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Research Article

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Autonomous Water Disinfection Complex for the Rural Location

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Abstract
Currently, one of urgent problem is provide drinking water to the population living in remote rural areas in the world. As a rule, the sources of water available there are heavily polluted with pathogenic bacteria, and they must be decontaminated before consumption. Due to the remoteness of settlements, traditional for urban conditions methods to accomplish this task for economic reasons is impossible. The problem is the lack of a developed infrastructure (electricity, communication) because of the economic situation and the remote location of these settlements.

In view of this, the scale of infectious diseases of people from poor-quality water in rural areas of the world is quite high. In this regard, the development of compact and efficient devices for water purification, the cost of which should be accessible to the rural population, is especially topical.

Keywords Disinfection of water, ultraviolet cleaning, autonomous power source, photoelectric module

Introduction

The water purifier with ultraviolet disinfection is connected to artesian wells. Water can contain many kinds of contaminants, including, for example, microparticles, harmful chemicals and several types of microorganisms, such as bacteria, parasites, cysts and viruses. Any harmful contaminants must be removed from the water before it is suitable for safe human consumption. The consequences associated with exposure to contaminated water can be very serious and even deaths are possible, especially in rural areas. At the same time, there are several factors, including lack of electricity, which can contribute to water pollution.

In order to make water suitable for human consumption, many types of different water purification systems based on one or more purification methods have been developed. Water purification methods are well known, including distillation, boiling, chemical disinfection, reverse osmosis, water filtration and ultraviolet (UV) irradiation treatment.

So UV decontamination is a well-known method of preparing safe drinking water. UV irradiation of untreated water destroys in it all living microorganisms due to the influence of UV rays on their DNA. However, the use of ultraviolet lamps requires electricity. In many rural areas, where electricity supplies cease at certain times of the day or there is no electricity at all, UV water purification systems require the development of an autonomous power supply.

General scheme of the proposed device [1] is shown in Fig. 1, where the device blocks are schematically represented, as well as the direction of the water flow and the electrical connection of the units.

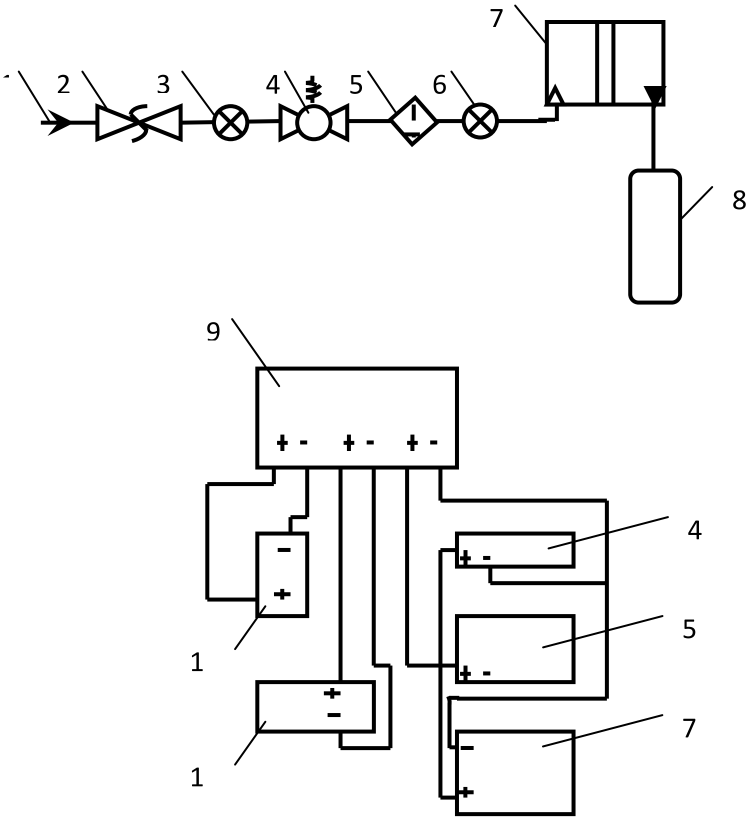

Figure 1: Autonomous device for water disinfection

An autonomous water purification device, as shown in Fig. 1, contains a pipeline 1 for supplying contaminated water, an inlet valve 2, a pressure sensor 3, a solenoid valve 4, an electromagnetic cleaner 5, a water quantity counter 6, a UV camera 7 with an ultraviolet lamp, a storage tank of purified water 8.

The pressure sensor 3 and the counter of the amount of filtered water 6 are connected electronically to a control means 9, which, in response to their signals, includes a solenoid valve 4 and an ultraviolet lamp in the ultraviolet chamber 7.

The control means 9 comprises a delay element to provide heating of the ultraviolet lamp to full power in the ultraviolet chamber, providing irradiation of water with a sufficient dose of ultraviolet light. The device also comprises an integrated battery 10 that is electrically connected via the control means 9 to the photovoltaic panel 11. The control means 9 includes a printed circuit on which several electronic components and circuits are mounted. The device can also contain conventional components, such as transformers, for converting a 12V battery voltage into an alternating voltage of 120-220V, if necessary.

The autonomous water purification device works as follows. Contaminated water from the artesian well flows through the pipeline 1 through the inlet valve 2 and, at a sufficient pressure controlled by the sensor 3, also the solenoid valve 4 into the electromagnetic cleaner 5, which filters water from mechanical particles up to 5 μm in size. The counter 6 monitors the predetermined amount of filtered water supplied to the UV decontamination chamber 7 corresponding to the volume of the storage tank 8. The flow counter 6 is electrically connected by an electronic channel to the control means 9, which electrically closes the valve 5 to interrupt the supply of contaminated water after cleaning the predetermined amount of water.

When a power outage occurs during the night, the battery 10 serves as a power source for the device until the power supply is restored again. In daylight and clear weather, PV panels 11 provide direct power to the units of an autonomous water treatment unit.

Figure 2 shows the design of an electromagnetic cleaner with a traveling wave entering the autonomous device for water purification. An autonomous water purification device comprises, instead of a filtering means, an electromagnetic water filtration unit disposed in a fluid medium to the UV-purifying means.

On the outer surface of the housing 12 is located in the upper part of the electromagnetic system 13, creating a traveling magnetic field. The magnetic field attracts, on the one hand, ferromagnetic particles located in the gap between the housing 12 and the liquid-withdrawing pipe 14 to the outer wall of the housing, and on the other hand moves the ferromagnetic particles towards the hopper 15 where they are held by the magnetized packing 16 including the magnetized sorbents in the form small-scale metalworking waste of stainless ferromagnetic steels.
If it is necessary to remove the contaminants separated from the liquid, a hopper 15 opens. The cleaned liquid through the outlet pipe 14 is supplied for further decontamination to the UV chamber.
In the electromagnetic purification of contaminated water before UV irradiation, impurities are destroyed that could worsen UV disinfection. In magnetic deposition processes, particles, in particular magnetite particles also perform a concomitant "transport" function, involving other organic particles upon precipitation, which leads to deeper purification of liquids, even from those impurities that do not precipitate in the magnetic field.
A drawback of known electromagnetic cleaners is usually relatively difficult to replace trapping discs from soft magnetic material. In the case, many components take up a lot of space. This makes it difficult to operate a water purification device in a remote location. In addition, for thin magnetic-filtration cleaning of liquids, disks of soft magnetic material are generally unsuitable, due to increased corrosion, which worsens and can negate the efficiency of magnetic deposition.

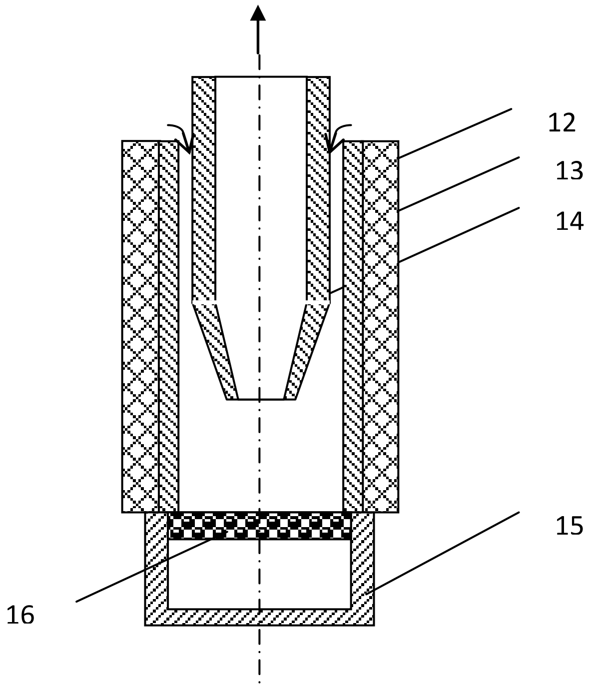

Figure 2: Electromagnetic cleaner with running magnetic field

The proposed design of an electromagnetic cleaner with running electromagnetic field allows saving energy, eliminating problems with the regeneration of the cleaner, and expensive electrical engineering materials are not used in it.

Experimental Part

Unlike most disinfectants, ultraviolet (UV) irradiation does not inactivate microorganisms by chemical interaction. UV irradiation inactivates organisms by absorbing light, which causes a photochemical reaction that changes the molecular basis of the components to the cell function. Since UV rays penetrate the cell membrane of a microorganism, energy reacts with nucleic acids and other vital components, leading to injury or death of cells exposed to it. It is obvious that if sufficient doses of ultraviolet energy are reached, organisms, UV irradiation can disinfect water to any desired degree.

Based on the studies [2], compared with the disinfection of small microorganisms, such as bacteria and viruses, the ultraviolet doses required to inactivate a larger protozoa, such as *Giardia* and *Cryptosporidium*, living in groundwater several times higher than for bacterial and viral inactivation.

UV radiation quickly dissipates in water, part of which is absorbed or reflected from the material within the water. Ultraviolet radiant energy waves have a range of electromagnetic waves of 100 to 400 nm of length, located between X-rays and visible light spectra. Classification of UV radiation can be represented as UV-C (200-280 nm), UV-B (280-315 nm) and UV-A (315-400 nm). In terms of germicidal effects, the optimal ultraviolet range is between 245 and 285 nm. Ultraviolet disinfection also uses low-pressure lamps that emit maximum energy at a wavelength of 253.7 nm; medium pressure lamps that emit energy in wavelengths from 180 to 1370 nm; or lamps that emit in other wavelengths in high intensity.

The degree to which the destruction or inactivation of microorganisms occurs due to UV radiation is directly related to the ultraviolet dose. The ultraviolet dosage is calculated as:

$$D = I \cdot t \qquad (1)$$

where: D - ultraviolet dose, $mW \cdot s / cm^2$, I - intensity, mW / cm^2, t - irradiation time, s

Studies have shown that when microorganisms are exposed to ultraviolet radiation, a constant fraction of microorganisms is inactivated during each progressive increment of time. These dose values for the germicidal effect indicate that a high intensity UV irradiation energy in a short period provides disinfection, while a lower intensity is triggered in a proportionally longer time interval.

The UV dose required for effective inactivation depends on the water quality parameters in terms of contamination and turbidity. Survival of microorganisms can be calculated as a function of the dose and time of exposure. For a high degree of decontamination, the remaining concentration of organisms is exclusively associated with dose and water quality, and independent of the initial density of the microorganism. In [3] the following relations are given:

$$N = f \cdot Dn \qquad (2)$$

where: N - flux density, 1/100 ml , D - ultraviolet dose, $mW \cdot s / cm^2$, n - empirical coefficient associated with the dose , f - empirical water quality factor

Empirical water quality factor reflects the presence of particles, colors, etc. in water. For aqueous treatment, the water quality factor is expected to be a function of turbidity and transmittance (or spectral absorbance).

Since ultraviolet radiation is energy in the form of electromagnetic waves, its effectiveness is not limited by chemical water quality parameters: pH, temperature, alkalinity, and the total amount of ultraviolet radiation.

A continuous wave of ultraviolet radiation at doses and wavelengths, typically used in the disinfection of drinking water, significantly do not change the chemistry of water, nor does it significantly interact with any of the chemicals in the volumes of water. Therefore, no natural features of the structure of water are changed and no dangerous chemical agents in the form of chemicals fall into the water.

The creation of ultraviolet radiation requires that electricity lead the ultraviolet lamps into action. Lamps, commonly used in ultraviolet disinfection, consist of a quartz tube filled with an inert gas such as argon, and small amounts of mercury.

A device measures the ultraviolet water requirement with a spectrophotometer at a wavelength of 254 nanometers, per layer of 1 cm of water thickness. The resulting measurement represents the absorption of energy into the depth of a unit, or the spectral absorption capacity. Percent transmittance is a parameter commonly used to determine the suitability of ultraviolet radiation for disinfection. The percent transmittance is determined from the spectral absorbance (A) by the equation

$$\text{Transmission coefficient (\%)} = 100 \times 10^{-A} \qquad (3)$$

Table 2 provides appropriate measurements of the absorbance and transmittance in percent, depending on the quality of the water.

Table 2: Water quality and ultra violet radiation parameters

Initial quality of water	**Spectral absorptivity (units of spectral absorbance/cm)**	**Transmission factor (%)**
Excellent	0.022	95
Good	0.071	85
Low	0.125	75

Ultra-violet lamps work in much the same way as fluorescent lamps. UV radiation is emitted from the electron beam to ionized mercury vapor to produce UV energy in most units. The difference between these two lamps is that the fluorescent lamp bulb is coated with a phosphorous compound that converts ultraviolet radiation into visible light. UV lamp is not covered, so it transmits ultraviolet radiation produced by the arc.

Lamps of low and medium pressure are effective for disinfection. Low-pressure lamps emit their maximum energy at a wavelength of 253.7 nm, while medium pressure lamps emit energy with wavelengths ranging from 180 ÷ 1370 nm. The intensity of medium-pressure lamps is much larger than low-pressure lamps. Thus, fewer medium pressure lamps are required for an equivalent dosage. For small systems, the average pressure system can consist of a single lamp. Although both types of lamp work are equally good for inactivating organisms, low-pressure lamps are recommended for small systems because of the reliability associated with their multiple incorporation as opposed to a single medium pressure lamp and for adequate action during disinfection cycles.

Recommended specifications for low-pressure lamps include:

- L-type quartz without ozone;
- Instant start (minimum start delay);
- Anti-vibration and shock resistant;
- Standard lamp design.

Typically, low-pressure lamps are located in a quartz sleeve to separate water from the lamp surface. This requirement remaintaining the operating temperature of the lamp surface near its optimum 40^{o}C, developed as an alternative to the Teflon sleeve quartz sleeves. However, quartz arms absorb only 5 percent of ultraviolet radiation, while Teflon's sleeves absorb 35 percent.

Ballasts are transformers that control the power of ultraviolet lamps. Ballasts must operate in temperatures is below 60^{o} C, in order to prevent premature failure. As a rule, ballasts are strongly heated, which requires means for cooling fans.

Two types of transformers are commonly used with UV lamps, namely, electronic and electromagnetic. Electronic ballasts operate at a much higher frequency than electromagnetic ballasts, resulting in lower lamp operating temperatures, less energy usage, less heat, and longer ballast operation.

Primary use of UV radiation should inactivate pathogens. UV radiation is a physical disinfectant that leaves no residue.

The most common point of application for UV radiation is the last step in the cycle of the processing process only to the distribution system and after filtration. The use of ultraviolet disinfection has no effect on other processes in the water treatment facility.

In contrast to most alternative disinfectants, UV irradiation is a physical process that requires a contact time of the order of seconds to achieve pathogenic inactivation. Like any disinfectant, UV radiation has limitations on use.

UV radiation is effective in inactivating the plant in the forms of sporoid bacteria, viruses, and other pathogenic microorganisms. Electromagnetic radiation at wavelengths ranging from 240 ÷ 280 nm (nanometers) effectively inactivates microorganisms, hopelessly damaging their nucleic acid .The most powerful length waves for damaging deoxyribonucleic acid (DNA) - about 254 nm. Other UV wavelengths, such as 200 nm, showed to show the peak spectral absorbing with the ability in aqueous DNA solutions.

Effects of germicidal UV light involve photochemical damage of RNA and DNA within microorganisms. Nucleic acids of a microorganism are the most important absorbers of light energy at a wavelength of 240 ÷ 280 nm. DNA and RNA carry the genetic information necessary for reproduction; therefore, damage to any of these substances can effectively sterilize the body. Damage often results from the dimerization of pyrimidine molecules. The nucleic acid response becomes very difficult once the pyrimidine molecules are bound together due to the distortion of the helical DNA.

An important phenomenon in the use of UV disinfection in the treatment of water is the ability of certain organisms to photo-revival at the next exposure to certain light wavelengths. Under certain conditions, some organisms are capable of restoring damaged DNA and returning to an active state in which reproduction is again possible. As a rule, photo-irradiation occurs as a consequence of the effects of sunlight catalysis in visible wavelengths outside the effective range of disinfection. The degree of revitalization varies among organisms. Because DNA damage tends to become irreversible for a long time, photographic life can occur during a critical period. To minimize the effect photo reanimation, run the UV lamp mechanism should be designed so that the flow of the process or to protect or limit the exposure of the disinfected water to sunlight immediately after disinfection.

Waters containing high concentrations of iron, hardness, hydrogen sulphide, and microorganisms are more susceptible (i.e., forming a thin coating on the lamp surfaces), which gradually reduces the effective ultraviolet intensity. This will happen if inorganic concentrations exceed the following limits:

- Iron, more than 0.1 mg / l;
- Hardness greater than 140 mg / l;
- Hydrogen sulfide, more than 0.2 mg / l.

Figure 3 shows the UV dose required for the inactivation of microorganism MS 2 coliphage for the two experimental samples of water. A possible explanation for a higher dose of ultraviolet radiation for the same degree of inactivation required for drinking water 2 could be the amount of calculation caused by higher iron concentrations in this water composition. The concentrations of Fe in the composition of water 2 were in the range of 0.45 to 0.65 mg / l, which exceed the limit specified above.

A variety of chemicals can reduce ultraviolet transmission, including humic acids, phenolic compounds, and lignin sulfonates, as well as chromium, cobalt, copper, and nickel.

Particles can affect the effectiveness of ultraviolet disinfection, providing shelter to bacteria and other pathogens, partially protecting them from ultraviolet radiation, and scattering ultraviolet light. As a rule, low ground water turbidity results in minimal impact on the effectiveness of disinfection. However, higher turbidity of surface water can affect the effectiveness of disinfection. Similar to particles that cause turbidity, the congestion of a microorganism can affect the effectiveness of disinfection, providing shelter to pathogens within the aggregates and shading pathogens that would otherwise be inactivated.

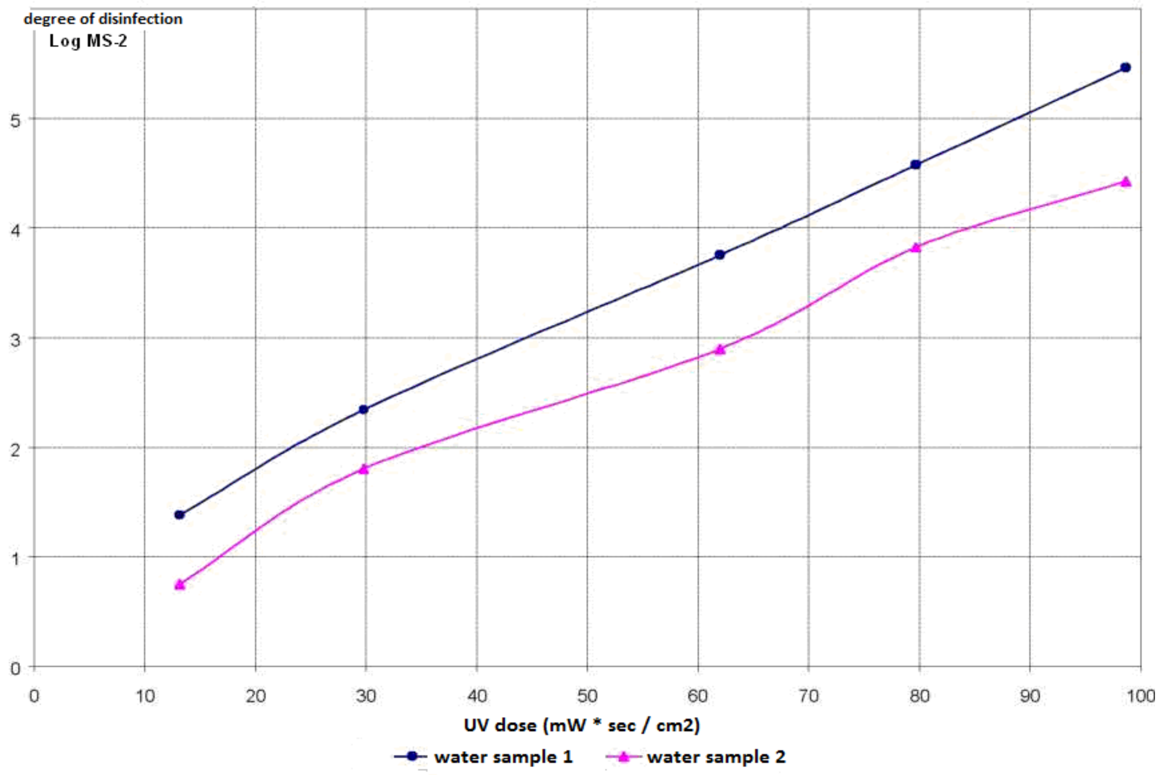

Figure 3: The dose of UV radiation needed to inactivate MS 2 Coliphage

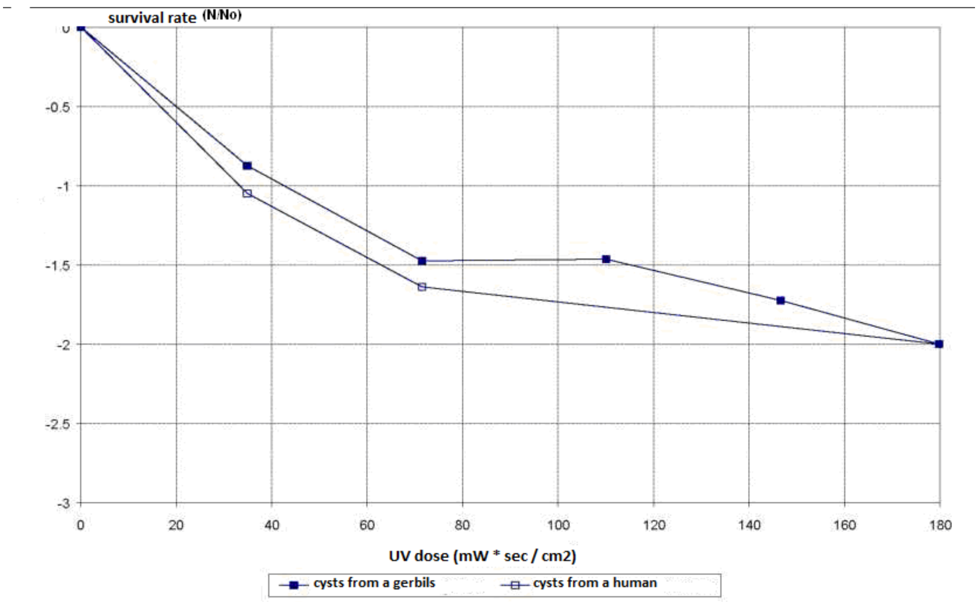

Figure 4: The ultraviolet doses required for the inactivation of Giardia cyst obtained from two different sources

The UV lamp contactor (which creates an interval between the lamps) can leave dead areas where inadequate disinfection occurs. A key consideration to improving decontamination is to minimize the number of passive sites. Some turbulence must be created to ensure radial flow mixing.

As was mentioned earlier, ultraviolet system provides contact times of a few seconds. Therefore, it is extremely important; to limit the system configuration was shorter.

Ultraviolet disinfection should be set up adequately to inactivate bacteria and viruses. Most bacteria and viruses require relatively low ultraviolet dosages for inactivation, typically in the range 2 ÷ 6 mW·s/cm^2. Simple cysts, in particular *Giardia* and *Cryptosporidium*, is significantly more stable and to ultraviolet inactivation than other microorganisms.

Such ultraviolet doses required for bacterial and viral inactivation are relatively low.

The ability of UV light and free chlorine in disinfecting content virus groundwater showed that UV radiation - the more powerful Decontaminating than free chlorine, even after the residual chlorine was increased to 1 , 25 mg / l during contact for 18 minutes. The ultraviolet dose in this study was 25 mW·s/cm^2.

Table 2 shows the results of the experimental study at different ultraviolet doses in order to obtain the same level of inactivation; the characteristics of water affect the effectiveness of decontamination. They believed that a higher concentration of iron in experimental water sample 2 (Fig. 4) influenced the accumulation of MS 2 virus particles when treated with UV radiation. The susceptibility of MS 2 coliphage to the hepatitis virus, poliovirus, and rotavirus for 10 groundwater sources has been confirmed. MS 2, as studies have shown, was approximately 3 times more resistant to ultraviolet disinfection than the three mentioned human pathogens.

Table 2: Doses required for MS 2 inactivation

Log MS-2 inactivation	Sample 1 (mW·s/cm^2)	Sample 2 (mW·s/cm^2)
1	3.9	15.3
2	25.3	39.3
3	46.7	63.3
4	68	87.4
5	89.5	111.4
6	111.0	135.5

Inactivation of Protozoa Even though protozoa was once considered resistant to ultraviolet radiation, studies have shown that ultraviolet light is capable of inactivating protozoan parasites. However, the results indicate that disinfection of these organisms requires a much higher dose than for the inactivation of other pathogens.

Less than 80 percent of *Giardia* cysts were inactivated in ultraviolet doses of 63 mW·s/cm^2. Inactivation of *Giardia muris cyst* was obtained when the ultraviolet dose was increased to 82 mW·s/cm^2.

Two important factors to consider when determining dose requirements for *Giardia* inactivation are the source of the parasite and the stage of growth of the microorganism. Figure 3 shows that the source of parasites is important in determining the dose requirements. Figure 4 shows the results of the study, on the inactivation of Acanthamoeba rhysodes. These data show that the age of the protozoa can dramatically affect the dose required to achieve the desired level of inactivation.

Method of Application

The proposed method of water disinfection distinguishes, in addition to the independence of electricity supply, the ease of maintenance, low cost, and adaptability to a strict environment. The average person needs to consume 3.8 liters of water a day for normal vital activity [4-7]. Purpose-designed water supply for each person were 7.6 liters per day to ensure an adequate supply and safeguard against loss of production due to the lack of sunshine days. The minimal purpose of the water supply was to produce 1,900 liters per day. This was based on an estimated consumption of about 250 inhabitants.

The power of photovoltaic cells is chosen so as to cover the probability of load loss of 0, 1%. The shut-off valve is integrated in the water supply channel for shutdown in the event that the ultraviolet lamp is out of order or if there was no energy available from the PV modules or batteries.

The key advantage of the ultraviolet system is that the excess power in generating photo electricity can be stored in batteries and used during those days when cloudiness limits the operation of photovoltaic panels. Ultraviolet treatment requires that the level of prefiltration guarantees the presence of particles in the water of not more than 5 microns, which ensures the effect of ultraviolet light on the entire surface of the particle. The main inconvenience to this system is that it requires regular maintenance of the filter and subsequently higher annual operating costs.

The ultraviolet sterilizer and control systems consume approximately 20 watts, for continuous operation the system requires a minimum energy consumption of 480 Wh per day. In addition, batteries are detected at 80% discharge depth.

The system uses photovoltaic modules with a power of 200 peak watts. M The maximum voltage drop for the system is 2%.

Conclusion

The main result of this work is the confirmation of the effectiveness of the developed scheme of an autonomous device for disinfecting water exposed to radiation by an ultraviolet lamp with electricity from photovoltaic systems.

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