Solar Water Disinfection

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Abstract

The aim of my project was to determine whether solar disinfection is a suitable process to create safe drinking water. Reviewing past experiments and other information on my topic I discovered that it has been used as a viable disinfection option in developing countries with great success. I also found that a simple heat lamp is a suitable replacement for 6 hours of extremely hot sunlight, but it still does not have the UV rays that sunlight has which is so effective in killing bacteria. Further background research indicated that the heating element of both the sun and heat lamps is very effective and speeds up the disinfection process.

My investigation was carried out at home with creek water used to test the disinfecting abilities of both sunlight and the heat lamps. I tested different levels of covered (closed to light) bottles to indicate a process of extreme contamination to disinfection ranging from 25% covered up to 100% covered. This is also effective in proving the affectivity of the heat.

My results were as expected showing a degree of complete disinfection in uncovered (open to light) bottles in both sunlight and heat lamp. My results also indicated that it needs six hours exposure to light and be completely exposed to uncovered bottles otherwise complete disinfection is not guaranteed. This investigation informed me to the astounding affectivity of solar disinfection and how easy the process is.

My conclusions are based on results I obtained that were both repeated and averaged and through comparison with previous experiments I discovered that my results were quite accurate. I determined that Solar Disinfection is in fact effective in disinfecting contaminated water at a low cost. I hope to continue my research into this process by studying the synergistic effect of UV rays and infrared heat in relation to disinfection. This synergistic effect would be interesting and prove some challenges.

Background Information

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. The specific type of solar disinfection that will be used in this experiment is Solar Ultraviolet water disinfection. It involves the process where water is disinfected using the UV and Infrared rays as well as the heat created by sunlight. In this process polyethylene terephthalate (PET) bottles are filled with contaminated drinking water and left in the sun for approximately 6 hours. The 6 hours of direct sunlight has been proven to completely disinfect contaminated water, except water containing toxic chemicals or heavy metals. At temperatures higher than 45°C the synergistic effort of both the UV-A radiation and the heat can further advance the disinfection efficiency up to 3 times more effective than usual. The Red Cross says that it is, "impressive way of contributing by the simplest means to making water supplies better and safer."(2010)

Solar Disinfection uses two components of the sunlight for water disinfection. The first, UV-A radiation has a germicidal effect. The second component, infrared radiation, raises the water temperature and is known as pasteurization when the water temperature is raised to 40-45°C. The combined use of both UV-A radiation and heat produce a synergistic effect enhancing the efficiency of the process.

Solar Radiation can be divided into three ranges of wavelength: UV radiation, visible light and infrared radiation. The human eye cannot perceive UV radiation; it is very aggressive towards the skin and eyes and destroys living cells. Luckily most of the UV-C and UV-B light is absorbed by the ozone layer saving us from exposure to this. These types of UV are classified in the wavelength of 200-320 nanometers and are very harmful to all living cells. The wavelength of UV radiation that reaches the surface of the earth is called UV-A and ranges between 320-400 nanometers. The UV-A light has a lethal effect on all human pathogens present in water for example the coliform group. These pathogens are not well adapted to the aggressive sunlight and are more suited to conditions in the human gastrointestinal tract. UV-A radiation directly interacts with the DNA, nucleic acids and enzymes of the living cells, changes the molecular structure and leads to cell death. UV radiation also reacts with oxygen dissolved in the water and produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides). These reactive molecules also interfere with cell structures and kill the pathogens.

Another aspect of the sunlight is the long-wave radiation called infrared. The human eye cannot see this radiation, but we can feel the heat produced by light of the wavelength beyond 700nm. The infrared radiation absorbed by the water is responsible for heating it up. It can be seen that water does not have to be boiled in order to kill 99.9% of the microorganisms. Heating up the water to 50-60°C for one hour has the same effect.

At a temperature of approximately 30°C water needs to be exposed to a dose of 350-450 nm of solar radiation for 5 hours; this corresponds to around 6 hours of sunshine in mid-latitude summer conditions. This is required in order to have a reduction of enough bacteria to have safe drinking water but under these conditions only UV-A

radiation is under effect. The die-off rate of these bacterium significantly increases when the UV-A radiation and the excess heat is added to the water. When the water temperature is raised to anywhere above 45°C the synergistic effect of UV-A radiation and the temperature of the water only requires one hour of sun exposure.

Bacteria are often the biggest point of concern and the main priority for elimination with solar water disinfection. Of all the microorganisms present in water, the most harmful contaminant is bacteria. This microorganism is responsible for causing various harmful diseases like dysentery, cholera, hepatitis, giardiasis and typhoid. A well-known group of bacteria known for causing some of these diseases is the Coliform group of bacteria. It is not a single type of bacteria but a group that contains many strains such as E-Coli (found in fecal matter). This group of bacteria is ever present in nature and most groups are harmless. Ingesting or being exposed to this bacteria does not necessarily mean sickness and factors such as other bacteria present in the sample, as well as your immune systems' defense, are factors in determining how this bacteria affects you. These specialized bacteria prefer a humid and hot environment such as the human body.

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 and exposed to the harsh conditions outside the human body. They are not able to resist increased temperatures and they do not have any protection mechanisms fighting UV radiation. Therefore, temperature and UV radiation can be used to inactivate the pathogens and this is why Solar Water disinfection is such an effective method of purifying water. It is important to understand that Solar Water disinfection does not offer completely sterile water and organisms other than human pathogens can still survive in the water. These pathogens have adapted to survive in the water and will most likely thrive in the PET bottles. Although a sterile water source is not guaranteed by the process of Solar water Disinfection the pathogens that do survive are most likely not harmful to the human body and will not show up when tested for.

The efficiency of the Solar Disinfection process is dependent on the amount of sunlight available. Solar radiation however is unevenly distributed and varies in intensity from one geographical location to another depending on latitude, season and the time of the day. The recommended latitude that best serves the process of Solar Water Disinfection is between 15-35° N and 15-35°S. Sydney is positioned at a latitude of 33°S making it eligible for this experiment and can guarantee results if a suitable day was chosen to conduct the experiment.

Water turbidity is another factor affecting the success of the experiment and could also be a variable to take into consideration. Suspended particles in the water reduce the penetration of solar radiation into water and protect microorganisms from being irradiated. Therefore, the disinfection efficiency of Solar Disinfection is reduced in turbid water. The process requires relatively clear water with a Nephelometric Turbidity (NTU) reading of less than 30.

Solar Disinfection is more efficient in water containing high levels of oxygen: Sunlight produces highly reactive forms of oxygen (oxygen free radicals and

hydrogen peroxides) in the water. These reactive molecules react with cell structures and kill the pathogens. Recent research however revealed that the bottles should be shaken only at the beginning of the Solar Disinfection process. Once the bottles are exposed to the sun, they should not be moved anymore, as continuous shaking of the bottles during the solar exposure will reduce the efficiency of the process. Dr Daniels of the Swiss Federal Institute of Aquatic Science and Technology claims that, "Research has shown that pathogenic bacteria and viruses are completely destroyed by the UV-A radiation and without it there would be no Solar Disinfection." Dr Daniels also claims that the "oxidizing of the water by shaking the bottle at the start of the process has proven to make the process up to 3 times as effective."(2011)

Various types of transparent plastic materials are good transmitters of light in the UV-A and visible range of the solar spectrum. Plastic bottles are made of either PET (Polyethylene Terephthalate) or PVC (Poly Vinyl Chloride). Both materials contain additives like UV-stabilizer to increase their stability or to protect them and their content from oxidation and UV radiation. The use of bottles made from PET instead of PVC is recommended as PET contains much less additives than bottles made from PVC. Therefore, for this experiment the purposes of PET are much more useful and will yield better results.

The use of an infrared heat lamp produces the same temperature change that exterminates bacteria but it does not have the UV-A element that destroys the microorganisms that is in sunlight. While the visible light in sunlight operates on a wavelength of 380-700nm, the wavelengths from infrared are recorded at 700-1000nm. This is why sunlight is often more successful at disinfecting the water and killing the bacteria. Although the infrared from a light can be magnified and more focused than sunlight it is customary that sunlight works more effectively than the infrared from a heat lamp. "Solar Disinfection reaches its peak at 254nm out of reach of infrared radiation but very close to the bounds of visible light"(Kang 2012)

In this experiment the theory of Solar disinfection itself is being tested as well as the single element of heating from a heat lamp. The synergistic effect from the heating of water as well as the UV-A radiation will not be a factor in this experiment as it is not mid summer and the maximum temperature that will be achieved at this time will be around 30°C which is not enough to encourage the synergistic effect enough for proper solar disinfection. The harmful pathogens that is being eliminated by this process struggle to survive outside of the comfort conditions in the human body and solar disinfection is ensuring that the pathogens are destroyed. The full six hours of sunlight that is being used to disinfect the water will most likely disinfect the water of all harmful pathogens and result in drinking standard water. The six hours of exposure to the infrared heat lamp will most likely not eliminate all the pathogens in the water and a further time will be needed to disinfect the water to a drinking standard.

Aim

To determine what effect both elements of solar disinfection (UV-A and Infrared) have on the disinfection of contaminated creek water over a period of six hours (recommended time for solar disinfection).

Hypothesis

That solar disinfection will be successful in removing most of the harmful pathogens from the contaminated water. The combination of 30°C infrared temperature influence and the UV-A radiation from the sun will most likely be more successful than the element of Infrared from a heat lamp by itself. This experiment will also show the relationship of disinfection of the water to what percentage of the bottle was exposed to the sun.

Materials used and cost:

Material/Piece of Equipment	Cost	Availability
Petri dishes x 40	$22 for all 40	High
Agar powder (23g)	$20	Medium
Heat lamp x 1	In possession before experiment	High
Incubator x 1	In possession before experiment	Very Low
PET Bottle x 36	$15 for all	High
Duck Tape x 1	$3	High
36 x 250ml creek water	-	High
Latex gloves (box)	$5	High
Stove top	-	High
Permanent Marker x 1	$2	High
Crate x 2	-	High
Pot	-	High
Disinfectant	-	High
Dust mask	$1	High
Poncho	$0.50	High
Glass Stirring Rod	$3	High

Risks/Hazards and Precautions

The experiment that was performed had several risks and hazards involved, but these were mitigated by numerous precautions to ensure the safety of the scientist and others around him. The risks included scenarios that could cause primary damage such as sickness or injury. Secondary risks identified included issues such as safe disposal of hazardous materials or the spreading of harmful bacteria. The first risk encountered in this experiment was the collecting of contaminated creek water from a local stream. The stream is connected to a stormwater disposal unit and is not very fast flowing. The stream also reeks terribly and has visible contamination.

A precaution to collecting water from this stream and not being infected or spreading any bacteria was to wear a dust mask, latex gloves and a poncho. The dust mask was to stop the spread of any bacteria from the mouth and nasal area. The latex gloves were to protect my hands from bacteria as well as any open cuts and to ensure clean hands after the experiment. The poncho was to ensure that no bacteria could get on clothes and later spread to the face and mouth and cause secondary infections. Without the poncho bacteria would get on clothes and spread to the rest of the environment. After collecting the water from the stream in the 36 PET bottles further precautions were taken. The dust mask, poncho and gloves were disposed of and the scientist clothes were changed along with a shower with soap.

Further precautions were taken during the experiment. When the agar was being produced gloves were worn to ensure disinfection. Heat gloves were worn at all times to ensure no burns as well as an apron to ensure the safety of the scientist. When the samples were collected from the PET bottles and placed onto the agar plates gloves were worn again to stop the spread of germs. The other hazard that was encountered was the malfunction of the incubator. The malfunction is not common but it could overheat and start a fire. This was avoided by placing the incubator in a family area during the day where everybody could see it and under the smoke detector at night to provide and early warning system if something went wrong. When the agar plates were handled after incubation extreme care was taken to reduce the spread of germs and to keep them as contained as possible. This was achieved through common sense and adult supervision as well as gloves.

Photographic Evidence

Method

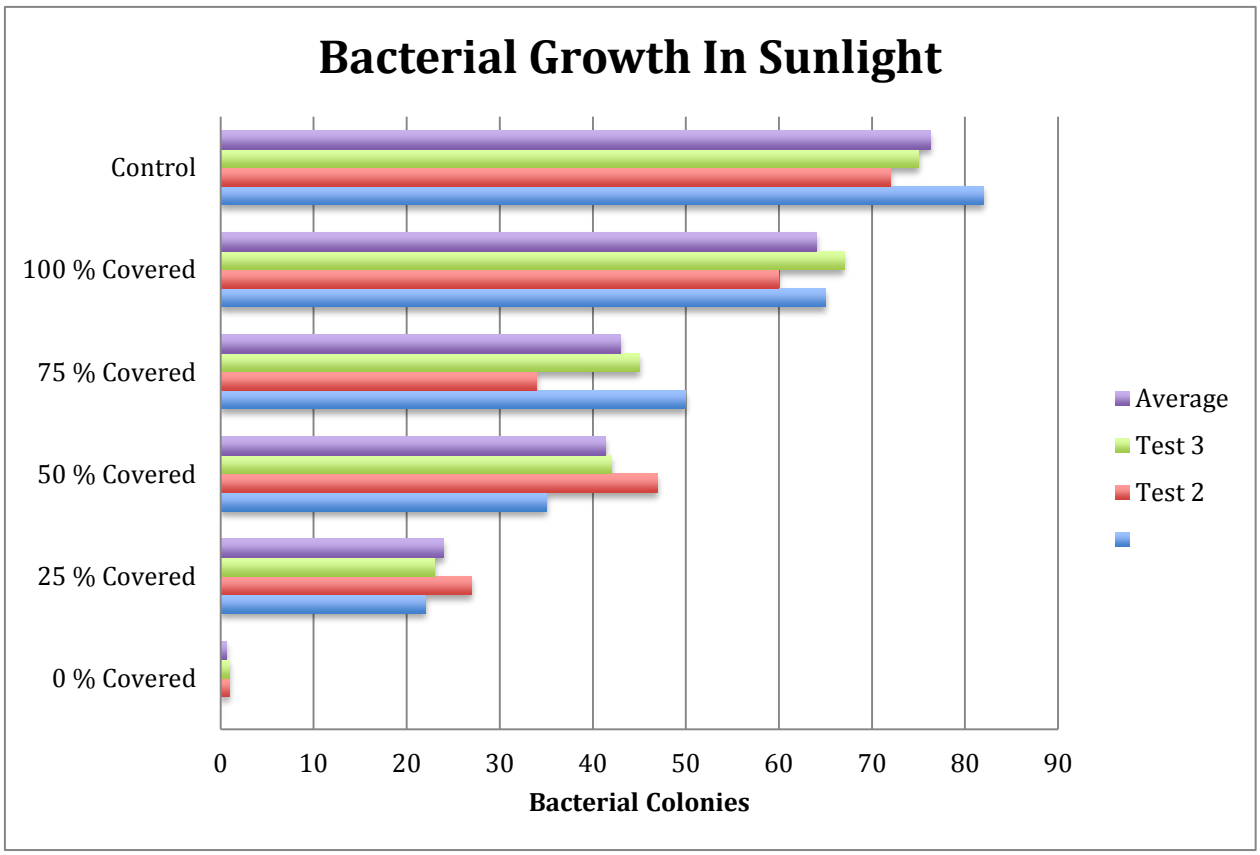
- Equipment was gathered for the experiment.
- All equipment was cleaned, disinfected and stored so it cannot be contaminated. (In disinfected tubs etc.)
- All 36 PET bottles were emptied of the original water.
- All 36 PET bottles and a tub were taken down to the local creek.
- The tub was filled with 5 litres of water and 9 bottles were filled from this. This was done to ensure that all water bottles had the same amount of Turbidity.
- This process was repeated until all 36 PET bottles were filled.
- The 36 PET bottles were taken back to the house.
- The 36 PET bottles were divided into two sections of 18
- 18 of them were marked 'Inside Light' while the other 18 were marked 'Outside Sunlight'.
- The 'Outside Sunlight' marked PET bottles were then again divided into six.
- 3 'Outside Sunlight' bottles were unpainted and marked 'Outside Sunlight Control'
- 3 'Outside Sunlight' bottles were marked 'Outside sunlight 0% covered'
- 3 'Outside Sunlight' bottles were marked 'Outside sunlight 25% covered'
- 3 'Outside Sunlight' bottles were marked 'Outside sunlight 50% covered'
- 3 'Outside Sunlight' bottles were marked 'Outside sunlight 75% covered'
- 3 'Outside Sunlight' bottles were marked 'Outside sunlight 100% covered'
- Depending on the amount of covering needed the bottles were covered from 25-100% in Duck tape
- This process was done by measuring the bottle (21.5cm) and dividing it into 3 sections of 5cm from the bottom and then 6.5cm on top because of the tops' size.
- All 18 'Outside Sunlight' bottles were then placed in a crate which said 'Outside control'
- 3 'Inside light bottles were marked 'Inside Light Control'
- 3 'Inside light bottles were marked 'Inside Light 0% covered'
- 3 'Inside light bottles were marked 'Inside Light 25% covered'
- 3 'Inside light bottles were marked 'Inside Light 50% covered'
- 3 'Inside light bottles were marked 'Inside Light 75% covered'
- 3 'Inside light bottles were marked 'Inside Light 100% covered'

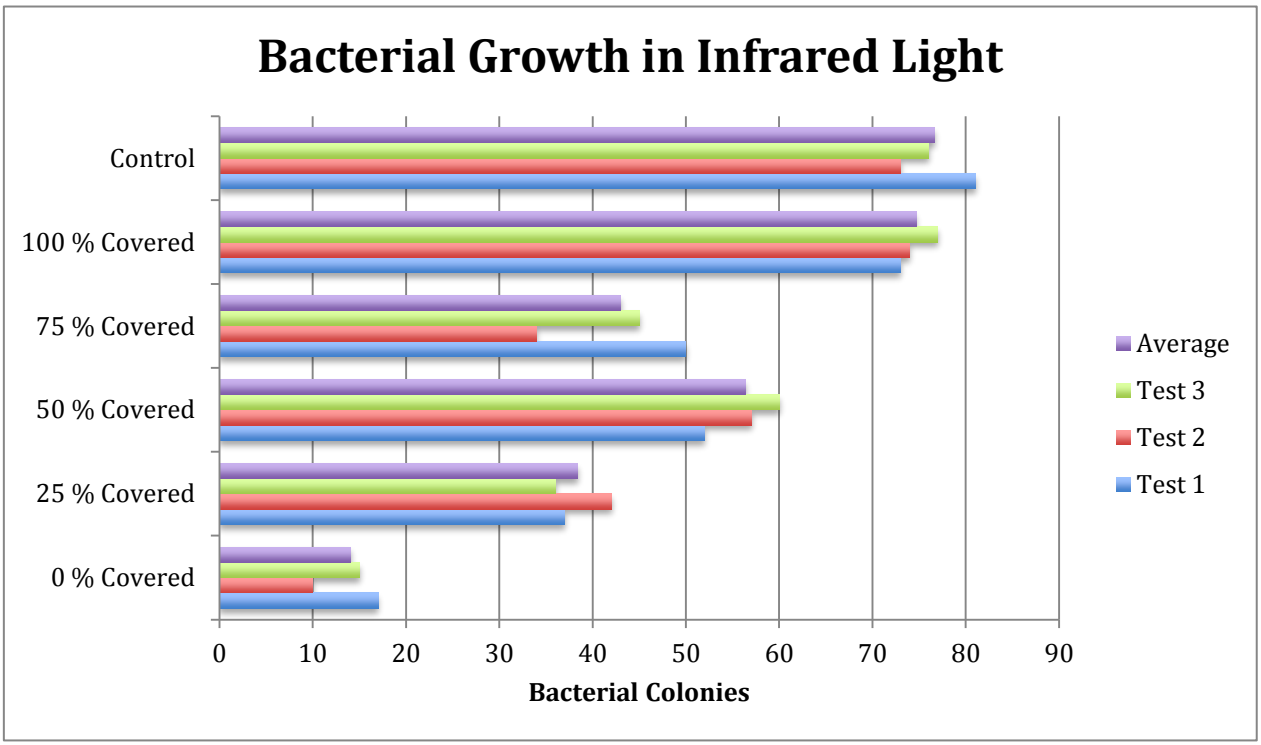
- All 18 ‘Inside light’ bottles marked and covered or not covered they were placed in a crate.
- With the two crates marked ‘Outside Sunlight’ and ‘Inside Light’ ready a sunny day was selected.
- At 10 AM all the ‘Outside Sunlight’ bottles were placed caps facing in a northern direction except the three bottles marked ‘Outside Sunlight Control’, which were placed inside in a dark box with the ‘Inside Light Control’
- A Clock starts timing when the bottles are placed in the sun with alarms at a time of 6 hours after starting time.
- After the 6 hour time is up all ‘Outside light’ bottles were moved inside the house and placed in a relatively dark area.
- 3 of the ‘Inside Light’ bottles were placed under the Infrared heat lamp for 6 hours at a time to ensure equal covering.
- 23g of Nutrient agar powder was dissolved into 1L of Distilled water and placed inside a sterile pot
- This was then boiled to a point where a froth started to appear
- This solution was cooled until it was at 50°C
- The solution was then equally divided into 40 agar plates (25ml a plate)
- These agar plates were then left to cool until the agar hardened.
- These agar plates were then placed inside the fridge upside down to prevent condensation and contamination.
- All the bottles were collected and placed next to a sterile bench.
- The agar plates were taken out of the fridge
- 3 ml of water from each bottle was placed in different agar plates and the plates were marked according to the bottle the water came from
- This 3ml of water was moved around the agar plate with a disinfected glass-stirring rod (which was disinfected after each use) to ensure equal covering.
- 1 extra agar plate was marked ‘Control Agar’ and nothing was added to it
- 1 extra agar plate was marked ‘Control glass rod’ and the disinfected glass rod was moved over the agar.
- 1 extra agar plate was marked ‘Distilled water’ and 3ml of distilled water was moved around the plate to ensure equal covering
- 1 extra plate was marked Tap water’ and 3ml of tap water was added to the agar plate and moved around.
- All these agar plates were placed inside the incubator for 24 hours and collected.
- Results were recorded and moved into graphs and tables.

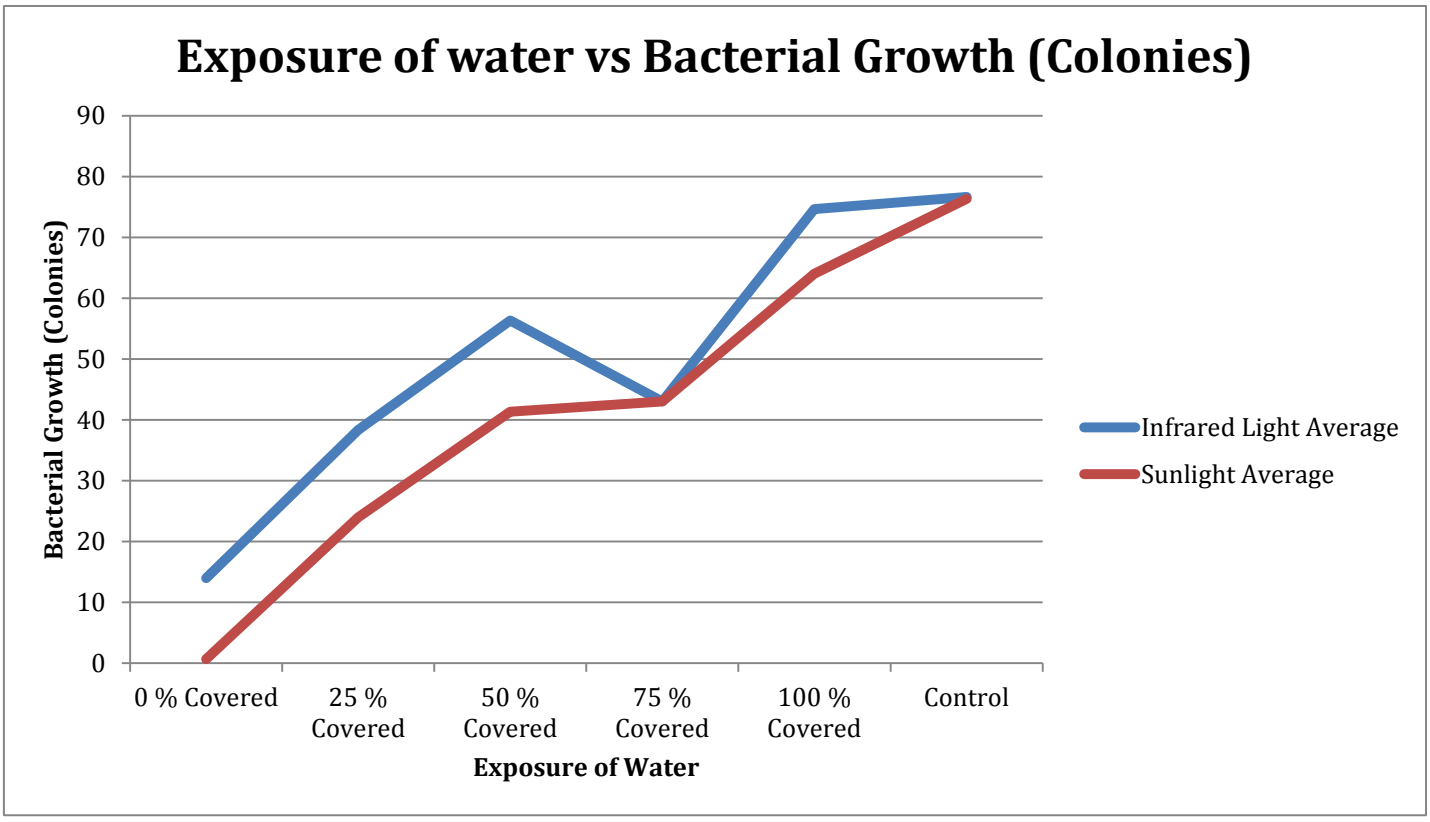
Results

Sunlight				
Percentage Covered	Bacterial Colonies			Average
0 % Covered	0	1	1	0.666666667
25 % Covered	22	27	23	24
50 % Covered	35	47	42	41.33333333
75 % Covered	50	34	45	43
100 % Covered	65	60	67	64
Control	82	72	75	76.33333333

Infrared Heat Lamp				
Percentage Covered	Bacterial Colonies			Average
0 % Covered	17	10	15	14
25 % Covered	37	42	36	38.33333333
50 % Covered	52	57	60	56.33333333
75 % Covered	50	34	45	43
100 % Covered	73	74	77	74.66666667
Control	81	73	76	76.66666667




Bacterial Growth in Infrared Light
Control
100 % Covered
75 % Covered
50 % Covered
25 % Covered
0 % Covered
0
10
20
30
40
50
60
70
80
90
Bacterial Colonies
Average
Test 3
Test 2
Test 1


Exposure of water vs Bacterial Growth (Colonies)
Bacterial Growth (Colonies)
90
80
70
60
50
40
30
20
10
0
0 % Covered
25 % Covered
50 % Covered
75 % Covered
100 % Covered
Control
Exposure of Water
Infrared Light Average
Sunlight Average

Discussion

The original hypothesis of the experiment was that Solar Water Disinfection would in fact work and produce disinfected water. This as well as that it would only work under sunlight and that the Infrared light would work but not to the level that sunlight would. This experiment confirmed that Solar Water Disinfection does work and has proven the original hypothesis true. The results are not much different to what was expected and only a few differences in the repetition of the test as well as the predicted outcomes for the experiment were noted. All three of the completely uncovered bottles that were placed in the sunlight, obtained a result of 0 bacterial colonies on the agar plate that had these bottles' samples on. This was expected although it does proof that no other contamination of the agar plates had occurred between the making of the agar and the placing of the sample onto it. This is also a good verification of the background information and it does confirm the effectiveness of this technique of solar disinfection. The combination of the UV-A and the Infrared light that is produced from the sun does as mentioned before destroy the harmful pathogens.

The completely uncovered bottles that were used in the test of only the infrared light recorded an average of 14 colonies of bacteria per agar plate. This is most likely due to the effect that the infrared light does not expose the water to the same amount of UV-A light that sunlight does. There is a clear deduction in the amount of bacteria from the control to the uncovered bottles but those bottles would still be unsafe to drink. When the results of the Infrared 50% covered and 75% covered are compared it is relatively clear that the outcomes are similar to each other and there is no distinct difference between the two. This is a clear example of what effect the heat of the Infrared light has on the contaminated water. These two bottles' results are similar because the presence of light does not matter to the water as much but it is more the presence of heat that affects the bacterial growth. The infrared light does bring the water up to a higher heat than the sunlight does and although it does not expose it to the harmful UV-A radiation it does heat up the bacteria enough to eliminate most of the bacteria but not up to a point where it is completely disinfected.

The aim of the experiment was to determine the effects of both elements of solar disinfection have on the bacterial growth in contaminated water. This experiment has proven that the UV-A radiation that the sun provides is key in the process of solar disinfection and without it the process does not guarantee disinfected water. This element of solar disinfection is what destroys the cell structures of the bacteria as well as reacting with oxygen that produces oxygen free radicals, which also interfere with cell structure and lead to death. The infrared radiation that is emitted from both the sun and the infrared light is very effective in killing the bacteria. The element that heats up the water is very important and without it the bacteria would not be out of its preferred environment. If the bacteria are out of the preferred temperature water it is more susceptible to the devastating effects of the UV-A radiation.

The results of this experiment have been affected by errors and may have influenced the results. Collecting water for the experiment is one of the areas that a few errors might have occurred that influenced the results. Collecting the water in a 5L tub before collecting it into bottles is done to ensure that all the water quality is the same but if this is done four times the water quality of all the bottles might not be equal in

turbidity or the volume of bacteria that it holds may be different. This could have been avoided by collecting all of the water at once or by collecting 22L of uncontaminated water and then contaminating it to ensure equal distribution of bacteria and that all the turbidity is the same.

Another error that could have occurred would be the making of the agar that was used to determine the amount of bacteria in the water. Bacteria from other features in the immediate area could have manipulated the results as well as bacteria in the incubator that have influenced the results that were recorded. This type of agar is simple nutrient agar that allows the growth of most bacteria but not the growth of all. Other variants of the agar could include LB agar or Tryptic soy powder and these might have allowed for the growth of more types of bacteria or a type that is more prevalent in the samples of creek water.

The investigation has proven the hypothesis to be correct and has achieved the aim. No unexpected results were recorded and all of the elements of the experiment worked and combines to form a successful experiment. The results have also proven the background information to be creditable and trustworthy. These results might have relied on the information by the background information but cross-referencing of instructions and techniques have allowed for a biased free experiment.

Major difficulties that were overcome during the experiment included: making of the agar and the counting of the bacterial colonies. When making the agar several difficulties were encountered that could've been avoided and that are easy to improve for the next experiment. When the agar cools down to 50°C it is recommended that it is poured into the petri dishes and the lid is reattached as quickly as possible to avoid further contamination. When the agar liquid was poured into the petri dishes and the lid was put on, the steam caused condensation of the lids. This potentially jeopardized the experiment because the condensation could have contaminated the agar. Luckily this was realized within the first few minutes, corrected and allowed for a fair test.

If any further research were done into this field it would be to compare the synergistic effect of both the UV-A and Infrared radiation in combination. This would be a difficult experiment to conduct because you cannot heat up the water without taking away the sun. Another area that might be interesting in investigating would be to magnify the suns energy with either a magnifying glass or mirrors. This could speed the process along as well as making it more effective and trustworthy.

Conclusion

This experiment determined that Solar Disinfection is very effective in disinfecting contaminated creek water. It shows that both the UV-A and the Infrared radiation are effective in disinfecting water but without the UV-A radiation there is no guarantee for effective disinfection. This experiment also shows the relationship between the amount of a bottle is covered and the deduction of bacteria is not essential although it does have a simple pattern. The aim has been achieved and expected results have been obtained with few errors that could have influenced the experiment. This experiment is key in showing the process of Solar Disinfection and how it can be used to disinfect contaminated water easily and with guaranteed results.

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