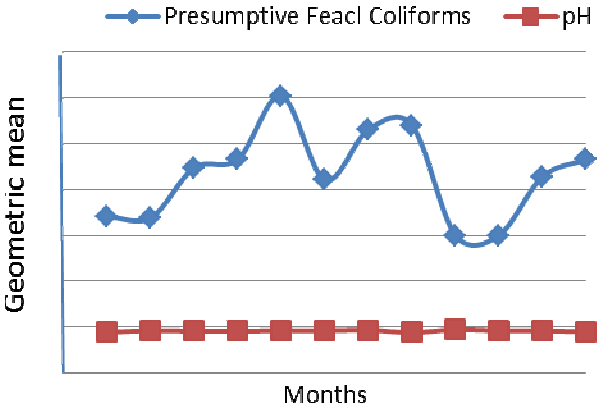
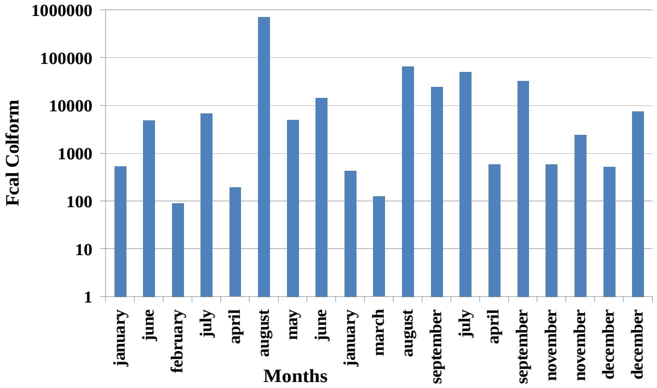
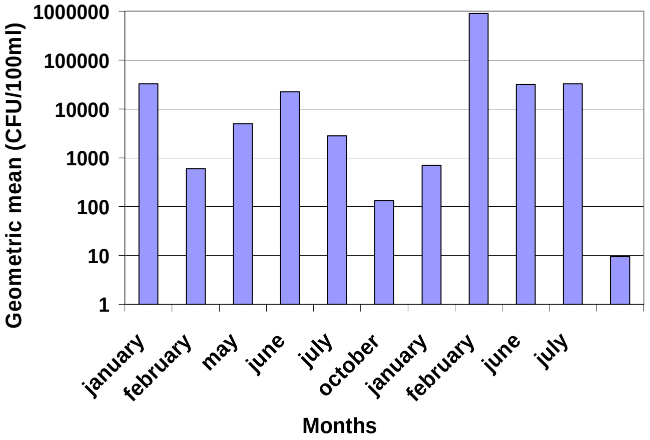


Fig. (11) : Mean values of pH and Feacl Coliforms in greywater in Baghdad





Fig(13): The monthly Fecal Coliform in Baghdad

Fig(14): Fecal Coliform in Baghdad city

3.4. Effects of UV-radiation

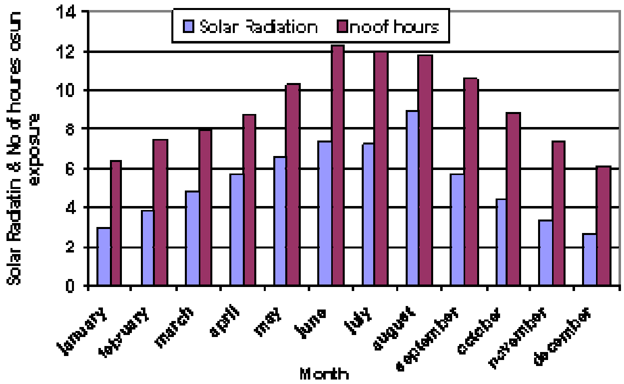
Solar radiation in to three ranges of wave length: UV radiation, visible light and infrared radiation. UV radiation is a very aggressive radiation that can cause severe damage to the skin and eyes and destroys living cells.Luckily most of the UV-Cand UV-Blight in the range of 200 to 320nm is absorbed by the ozone (O3)layer in the atmosphere which protects the earth from radiation coming from space. Only a higher fraction of UV-Aradiation in the wave length range of 320nm–400nm, near the visible violet light, reaches the surface of the earth.

The solar UV-Aintensity shows both seasonal and daily variations.

The seasonal variation depends on the latitude and is mainly responsible for the climate in that region. In Baghdad for example(latitude:33°N),the UV-A radiationintensityreachesapeaklevelof0.19 KW/m$^2$ in May, July 0,16 KW/m$^2$ and decreases to 0.05 KW/m$^2$in December, while UV- A radiation intensity reaches a peak level of 0.16 Kw/m$^2$

The sola radiation intensity is also subject to daily variations. With increasing cloudiness, less radiation energy is available. During completely montor days the UV-Aradiation intensity is reduced to 30% of the intensity recorded during a cloudy day.

During very cloudy days, the Solar Collector have to be exposed for two consecutive days toreach the required radiation dose and to ensure the complete inactivation of the pathogens



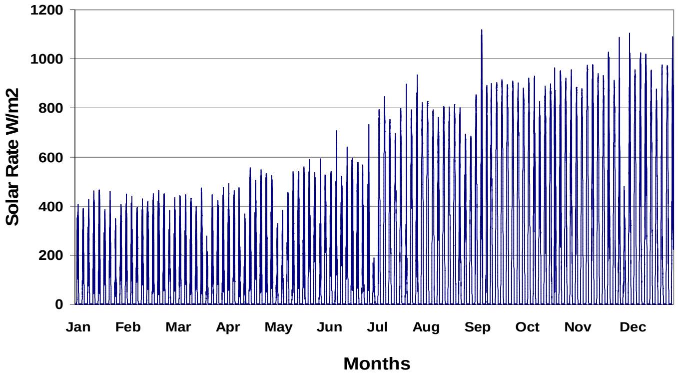


Fig (14): The monthly solar radiationo of sun exposure in Baghdad city

Fig (15) : The monthly Solar Rate in Baghdad city

UV-Alighthasalethaleffectonhumanpathogenspresentin water.Thesepathogensarenotwelladaptedtoaggressive environmentalconditionsastheyfindtheirspecificliving conditionsinthehumangastrointestinaltract.Therefore,they aremoresensitivetosunlightthanorganismscommonly abundant in the environment.

Three effects of solar radiation are believed to contribute to the inactivation of pathogenic organisms

- UV-A interferes directly with the metabolism and destroys cell structures of bacteria.
- UV-A (wavelength 320–400 nm) reacts with oxygen dissolved in the water and produces highly

reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) that are believed to also damage pathogens.

- Cumulative solar energy (including the infrared radiation component) heats the water. If the water temperatures rises above 50 °C (122 °F), the disinfection process is three times faster.

At a water temperature of about 30 °C (86 °F), a threshold solar irradiance of at least 500 W/m$^2$ (all spectral light) is required for about 5 hours for SODIS to be efficient. This dose contains energy of 555 Wh/m$^2$ in the range of UV-A and violet light, 350–450 nm, corresponding to about 6 hours of mid-latitude midday summer sunshine.\At water temperature higher than 45$^0$C (113 $^0$F), synergistics effects of UV radiation and temperature further enhance the disinfection efficiency (more than 30 NTU and distillation ability decreases extremely. Greywaterfilteration is very important before solar disinfection when the turbidity is more than 30 NTU and distillation ability decreases extremely

## Conclusions

Solar disinfection of greywater using multi-stage solar collector has been conducted and tested during period ( Febreuary 2013 to December 2013).The basic conclusions can be:

1- The solar reactor performance depends on sunlight available , solar radiation, turbidity and water temperature, air temperature, relative humidity and sun shine duration.
2- The disinfection effeciency of multi stage solar reactors reduced extremely when greywater turbidity more that 60 NTU, and increased with significant rate for greywater turbidity less than 30 NTU.
3- At water temperatures higher than 45 °C (113 °F), synergistic effects of UV radiation and temperature further enhance the disinfection efficiency. More than 98% for turbidity less than (30 NTU).
4- Theseasonaldifferencesofsolarradiationareimportant fortheapplicabilityofsolarwaterdisinfection.Atotal solar radiation intensity of at least 0.5 KW/m$^2$ is required for approximately 6 hours for Solar reactor to be effective.

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