Effectiveness of Solar Disinfection (SODIS) in Removing Pathogenic Microorganisms.

A Thesis Submitted in Partial Fulfillment of the Requirements for the Bachelor of Science Degree in Civil Engineering.

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NOVEMBER, 2014

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APPROVAL

This is to certify that the thesis submitted by Jahid Ferdous and Md. Mahedi Hasan entitled as "EFFECTIVENESS OF SOLAR DISINFECTION (SODIS) IN REMOVING PATHOGENIC MICROORGANISMS" has been approved, in partial fulfillment of the requirements for the Bachelor of Science degree in Civil and Environmental Engineering.

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DECLARATION

We hereby declare that the thesis entitled "EFFECTIVENESS OF SODIS IN RURAL AND URBAN AREAS OF BANGLADESH", has been performed by us and this work has not been submitted elsewhere for reward of any degree or diploma (except for publication).

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ACKNOWLEDGEMENT

First, and foremost, to God be all the glory. We are truly blessed to have had the experience to do this type of research, and have been blessed with the people/events that have taken part in my life to make this research possible. Thank you, God, for all these things! We've been given more blessings than we deserve and it is my intention to share our abundance with the world!

We'd like to thank our family, and especially our parents, for believing in us and always showing unwavering love and support. They have sacrificed themselves for the sake of their children's advancement and prosperity and have been the embodiment of love in my life. Because of them, we have much to give, and it is our life's purpose to do so.

To Prof. Dr. Rezaul Karim, for his generosity and kindness, without his cooperation this thesis would never be completed.

We would like to thank all the instructors and other staffs of Environmental Lab for their sincere and spontaneous assistance. In the end we would like to thank each other for our perseverance and group spirit which helped us make the research a success.

ABSTRACT

Water is the most important natural resource in the world and availability of safe drinking water is a high priority issue for human existence and quality of life. Unfortunately water resources are coming under increasing pressure due to population growth, over-use and wastage. The World Health Organization (WHO) estimates that 884 million lack access to improved water supplies. Many more are forced to rely on sources that are microbiologically unsafe, resulting in a higher risk of waterborne disease transmission including typhoid, hepatitis and cholera.

As ever, the poor are the worst affected from waterborne disease. In n developing countries, 50% of the population are exposed to polluted water sources and these peoples are the main contributors to an estimated 4 billion case of diarrhea each year. These factors result in an estimated 2.2 million deaths each year, the majority of which are children under the age of five.

Solar disinfection (SODIS) of drinking water is one of the WHO approved point-of-use household water treatment technologies for drinking water (WHO/UNICEF 2011). It requires that water in transparent containers (usually poly-ethylene terephalate (PET) bottles) be exposed to direct sunlight for minimum period of 6 hours under clear sky conditions in which waterborne pathogens are inactivated thus making the water safe to drink. Pathogenic inactivation is due to the synergistic effect of ultraviolet (UV) light and heat produced by solar radiation. SODIS is very cost effective and user friendly water treatment technology comparing to the existing systems. To reduce childhood mortality, SODIS would be a realistic and cheap opinion for provision of safe drinking water in Bangladesh since ample sunlight is available throughout the year.

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CHAPTER ONE

INRODUCTION

1.1 General

Water is the most important natural resource in the world for the survival of human being. So availability of safe drinking water is a high priority issue for human existence and quality of life. Unfortunately water resources are coming under increasing pressure due to population growth, urbanization, over-use and wastage. World's population is increasing day by day and making the water problem more critical. The World Health Organization (WHO) estimates that 884 million lack access to improved water supplies and 2.5billion lack adequate sanitation. Many more are forced to rely on sources that are microbiologically unsafe, resulting in a higher risk of waterborne disease transmission including typhoid, hepatitis and cholera [1-2]. Currently, about one in seven people worldwide lack access to clean water, and meeting the needs of a growing population will only further stress our existing resources (Gleick 2002).

Bangladesh is a highly populated country with limited resources. The average population density is above 832 inhabitants per km^2, making Bangladesh one of the most densely populated countries in the world (Asiatic Society of Bangladesh, 2004). The United Nations Development Program's (UNDP) "2013 Human Development Report" ranked Bangladesh 146th among the 187 countries in the Human Development Index (HDI). 49 percent of total population live below the national poverty line (According to World Bank in 2005). About 20% of rural and 37% of urban population living below the national poverty line. These people have limited access to safe drinking water. Lack of access of safe drinking water increases the risk of contracting water borne diseases including cholera, diarrhea, typhoid, hepatitis A and Amoebic dysentery. The World Health Organization says that every year more than 3.4 million people die as a result of water related diseases, making it the leading cause of disease and death around the world, the majority of which are children under the age of five.

Salinity in ground and surface water in the coastal regions, arsenic contamination of shallow aquifer, lack of aquifer, too much extraction of surface water for cultivation and difficulties in extracting saline free water are some of the causes of insufficient safe water in Bangladesh. The use of chemicals for disinfection requires the addition of an oxidizing agent, such as with chlorine, chlorine compounds, or ozone, to inactivate pathogenic organisms in water (Crittenden, et al. 2012). The chemical treatment of water is a costly process and usually suitable for developed countries. Physical disinfection can include processes such as filtration, reverse osmosis, UV, and heating, to name a few (Crittenden, et al. 2012). Some of these processes are used in a treatment train, or a series of unit operations. (Crittenden, et al. 2012). The need and available resources determine which processes will be used. These are the low cost process which may be suitable for developing countries like Bangladesh. As Bangladesh is developing country, we need more economic and effective process for disinfection of water. Solar disinfection (SODIS) of drinking water is one of the WHO approved point-of-use household water treatment technologies for drinking water (WHO/UNICEF 2011). It requires that water in transparent containers (usually poly-ethylene terephalate (PET) bottles or glass bottle) be exposed to direct sunlight for minimum period of 6 hours under clear sky conditions in which waterborne pathogens are inactivated thus making the water safe to drink [3-4]. Pathogenic inactivation is due to the synergistic effect of ultraviolet (UV) light and heat produced by solar radiation [5-6]. SODIS is very cost effective and user friendly water treatment technology comparing to the existing systems. To reduce childhood mortality, SODIS would be a realistic and cheap opinion for provision of safe drinking water in Bangladesh since ample sunlight is available throughout the year.

1.2 Objective of the Study

The objective of this study is to determine the effectiveness of SODIS using PET bottle under various conditions in terms of Escherichia Coli (*E. coli*) inactivation.

The purpose of this experiment is to compare the effectiveness of SODIS in the perspective and different conditions of Bangladesh. The Effectiveness is compared by undertaking the SODIS experiment with some variations like

1. In different weather condition (sunny or cloudy shy)
2. Using water with different turbidity
3. Various angular position (Standing, Lying & angle 45 degree)

1.3 Scope of this Study

The research work is to be carried out by collecting samples from different surface water sources in Board Bazar, Gazipur district in Bangladesh. Water samples were exposed to sunlight in PET bottles. PET bottles were used because they are common, inexpensive containers that can be found worldwide. For each experiment, the test bottles were prepared. The initial temperature and turbidity of each test bottle were recorded and samples were taken to enumerate the starting concentration of bacteria. The test bottles were then exposed to sunlight and samples were collected at predetermined intervals to determine the Escherichia Coli (*E. coli*) concentration. During each sampling time air temperature, water temperature and solar radiation intensity were measured. Laboratory experiments were carried out to determine the following.

- Water quality before the solar disinfection in terms of *E. coli* inactivation
- Water quality after the solar disinfection in terms of *E. coli* inactivation
- Determination of effective angular variation.

1.4 Limitation of the Study

SODIS is a very low cost household water treatment technology but it has some limitations. It requires sufficient solar radiation. Therefore it depends on the weather and climatic conditions. For SODIS water sample should be clear. Water with high turbidity is not effective for SODIS. SODIS cannot change the chemical properties of water. Treatment of large volume of water using SODIS is difficult. In case of laboratory testing we are not, Salmonella, Shigella bacteria etc.

1.5 Outline of Thesis

There has been many research work carried out about SODIS. These related works that has been carried out is discussed in the chapter of literature review. Different findings from previous works related to microbial water quality and SODIS has also been discussed in this chapter. The chapter methodology contains introduction of parameters that are related with the study. Sampling, media preparation and overall methodology is discussed in this chapter. The result, data sheet, graphs are provided in the chapter four. Chapter five contains the analysis of the collected data.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter we will discuss the worldwide problem regarding the shortage of drinking water, and the impacts of poor water quality on people in developing countries. Also the poor water quality in the respective areas of Bangladesh from where the samples for the experiments are collected. The specific water treatment options are presented, including chemical treatment options and physical treatment options.

2.2 DEVELPOING COUNTRIES

More than one third of the people living in developing countries do not have access to save drinking water. Microbiologically contaminated drinking water can cause diarrheal diseases, which are particularly dangerous to children. Roughly one third of infant mortality is caused by such diarrheal diseases, and every day around 6.000 children die due to the direct or indirect effects of diarrheal diseases – in many cases caused by contaminated drinking water. In 2003, the United Nations have included safe drinking water in their list of Millennium Development Goals, with the goal to halve the amount of people with no access to safe drinking water by the year 2015 (United Nations, 2003). This ambitious goal can be reached in two ways: on one hand, new and safe installations (pipes, boreholes, etc.) can be set up; on the other hand, people can be educated not to drink untreated water. Of course, on the long run it surely is a goal to provide safe drinking water from the tap, however, this will still be a long way to go. Household water treatment and safe storage (HWTS) interventions can lead to dramatic improvements in drinking water quality and reductions in diarrheal diseases – making an immediate difference to the lives of those who rely on water from polluted rivers, lakes and, in some cases, unsafe wells or piped water supplies (WHO, 2008).

2.2 THE CONDITION OF BANGLADESH

Bangladesh is a country in South Asia located at the apex of the Bay of Bengal. The United Nations Development Program's (UNDP) “2013 Human Development Report” ranked Bangladesh 146th among the 187 countries in the Human Development Index (HDI). Bangladesh is one of the world's most densely populated countries with 150 million people, 49 percent of whom live below the national poverty line (According to World Bank in 2005). About 20% of rural and 37% of urban population living below the national poverty line. These people have limited access to clean drinking water. The poor health condition in Bangladesh is mostly attributed by the lack of safe drinking water. Many Bangladesh’s health problems, including high infant and child mortality and high incidence of fecal-orally transmitted disease, are related to contaminated water. Salinity in ground and surface water in the coastal regions, arsenic contamination of shallow aquifer, lack of aquifer and difficulties in extracting saline free water are some of the causes of insufficient safe water in Bangladesh.

2.3 SODIS METHOD

This part summarizes all relevant research that has been published and insights that have been gained about SODIS. Different topics will be included, namely, biological studies on the effectiveness on eliminating microorganisms, a short overview about the effects of SODIS on the reduction of diarrhea (health impact), some analyses on economical savings, and a review of studies that have investigated behavioral factors determining SODIS use or analyzed SODIS promotion.

2.3.1 SOLAR RADIATION AS A DISINFACTION MECHANISM

For over 4000 years, sunlight has been used as an effective disinfectant (Conroy *et al.*, 1996). When organisms are exposed to sunlight, photosensitizers absorb photons of light in the UV-A and early visible wavelength regions of 320 to 450 nm. The photosensitizers react with oxygen molecules to produce highly reactive oxygen species. In turn, these species react with DNA; this leads to strand breakage, which is fatal, and base changes, which result in mutagenic effects such as blocks to replication. For bacteria, the process is reversible as the bacteria may again become viable if conditions allow cells to be repaired (Kehoe *et al.*, 2001; McGuigan *et al.*, 1999). Viruses are unable to repair DNA damage and are therefore sensitive to optical inactivation (McGuigan *et al.*, 2001).

2.3.2 SOLAR DISINFACTION PROCESS VARIABLES

Previous studies have found that solar disinfection is affected by numerous variables. These variables include solar radiation wavelengths, water temperature, turbidity, and container selection. Several process enhancements have also been studied.

2.3.2.1 SOLAR RADIATION WAVELENGTH

Studies have shown that visible violet and blue light have little disinfection capability. However, the other components of sunlight, UV-A, UV-B, and UV-C radiation, are able to inactivate organisms. UV-C radiation, at approximately 260 nm, has the greatest potency because it corresponds to maximum absorption by DNA. Municipal treatment plants use UV-C (at 254 nm) to disinfect drinking waters and secondary wastewater effluents because of its germicidal ability to initiate changes in nucleic acids and other structures such as enzymes and immunogenic antigens. However, near ultraviolet

(UV-A) light has been found to be the most significant component of sunlight that is responsible for the inactivation of microorganisms, with an increase in effectiveness due to the synergistic effects of UV-A and violet light. This is because the UV-C component of solar radiation does not reach the earth (Wegelin *et al.*, 1994).

Acra *et al.* (1984) compared the germicidal effects of different wavelengths of light by measuring the average number of coliforms inactivated upon exposure to the varying wavelengths. They found that the most significant decrease in viable bacterial organisms occurred when they were exposed to wavelengths between 260 to 350 nm (compared to inactivation at wavelengths between 550 to 850 nm). Because wavelengths below 290 nm do not reach the earth, Acra *et al.* (1984) concluded that the most bactericidal wavelengths were between 315 to 400 nm, which corresponds to the wavelengths of the near-ultraviolet region that are not visible to the eye. The findings of Acra *et al.* (1984) are further supported by the research of others. Davies and Evison (1991) attributed half of the toxic effects of sunlight to wavelengths lower than 370 nm. Wegelin *et al.* (1994) concurred, stating that wavelengths between 300 and 370 nm have significant effects on inactivating bacteria and viruses.

2.3.2.2 HEATING

Temperatures at or above boiling can be used to effectively pasteurize water. Liquids may also be pasteurized using lower than boiling temperatures, provided the liquids are kept at such temperatures for an extended period of time. For example, enteric viruses in water can be pasteurized in approximately 1 hour at 62°C or in 1 day at 50°C (Burch and Thomas, 1998). It is known that 10 minutes at 56°C will inactivate *Giardia lamblia, G. muris* and *Entamoeba histolytica*. If a temperature of 50°C is attainable, amoebic cysts are inactivated (Acra *et al.*, 1984). Ciochetti and Metcalf (1984) state that milk pasteurization occurs at 62.8°C for 30 minutes or at 71.7°C for 15 seconds, and Burch and Thomas (1998) state that the typical pasteurization of any liquid is at 75°C for 10 minutes.

Pasteurization may not be ideal for some drinking water treatment situations. Effective treatment by heating requires knowledge of the water quality in order to determine the temperature the water must reach and the duration of heating that is needed. In addition, disinfection by heating may be impractical for wide scale use because pasteurization is a labor-intensive process and requires a significant amount of fuel (Burch and Thomas, 1998). However, heating may be accomplished by using sunlight, thus alleviating the problem of needing wood or other fuels for boiling.

2.3.2.3 CONTAINER SELECTION

Container shape and color may have significant impacts on the effectiveness of solar disinfection. The bottle shape may interfere with the sun's disinfection capabilities: as the sun moves across the sky, the intensity will change and may be reduced depending on the bottle shape. Acra *et al.* (1984) therefore recommend using round, conical bottles as opposed to square or irregularly shaped containers. However, the major limiting factor is the availability of the bottles themselves, with variables such as plastic thickness and light transmittance characteristics being difficult to assess in the field.

Acra *et al.* (1984) also noted that colorless containers allow the most transmittance of ultra-violet wavelengths and are therefore the optimal choice for use in solar disinfection. Blue and violet tinted containers also transmit radiation, yet other colors, such as orange, yellow, red and green, will absorb wavelengths with the most lethal bactericidal effects and therefore must be avoided (IDRC, 1998). With regard to pasteurization, a water sample exposed to sunlight increases in temperature due to the red and infrared components of sunlight. Blue containers would therefore absorb these components and minimize any temperature increases (Acra *et al.,* 1984). Therefore, to maximize the effects of both solar radiation and heating, colorless containers are recommended. Container size may also be an important parameter in the solar disinfection process. Acra *et al.* (1984) specify that container size is a variable that affects solar disinfection. However, their studies do not specifically test the effect of volume size on solar disinfection. Kehoe *et al.* (2001) found no significant difference in the population dynamics of 0.5 and 1.5 L samples. In contrast, Reed *et al*. (2000) compared the time needed to achieve a 99.9% reduction in the initial fecal coliform counts of 22 L and 25 L samples and found that exposure times of 150 minutes and 290 minutes were required, respectively. A more extensive study on volume variations may be useful.

2.4 EFFECTIVENESS ON ELIMINATING MICROORGANISMS

The Solar Water Disinfection (SODIS) process is a simple technology used to improve the microbiological quality of drinking water. SODIS uses solar radiation to destroy pathogenic microorganisms which cause water borne diseases. SODIS is ideal to treat small quantities of water. Contaminated water is filled into transparent PET bottles and exposed to full sunlight for six hours (or for two days if the sky is more than 50% cloudy). SODIS is especially designed for the use at household level, because it only relies on locally available resources such as PET bottles and sunlight. Sunlight is treating the contaminated water through two synergetic mechanisms: Radiation in the spectrum of UV-A (wavelength 320-400nm) and increased water temperature (SODIS Reference Center, 2008a).

Research on solar water disinfection was first conducted by Professor Aftim Acra at the American University of Beirut in the early 1980s (Acra, Karahagopian, Raffoul & Dajani, 1980). Follow-up research at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) revealed that at 30°C water temperature, a threshold solar radiation intensity of at least 500 W/m2 (all spectral light) is required for five hours for solar water disinfection to be efficient. This dose corresponds to five hours of mid-latitude midday summer sunshine. The bottles used for SODIS should not exceed three liters and as suspended solids block UV radiation, preliminary treatment is necessary if turbidity exceeds 30 NTU (sedimentation, flocculation, and filtration; Sommer et al., 1997). A large body of microbiological research followed, which assessed and demonstrated the effectiveness of SODIS in destroying diarrhea-causing bacteria (Campylobacter jejuni, Yersinia enterocolitica, enteropathogenic Escherichia coli, Staphylococcus epidermidis, Vibrio cholerae, Salmonella typhimurium, Shigella dysenteriae, Pseudomonas aeruginosa), viruses (Poliovirus), parasites (Giardia spp., Cryptosporidium spp., Acanthamoeba) and fungi (Candida albicans, Fusarium solani; Berney, Weilenmann & Egli, 2006; Berney, Weilenmann, Simonetti & Egli, 2006; Boyle et al., 2008; Conroy, Elmore-Meegan, Joyce, McGuigan & Barnes, 2001; Gaafar, 2007; Heaselgrave, Patel, Kilvington, Kehoe & McGuigan, 2006; Kehoe, Barer, Devlin & McGuigan, 2004; Lonnen, Kilvington, Kehoe, Al-Touati & McGuigan, 2005; MacKenzie, Ellison & Mostow, 1992; McGuigan, Joyce, Conroy, Gillespie & Elmore-Meegan, 1998; McGuigan et al., 2006; Méndez-Hermida, Castro-Hermida, Ares-Mazás, Kehoe & McGuigan, 2005; Smith, Kehoe, McGuigan & Barer, 2000). Only spore forming bacterial species may survive the SODIS disinfection process (Boyle et al., 2008; Lonnen et al., 2005).

2.5 HEALTH IMPACT

Regular application of SODIS has the potential to reduce diarrhoeal diseases by up to 50%. Up to date SODIS is used in about 30 countries by more than 2 million people and is recommended by the World Health Organization (WHO, 2008). The health impact of consuming SODIS-treated water was first examined in Kenya in the 1990s. The study conducted among Maasai children under the age of five showed a 16-24% diarrhea reduction and an 86% reduction in cholera cases during an outbreak (Conroy, Elmore-Meegan, Joyce, McGuigan & Barnes, 1996, 1999, 2001). From 2000 to 2003, the Swiss Tropical Institute conducted an epidemiological study in Bolivia in collaboration with Eawag to assess the health impact of SODIS on children below five. According to the study, SODIS reduced diarrhea incidence by more than 35% (Hobbins, 2003). A health impact study among 100 children in an urban slum in Tamil Nadu revealed that the risk of diarrhea was reduced by 40% by using SODIS (Rose et al.,2006). Further health evaluation studies showed a reduction of 13 to 39% in Pakistan (Gamper, 2004), in Uzbekistan by 53-57% (Grimm, 2004; Grimm, 2006) and of about 50% in projects conducted in Nepal, East Lombok and Assam, India (SODIS Reference Center, 2008b).

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

The SODIS method is ideal for treating water for drinking in developing countries. In order to study the effectiveness of SODIS method in the rural and urban areas of Bangladesh, The laboratory test requires several steps. The Methodology of SODIS consists of Sampling, Laboratory Experiment, Preparation of Media, Testing Method, Incubation, Counting and Documentation and Data Interpretation.

3.2 SAMPLE COLLECTION

To quantify the inactivation of bacteria in the test bottles, samples were taken at 15 minutes, 30 minutes, or 1 hour intervals. During each sampling session, the time, sun intensity, weather conditions, water temperatures, air temperature, and sample volumes collected were recorded. The sun intensity was recorded first while the detector was horizontal and then while the detector was held above the head and pointed directly at the sun to avoid scattered light interference. Sun intensity readings during full sun exposure and during cloud cover were averaged. Because the test bottles are cylindrical, and therefore the test water is exposed to direct Sunlight**.**

Basically pond water and Rain water are taken in the plastic bottle. The bottle is ringed with the source water. The bottle should be air tight in order to avoid the contaminations. The water is collected for per hour exposure in the intense sunlight. First sample is picked in the 0 hour exposure in sunlight, then consecutively 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th} ,7^{th} hours sample are collected by each hour exposure in sunlight.

3.3 EXPOSURE TIME

The total exposure time of experiments varied from 6 to 8 hours. Sunlight is strongest from 10 am to 2 pm so initial experiments were conducted to encompass this time bracket by up to 1.5 hours before and up to 3 hours after (from 8:30 am to 4:30 pm). Results of these experiments showed that significant inactivation of *Escherichia Coli (E. Coli),* occurred within 6-hour exposure time.

3.4 SOLAR RADIATION MEASUREMENT

The curacy and a resolution of ±0.5% from 0 to 2800 W/m^2. The pyranometer was fixed beside the glass cover of the collector. Global solar radiation incident on an inclined surface was measured by using an Eppley Radiometer Pyranometer (PSP) coupled to an instantaneous solar radiation meter model HHM1A digital, Omega 0.25% b asic dc ac. A pyranometer is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square).There is a probe with the Pyranometer which is placed at 23.5 degree angle with sun at the specific time of sampling. Consecutively zero, 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th} hours of solar radiation data are collected

3.5 LABORATORY EXPERIMENT

In the laboratory, the hourly samples are collected for testing. First of all we prepared media for different parameters. For the preparation of media we used several agars and broth. Such as: MFC agar, mEndo broth, Nutrient agar etc. MFC media is used for the enumeration of total coliform(TC) and fecal coliform (FC), mEndo broth is used for the enumeration of Escherichia Coli (E. coli), Nutrient Agar is used for the enumeration of Heterotrophic plate count.

3.6 ANALYTICAL METHOD

All processes were carried out using aseptic technique, including the use of 70% ethanol to sterilize workspaces and hands. All glassware, test solutions, and media were sterilized by autoclaving at 121°C for an amount of time recommended by the autoclave manufacturer (Sterilmatic Sterilizer, Market Forge Industries Inc., Everett, MA), according to the volumes being autoclaved. Pre-sterilized pipette tips and petri dishes were used.

3.7 MEDIA PREPARATION

The preparation of the media is done by the following:

- 48 gm of m Endo Broth is dissolved in 1 liter of distilled water.
- 15.6 gm of Bacto Agar is also dissolved in that 1 liter of distilled water.
- Mixed water is heated to boiling temperature with constant shaking in every 25 seconds. After boiling, it is kept into the water bath to reduce the temperature.
- When it cools down to desired temperature the mixture is then poured into the Petri Dish and wait until it transfers from liquid to a stabilized state.

3.8 FILTERATION

For filtration of sample 22 micro meter filter paper is used. In each case, filter paper is taken over a vacuum pump then 10 ml of raw sample is passed through it. The filter paper is then carefully placed on the media.

3.10 INCUBATION

After placing the sample on media, we kept them in the incubator in different temperature for different media for 24 hours. HPC, mEndo and TC are kept at 35-37 degree Celsius temperature and FC is kept at 44 degree Celsius.

3.11 COUNTING

After keeping the media for 24 hours in the incubator the petri dishes are observed and counted. E. coli is identified Golden metallic shin.

3.12 DOCUMENTATION

We noted down our counted result in Excel sheet for evaluation.

3.13 CONCLUSION

This thesis research was conducted to study the effects of numerous variables on the disinfection properties of solar radiation. The variables tested Different seasons (summer, Rainy, winter season), Changing Backing surface (Black surface, Aluminum surface etc.), Using different material (PET bottle, Glass bottle etc.), various angular positions (Standing, Lying, Angle 45 degree etc.), and exposure time. Experiments were also conducted in the laboratory to quantify the effect of only solar disinfection a sample.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the results from experiments are included and discussed briefly. Various comparisons have been made through analysis of the results of different experiments. A total 6 experiments were performed. We performed our experiments in different days, there are variation in weather condition, Also variation in turbidity, pH different angular variation of PET bottles like horizontal, vertical and inclined (45°). The effects of solar radiation and heating on the inactivation of Escherichia Coli (*E. coli*), in several experiments were observed. Water samples were exposed to sunlight in variable conditions. Then after filtration and 24 hours incubation amount of E. coli are counted and listed in the charts.

4.2 Data of Different Experiments

4.2.1 Experiment No: 01

This experiment has been conducted in 10.06.2014 using PET bottle for different angular variation of PET bottle such as horizontal, vertical and inclined. The weather condition was sunny and very little amount white clouds were present in the sky. We find the sample water turbidity 59.6 FTU. The pH value of the sample water was 5.7 .

The following graph is drawn after the analysis of data from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

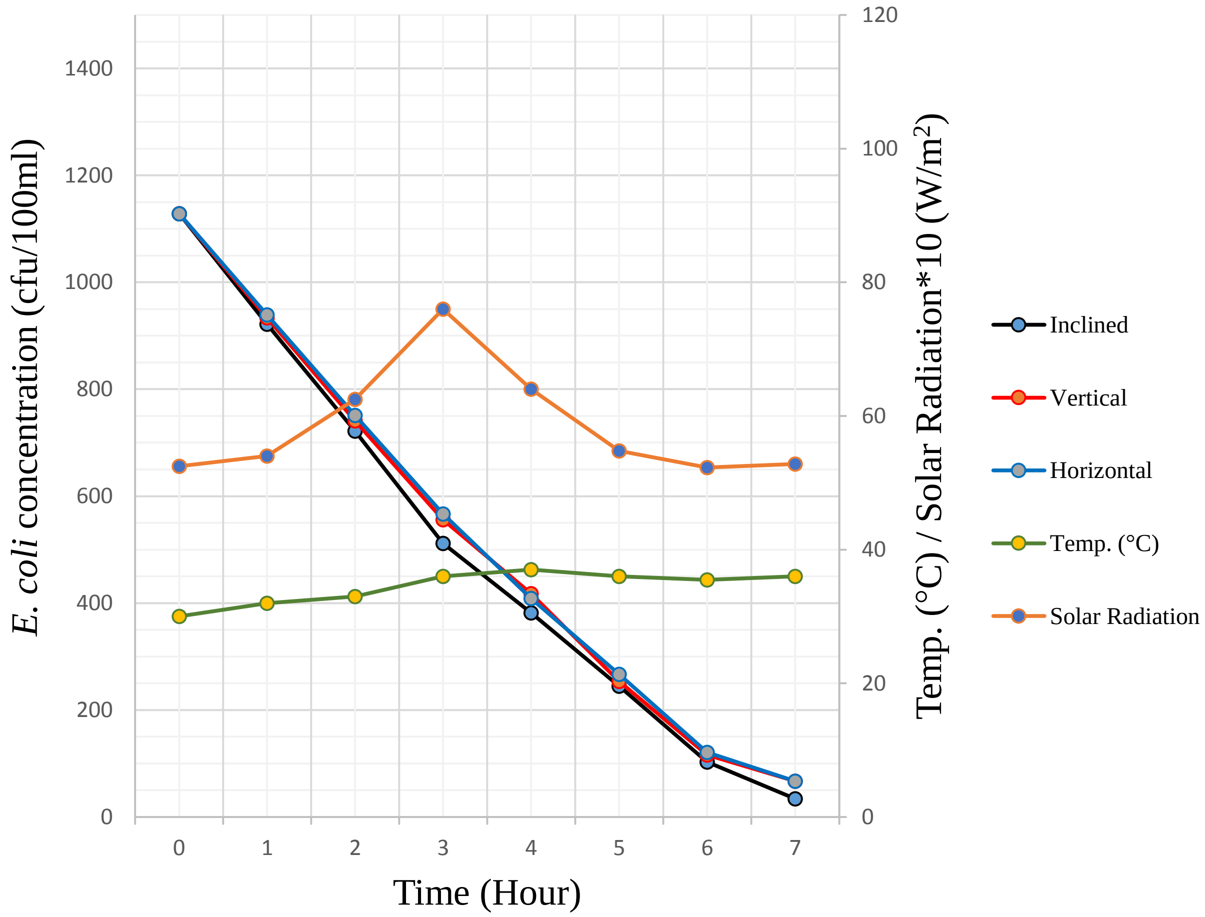

Figure 4.2.1.1 Shows the E. coli, Temp., Solar Radiation vs Time Graph

Table:4.1 Hourly Exposure, temperature, percentage reduction, solar radiation and Amount of E. coli.

Time	Hour	E. coli (c.f.u/100ml)			% Reduction per hour			% Reduction			Temperature (°C)	Solar Radiation (W/m^2)
		Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal		
08:30 am	Initial	1128	1128	1128	-	-	-	-	-	-	30	525
09:30 am	1st	922	934	939	18.26	17.20	16.76	18.26	17.20	16.76	32	540
10:30 am	2nd	722	741	751	21.69	20.66	20.02	35.99	34.31	33.42	33	625
11:30 am	3rd	512	556	567	29.09	24.97	24.50	54.61	50.71	49.73	36	760
12:30 pm	4th	382	418	409	25.39	24.82	27.87	66.13	62.94	63.74	37	640
01:30 pm	5th	245	254	267	35.86	39.23	34.72	78.28	77.48	76.33	36	548
02:30 pm	6th	103	116	121	57.96	54.33	54.68	90.87	89.72	89.27	35.5	523
03:30 pm	7th	34	67	67	66.99	42.24	44.63	96.99	94.06	94.06	36	528

The following graph is drawn after calculating % reduction rate per hour and cumulative % reduction from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

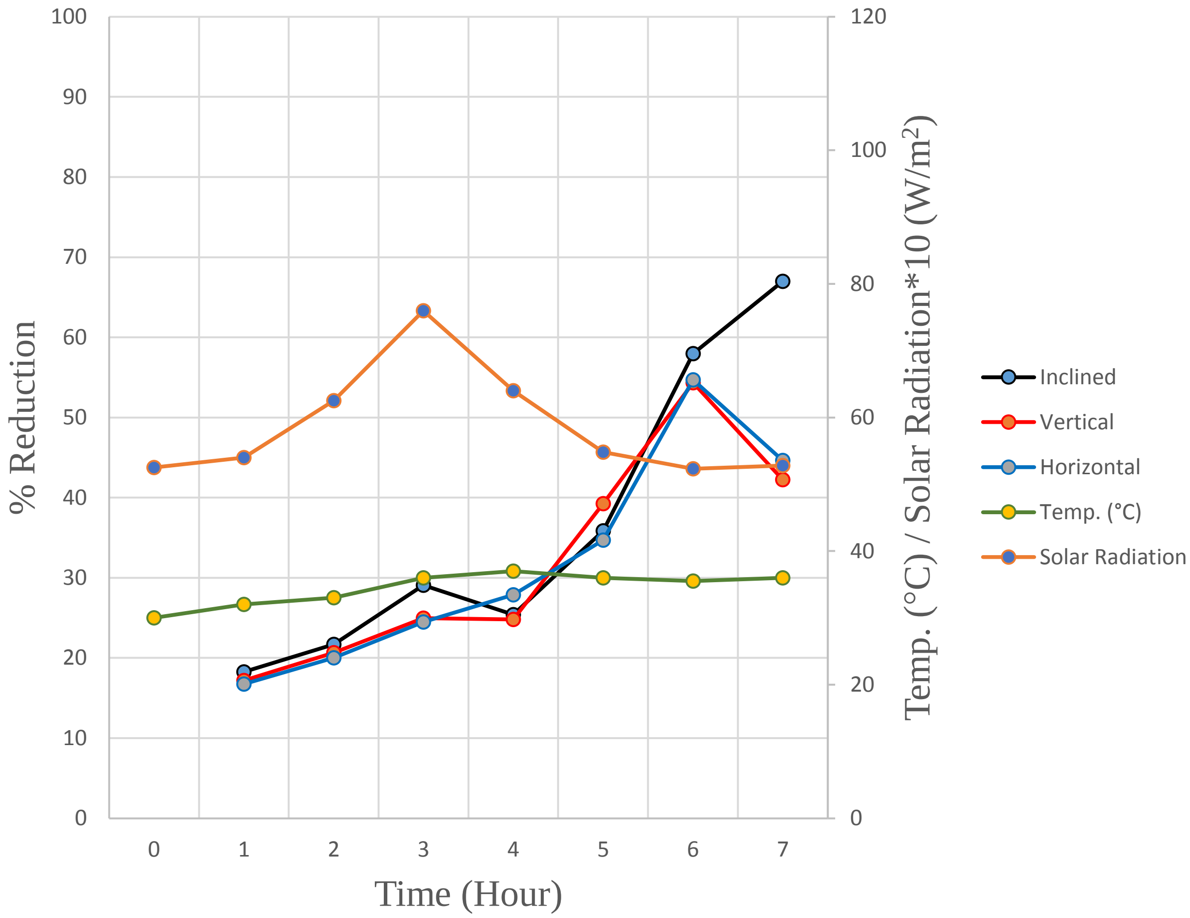

Figure 4.2.1.2 Shows the % Reduction vs Time Graph

4.2.2 Experiment No: 02

This experiment has been conducted in 17.06.2014 using PET bottle for different angular variation of PET bottle such as horizontal, vertical and inclined. The weather condition was at first Sunny then suddenly become cloudy and starts raining and first 3 hour little amount cloud then become cloudier. We find the sample water turbidity 41.1 FTU. The pH value of the sample water was 5.5 .

The following graph is drawn after the analysis of data from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

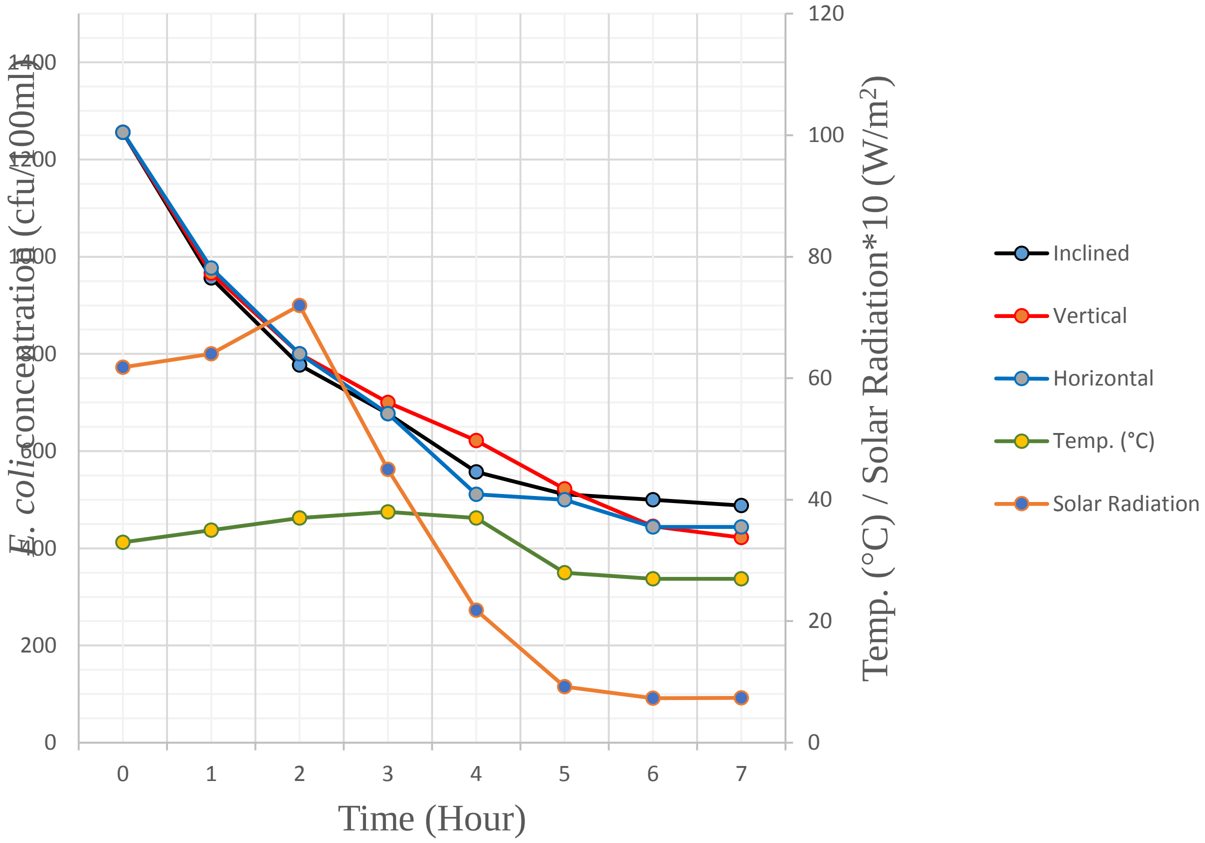

Figure 4.2.2.1 Shows the E. coli, Temp., Solar Radiation vs Time Graph

Table:4.2 Hourly Exposure, temperature, percentage reduction, solar radiation and Amount of E. coli.

Time	Hour	E. coli (c.f.u/100ml)			% Reduction per hour			% Reduction			Temperature (°C)	Solar Radiation (W/m^2)
		Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal		
08 am	Initial	1256	1256	1256	-	-	-	-	-	-	33	618
09 am	1st	956	966	977	23.89	23.09	22.21	23.89	23.09	22.21	35	640
10 am	2nd	777	800	800	18.72	17.18	18.12	38.14	36.31	36.31	37	720
11 am	3rd	677	700	677	12.87	12.50	15.38	46.10	44.27	46.10	38	450
12 pm	4th	557	622	511	17.73	11.14	24.52	55.65	50.48	59.32	37	218
01 pm	5th	511	522	500	8.26	16.08	2.15	59.32	58.44	60.19	28	92
02 pm	6th	500	445	444	2.15	14.75	11.20	60.19	64.57	64.65	27	73
03 pm	7th	488	422	444	2.40	5.17	0.00	61.15	66.40	64.65	27	74

The following graph is drawn after calculating % reduction rate per hour and cumulative % reduction from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

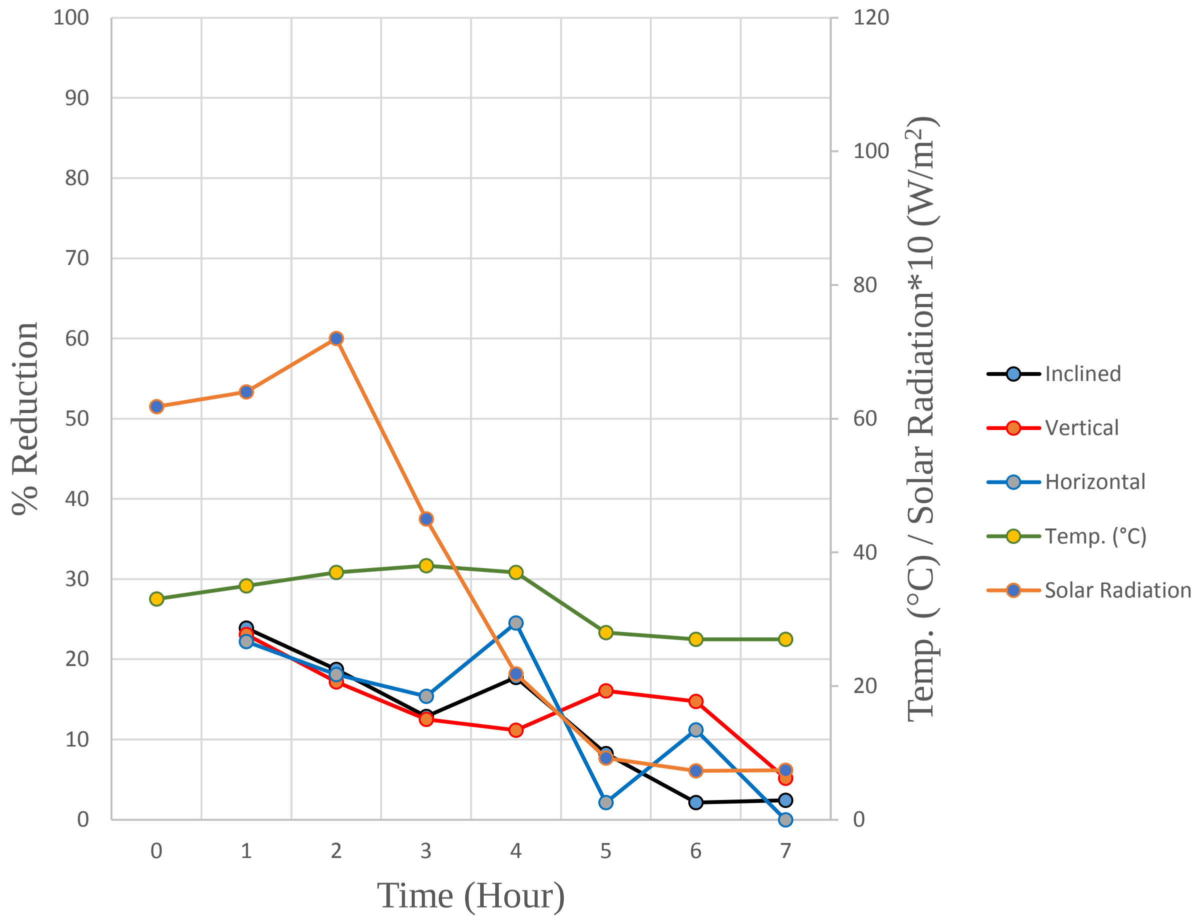

Figure 4.2.2.2 Shows the % Reduction vs Time Graph

4.2.3 Experiment No: 03

This experiment has been conducted in 09.08.2014 using PET bottle for different angular variation of PET bottle such as horizontal, vertical and inclined. The weather condition was sunny and there was no cloud in the sky. We find the sample water turbidity 41.8 FTU. The pH value of the sample water was 5.8 .

The following graph is drawn after the analysis of data from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

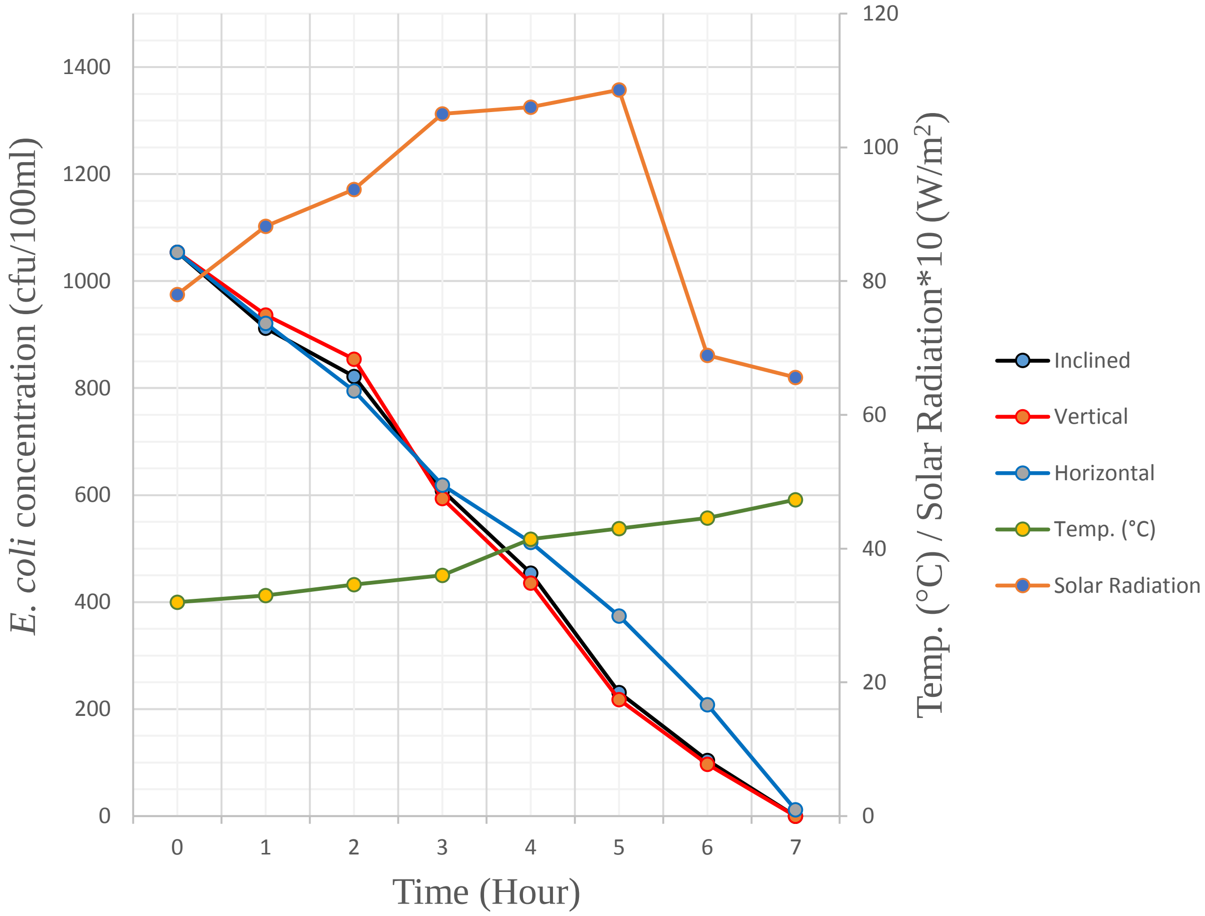

Figure 4.2.3.1 Shows the E. coli, Temp., Solar Radiation vs Time Graph

Table:4.3 Hourly Exposure, temperature, percentage reduction, solar radiation and Amount of E. coli.

Time	Hour	E. coli (c.f.u/100ml)			% Reduction per hour			% Reduction			Temperature (°C)	Solar Radiation (W/m^2)
		Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal		
08:45 am	Initial	1054	1054	1054	-	-	-	-	-	-	32	780
09:45 am	1st	912	937	921	13.47	11.10	12.62	13.47	11.10	12.62	33	882
10:45 am	2nd	822	854	795	9.87	8.86	13.68	22.01	18.98	24.57	34.6	937
11:45 am	3rd	609	594	619	25.91	30.44	22.14	42.22	43.64	41.27	36	1050
12:45 pm	4th	454	436	512	25.45	26.60	17.29	56.93	58.63	51.42	41.4	1060
01:45 pm	5th	231	218	374	49.12	50.00	26.95	78.08	79.32	64.52	43	1086
02:45 pm	6th	104	97	208	54.98	55.50	44.39	90.13	90.80	80.27	44.6	689
03:45 pm	7th	0	0	12	100.00	100.00	94.23	100.00	100.00	98.86	47.3	656

The following graph is drawn after calculating % reduction rate per hour and cumulative % reduction from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

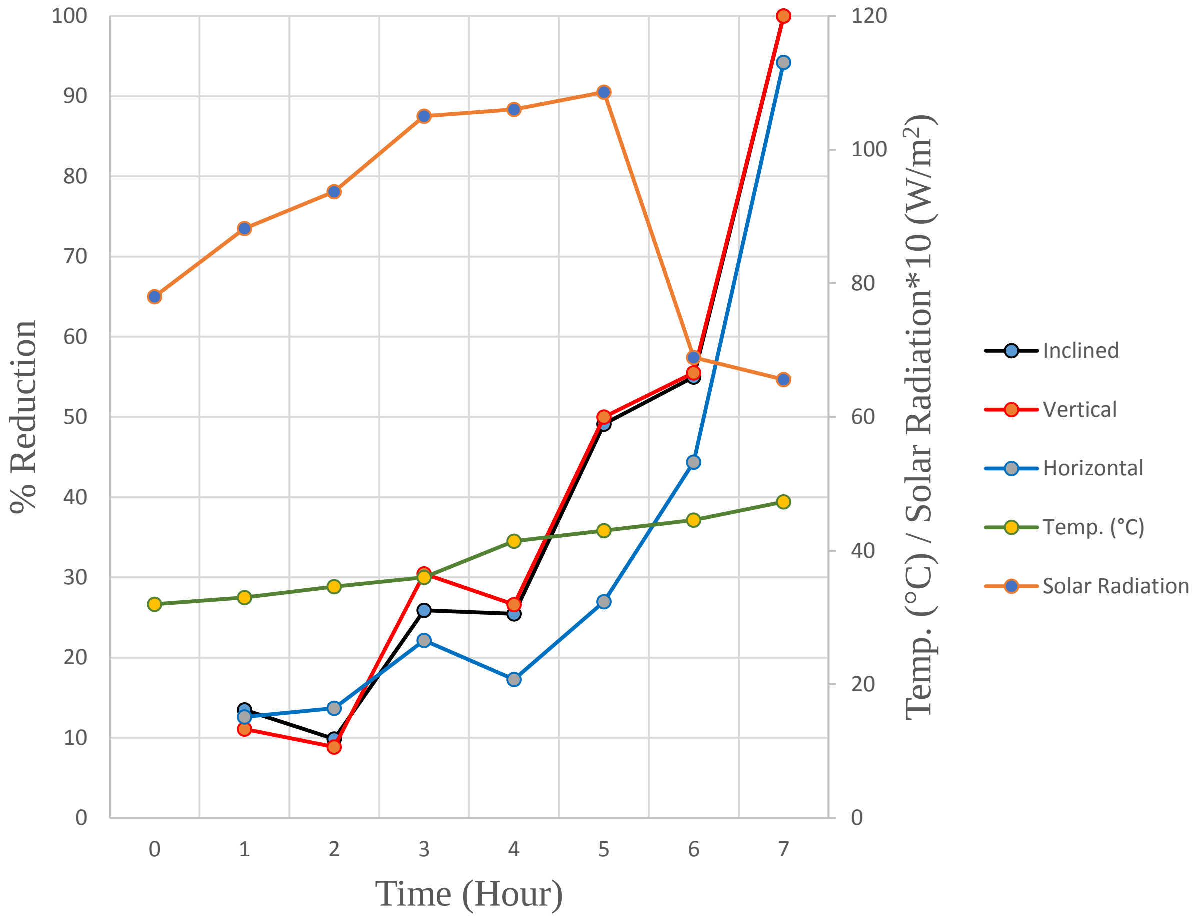

Figure 4.2.3.2 Shows the % Reduction vs Time Graph

4.2.4 Experiment No: 04

This experiment has been conducted in 12.08.2014 using PET bottle for different angular variation of PET bottle such as horizontal, vertical and inclined. The weather condition was partially cloudy and clouds were present in the sky. We find the sample water turbidity 39.2 FTU. The pH value of the sample water was 5.2 .

The following graph is drawn after the analysis of data from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

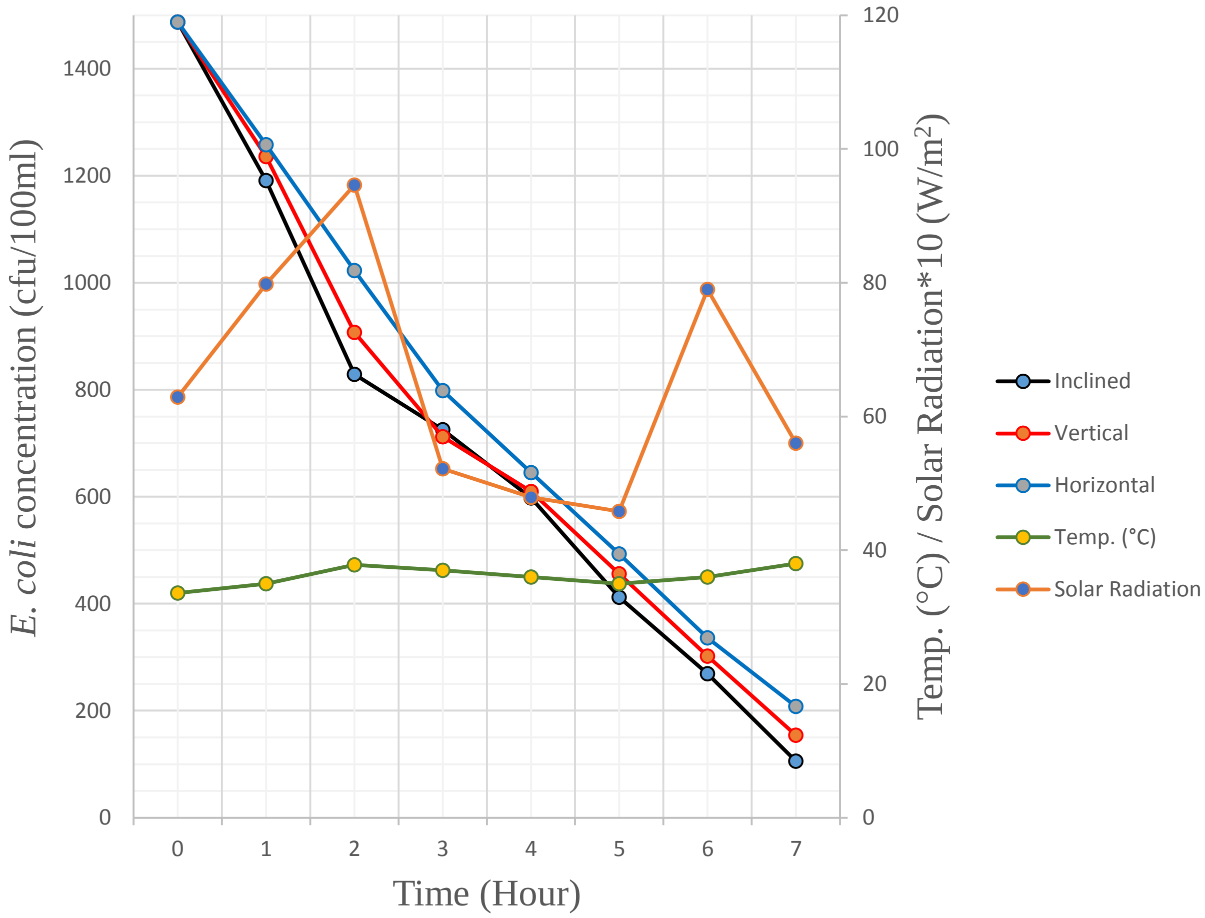

Figure 4.2.4.1 Shows the E. coli, Temp., Solar Radiation vs Time Graph

Table:4.4 Hourly Exposure, temperature, percentage reduction, solar radiation and Amount of E. coli.

Time	Hour	E. coli (c.f.u/100ml)			% Reduction per hour			% Reduction			Temperature (°C)	Solar Radiation (W/m^2)
		Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal		
08:30 am	Initial	1487	1487	1487	-	-	-	-	-	-	33.6	629
09:30 am	1st	1191	1236	1258	19.91	16.88	15.40	19.91	16.88	15.40	35	798
10:30 am	2nd	829	907	1023	30.39	26.62	18.68	44.25	39.00	31.20	37.8	946
11:30 am	3rd	725	712	798	12.55	21.50	21.99	51.24	52.12	46.33	37	522
12:30 pm	4th	598	610	645	17.52	14.33	19.17	59.78	58.98	56.62	36	479
01:30 pm	5th	412	456	493	31.10	25.25	23.57	72.29	69.33	66.85	35	458
02:30 pm	6th	269	302	336	34.71	33.77	31.85	81.91	79.69	77.40	36	790
03:30 pm	7th	106	154	208	60.59	49.01	38.10	92.87	89.64	86.01	38	560

The following graph is drawn after calculating % reduction rate per hour and cumulative % reduction from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

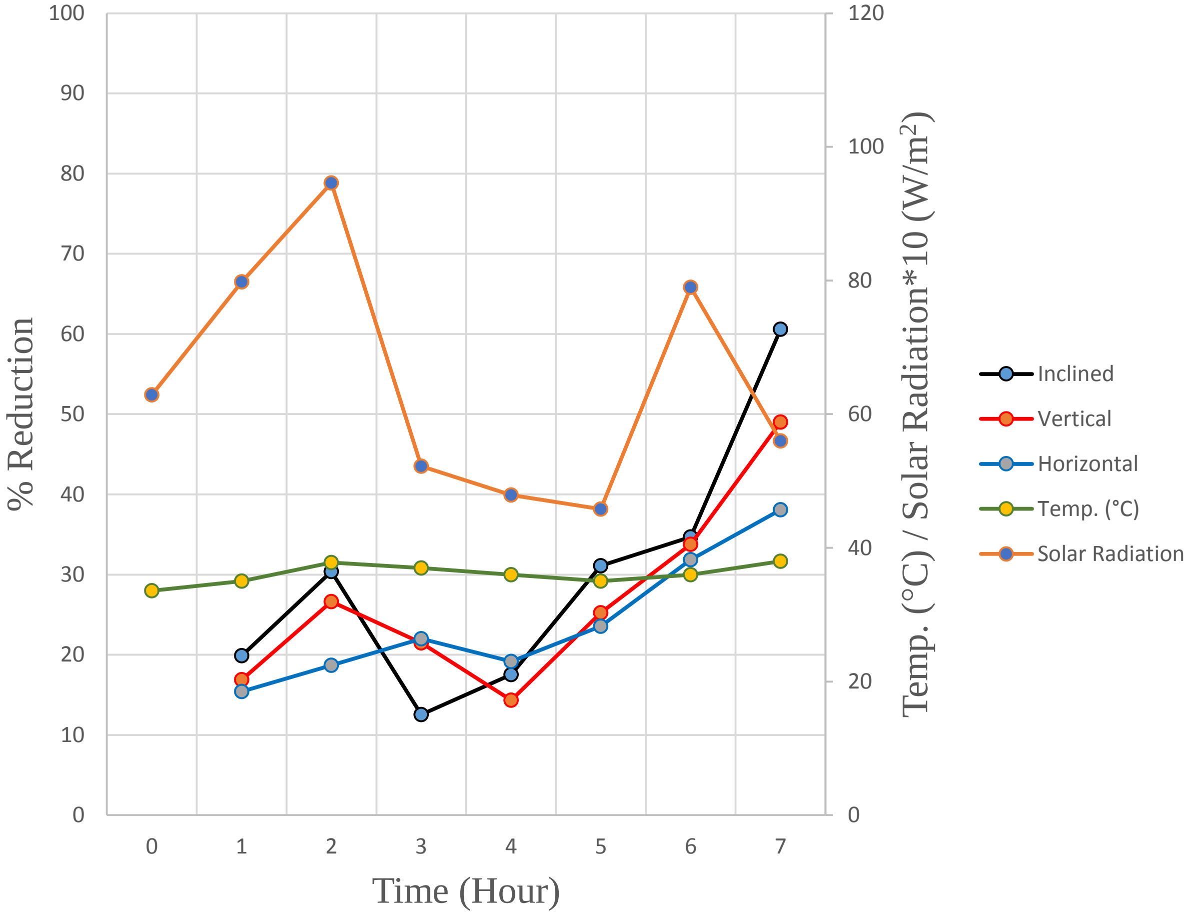

Figure 4.2.4.2 Shows the % Reduction vs Time Graph

4.2.5 Experiment No: 05

This experiment has been conducted in 02.09.2014 using PET bottle for different angular variation of PET bottle such as horizontal, vertical and inclined. The weather condition was partially cloudy and clouds were present in the sky. We find the sample water turbidity 57.8 FTU. The pH value of the sample water was 5.7 .

The following graph is drawn after the analysis of data from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

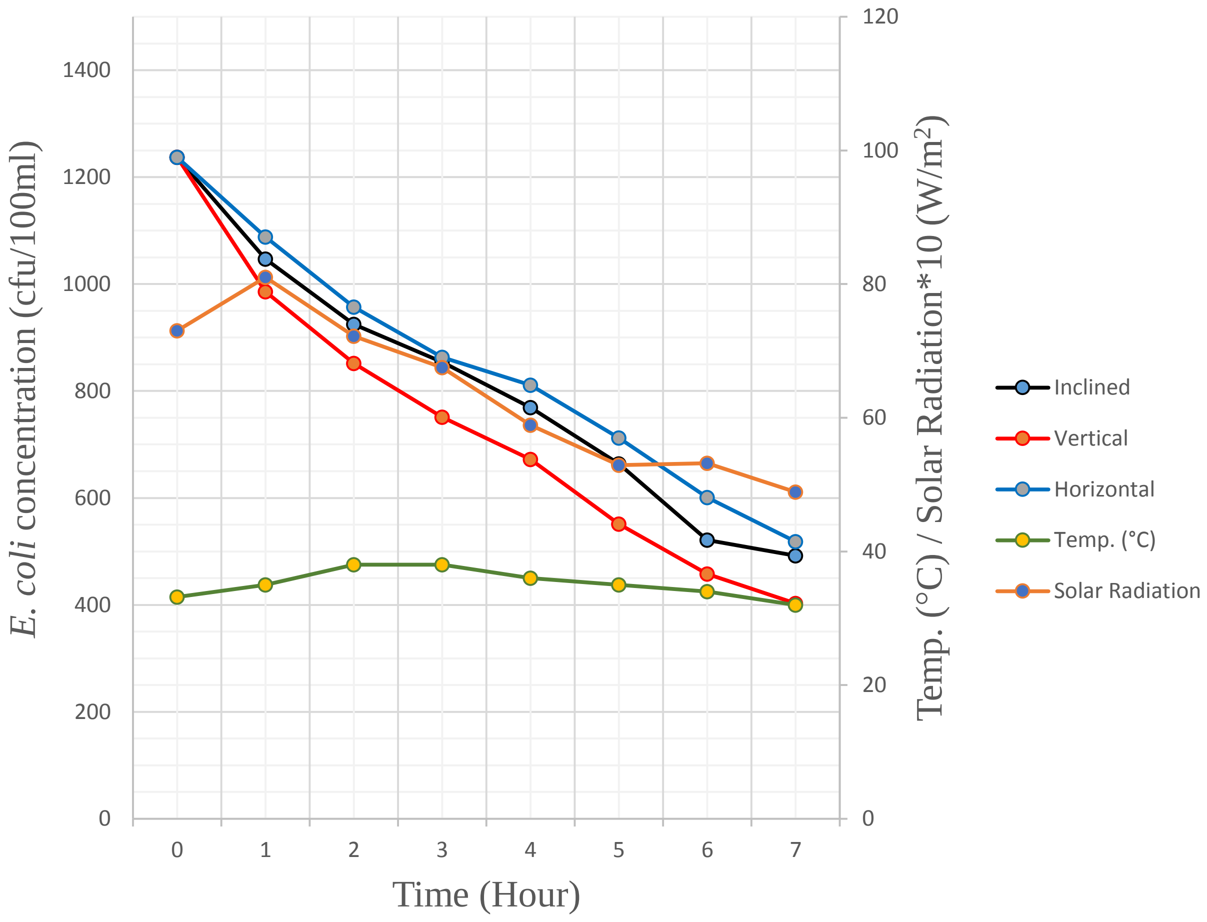

Figure 4.2.5.1 Shows the E. coli, Temp., Solar Radiation vs Time Graph

Table:4.5 Hourly Exposure, temperature, percentage reduction, solar radiation and Amount of E. coli.

Time	Hour	E. coli (c.f.u/100ml)			% Reduction per hour			% Reduction			Temperature (°C)	Solar Radiation (W/m^2)
		Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal		
08 am	Initial	1237	1237	1237	-	-	-	-	-	-	33.2	730
09 am	1st	1047	986	1088	15.36	20.29	12.05	15.36	20.29	12.05	35	810
10 am	2nd	925	852	957	11.65	13.59	12.04	25.22	31.12	22.64	38	722
11 am	3rd	854	751	863	7.68	11.85	9.82	30.96	39.29	30.23	38	675
12 pm	4th	769	672	811	9.95	10.52	6.03	37.83	45.68	34.44	36	589
01 pm	5th	664	551	712	13.65	18.01	12.21	46.32	55.46	42.44	35	529
02 pm	6th	521	458	601	21.54	16.88	15.59	57.88	62.97	51.41	34	532
03 pm	7th	492	403	518	5.57	12.01	13.81	60.23	67.42	58.12	32	489

The following graph is drawn after calculating % reduction rate per hour and cumulative % reduction from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

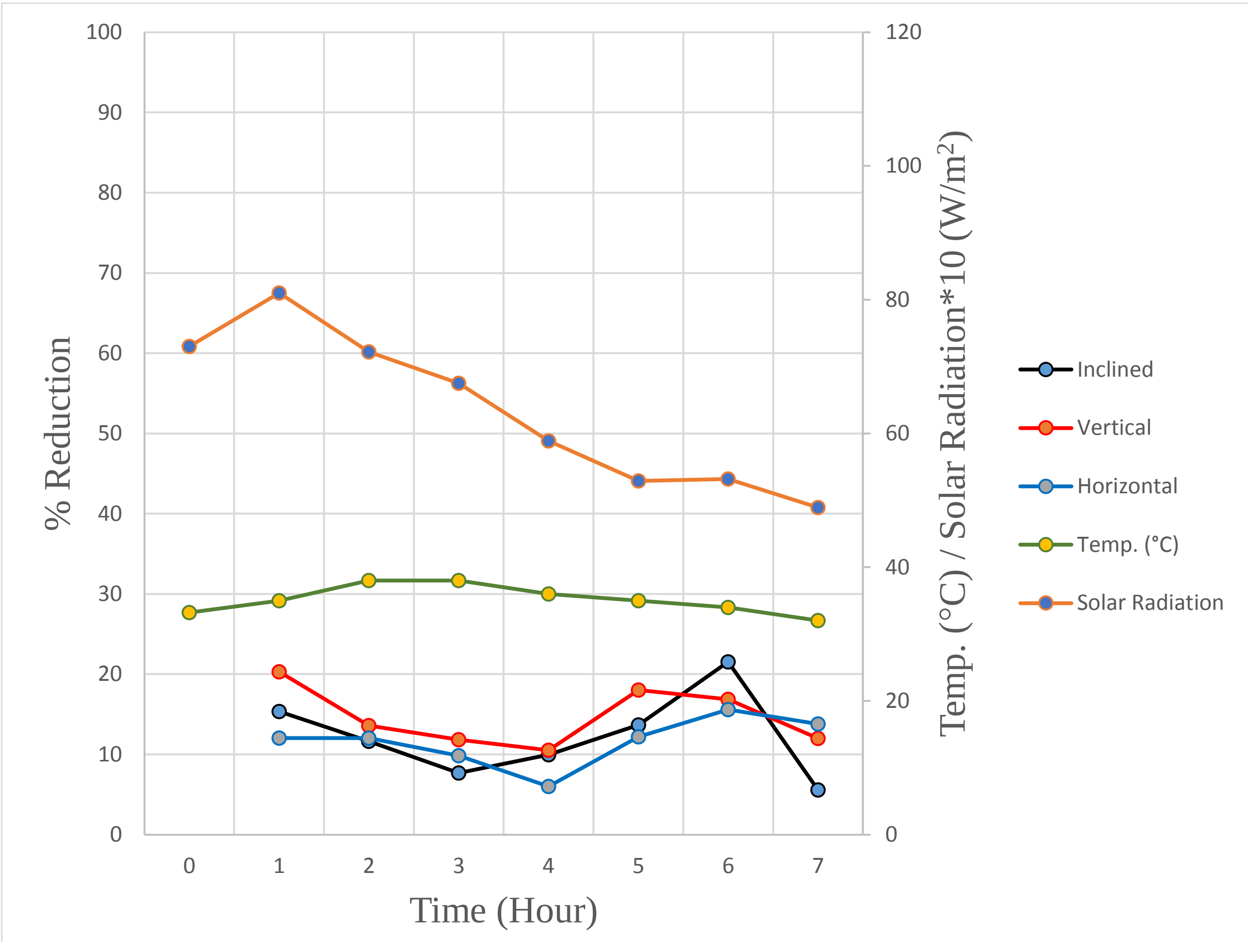

Figure 4.2.5.2 Shows the % Reduction vs Time Graph

4.2.6 Experiment No: 06

This experiment has been conducted in 09.09.2014 using PET bottle for different angular variation of PET bottle such as horizontal, vertical and inclined. The weather condition was partially cloudy and clouds were present in the sky. We find the sample water turbidity 57.8 FTU. The pH value of the sample water was 5.7 .

The following graph is drawn after the analysis of data from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

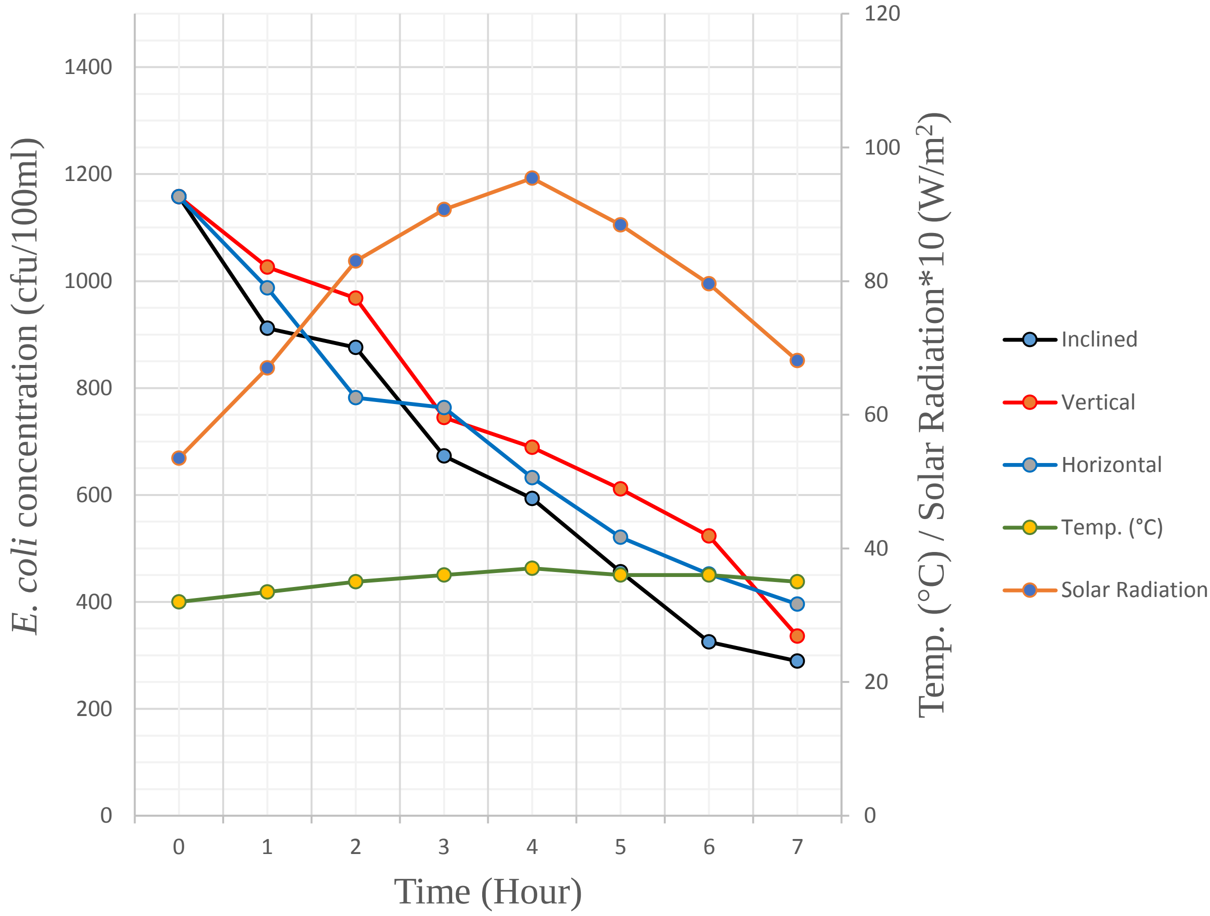

Figure 4.2.6.1 Shows the E. coli, Temp., Solar Radiation vs Time Graph

Table:4.6 Hourly Exposure, temperature, percentage reduction, solar radiation and Amount of E. coli.

Time	Hour	E. coli (c.f.u/100ml)			% Reduction per hour			% Reduction			Temperature (°C)	Solar Radiation (W/m^2)
		Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal	Inclined	Vertical	Horizontal		
08:40 am	Initial	1158	1158	1158	-	-	-	-	-	-	32	535
09:40 am	1st	912	1026	987	21.24	11.40	14.77	21.24	11.40	14.77	33.5	670
10:40 am	2nd	876	968	782	3.95	5.65	20.77	24.35	16.41	32.47	35	830
11:40 am	3rd	673	745	763	23.17	23.04	2.43	41.88	35.66	34.11	36	907
12:40 pm	4th	593	689	632	11.89	7.52	17.17	48.79	40.50	45.42	37	954
01:40 pm	5th	456	611	521	23.10	11.32	17.56	60.62	47.24	55.01	36	884
02:40 pm	6th	325	523	452	28.73	14.40	13.24	71.93	54.84	60.97	36	796
03:40 pm	7th	289	336	396	11.08	35.76	12.39	75.04	70.98	65.80	35	681

The following graph is drawn after calculating % reduction rate per hour and cumulative % reduction from Appendix A. In the Graph the black, red and blue lines represents the amount of E. coli in different times. The green and orange lines represent the water temperature and solar radiation with respect to time.

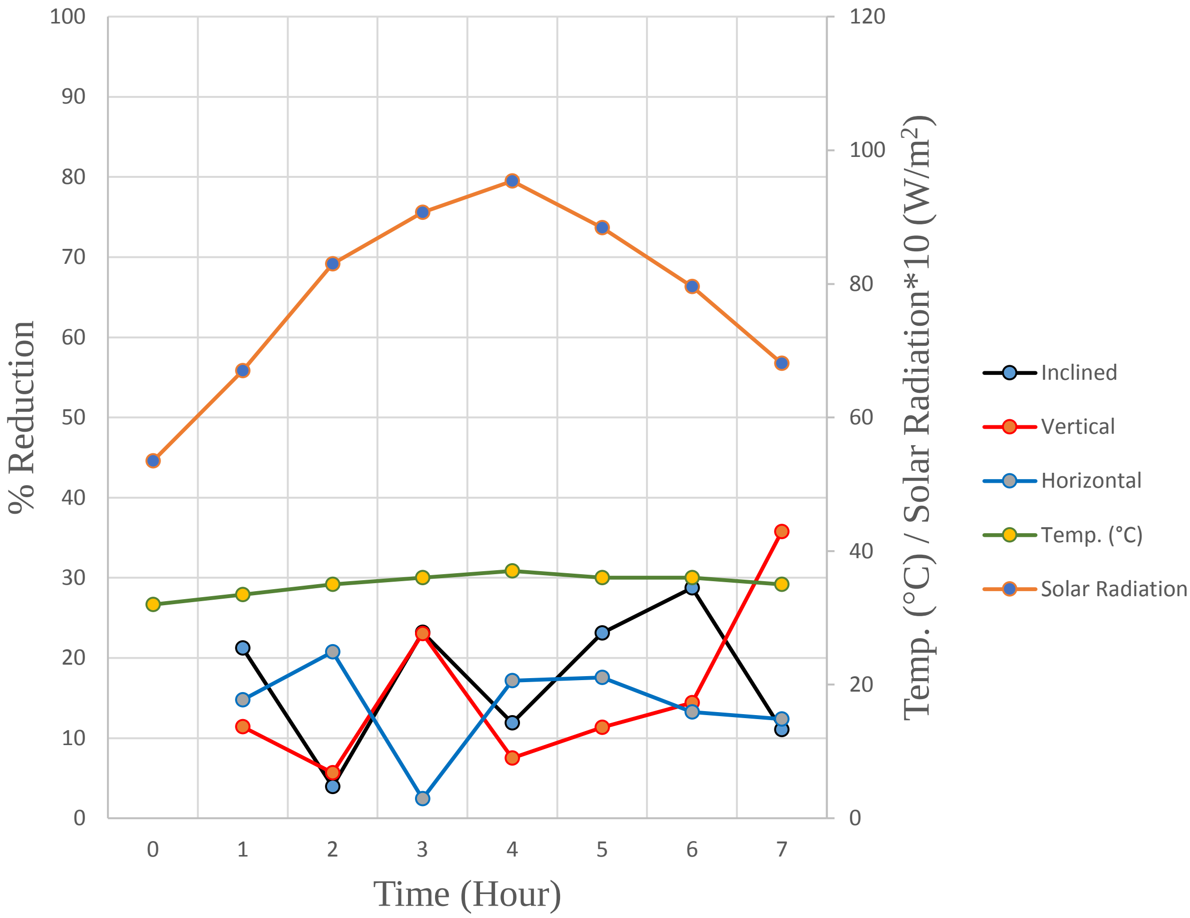

Figure 4.2.6.2 Shows the % Reduction vs Time Graph

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research was conducted to study the inactivation of E. coli by solar radiation and heating. The Effectiveness is compared by undertaking the SODIS experiment with some variations like by in different weather condition (sunny & cloudy), conducting experiment using samples having different turbidity. By using different angular variation of PET bottles like exposing it into sunlight horizontally, vertically and keeping it inclined. To quantify the inactivation effects of heating only, laboratory experiments were conducted. In analyzing the results of these experiments, the following conclusions were drawn:

- At least 7 hours of exposure in sunny day reduce significant amount (around 96%-100%) of *E. coli*.
- *E. coli* reduction rate is higher in sunny days than the partially cloudy days.
- Less amount of E. coli reduction occurs when turbidity is high.
- For a specific condition angular variation don't have much significance on *E. coli* reduction.
- But inclined bottle position has slightly higher reduction then other two position.
- In case of cloudy day comparatively very little inactivation occurs.

5.2 Recommendations

Based on this study the following points may be considered for improving future analysis:

- Undertaking the SODIS experiment with some variations like using reflected surface or surface having less reflection under the sample bottles and respective inactivation of several parameters could have been tested.
- SODIS is not useful to treat large volumes of water. So variation could have been tested by sampling different amount of water like 0.5 liter, 1 liter, 1.5 liter, 5 liter etc.
- In case of Laboratory testing we could test the inactivation of vibrio Cholera, Salmonella and Shigella bacteria, these parameters are also very important.
- The change in bacterial growth could have been observed in terms of pH.

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APENDIX A

Values of hourly *E. coli* on 10.06.2014

Date & Variations	Time	Hour	E.coli (c.f.u/100ml)			Temperature (C)	Solar Radiation (w/m^2)
			Inclined	Vertical	Horizontal		
10.06.2014	08:30 am	Initial	1128	1128	1128	30	525
IUT Lake Water	09:30 am	1st	922	934	939	32	540
PET Bottle	10:30 am	2nd	722	741	751	33	625
Turbidity : 59.6 FTU	11:30 am	3rd	512	556	567	36	760
pH : 5.7	12:30 pm	4th	382	418	409	37	640
	01:30 pm	5th	245	254	267	36	548
	02:30 pm	6th	103	116	121	35.5	523
	03:30 pm	7th	34	67	67	36	528

APENDIX B

Values of hourly *E. coli* on 17.06.2014

Date & Variations	Time	Hour	E.coli (c.f.u/100ml)			Temperature (C)	Solar Radiation (w/m^2)
			Inclined	Vertical	Horizontal		
17.06.2014	08 am	Initial	1256	1256	1256	33	618
IUT Lake Water	09 am	1st	956	966	977	35	640
PET Bottle	10 am	2nd	777	800	800	37	720
Turbidity : 41.1 FTU	11 am	3rd	677	700	677	38	450
pH : 5.5	12 pm	4th	557	622	511	37	218
	01 pm	5th	511	522	500	28	92
	02 pm	6th	500	445	444	27	73
	03 pm	7th	488	422	444	27	74

APENDIX C

Values of hourly *E. coli* on 09.08.2014

Date & Variations	Time	Hour	E.coli (c.f.u/100ml)			Temperature (C)	Solar Radiation (w/m^2)
			Inclined	Vertical	Horizontal		
09.08.2014	08:45 am	Initial	1054	1054	1054	32	780
IUT Lake Water	09:45 am	1st	912	937	921	33	882
PET Bottle	10:45 am	2nd	822	854	795	34.6	937
Turbidity : 41.8 FTU	11:45 am	3rd	609	594	619	36	1050
pH : 5.8	12:45 pm	4th	454	436	512	41.4	1060
	01:45 pm	5th	231	218	374	43	1086
	02:45 pm	6th	104	97	208	44.6	689
	03:45 pm	7th	0	0	12	47.3	656

APENDIX D

Values of hourly *E. coli* on 12.08.2014

Date & Variations	Time	Hour	E.coli (c.f.u/100ml)			Temperature (C)	Solar Radiation (w/m^2)
			Inclined	Vertical	Horizontal		
12.08.2014	08 am	Initial	1487	1487	1487	33.6	629
IUT Lake Water	09 am	1st	1191	1236	1258	35	798
PET Bottle	10 am	2nd	829	907	1023	37.8	946
Turbidity : 39.2 FTU	11 am	3rd	725	712	798	37	522
pH : 5.2	12 pm	4th	598	610	645	36	479
	01 pm	5th	412	456	493	35	458
	02 pm	6th	269	302	336	36	790
	03 pm	7th	106	154	208	38	560

APENDIX E

Values of hourly *E. coli* on 02.09.2014

Date & Variations	Time	Hour	E.coli (c.f.u/100ml)			Temperature (C)	Solar Radiation (w/m^2)
			Inclined	Vertical	Horizontal		
02.09.2014	08 am	Initial	1237	1237	1237	33.2	730
IUT Lake Water	09 am	1st	1047	986	1088	35	810
PET Bottle	10 am	2nd	925	852	957	38	722
Turbidity : 57.8 FTU	11 am	3rd	854	751	863	38	675
pH : 5.7	12 pm	4th	769	672	811	36	589
	01 pm	5th	664	551	712	35	529
	02 pm	6th	521	458	601	34	532
	03 pm	7th	492	403	518	32	489

APENDIX F

Values of hourly *E. coli* on 09.09.2014

Date & Variations	Time	Hour	E.coli (c.f.u/100ml)			Temperature (C)	Solar Radiation (w/m^2)
			Inclined	Vertical	Horizontal		
09.09.2014	08:40 am	Initial	1158	1158	1158	32	535
IUT Lake Water	09:40 am	1st	912	1026	987	33.5	670
PET Bottle	10:40 am	2nd	876	968	782	35	830
Turbidity : 51.7 FTU	11:40 am	3rd	673	745	763	36	907
pH : 5.9	12:40 pm	4th	593	689	632	37	954
	01:40 pm	5th	456	611	521	36	884
	02:40 pm	6th	325	523	452	36	796
	03:40 pm	7th	289	336	396	35	681