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Decentralized solar wastewater treatment machine, an innovation to develop water reuse approach

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Abstract

Nowadays water resources protection, by application of optimized, sustainable and economical approaches, for logical utilization of water has turned to one of the most vital and challenging issues worldwide. Additionally, water reuse, known as a strong factor in managing water crisis, is an appropriate alternative to handle this challenging crisis. This senior project discusses the design and construction of a solar water treatment system taking the advantage of ultraviolet (UV) radiation and a combination of natural processes. An UV wastewater treatment system is designed to demonstrate the wastewater treatment capability of the network. This system is specifically designed to eliminate bacterial contaminants and meet the needs of a community. Only sunlight is needed to power the treatment system. A solar panel collects energy from sunlight to be used for electrical consumptions such as pumping. Ultraviolet light disrupts bacteria and produces a source of drinking water. In fact, we try introducing an innovating idea of a decentralized solar wastewater treatment (DSWWT) machine, which is adaptable with environmental standards goals. In addition to being affordable and eco-friendly, it can be used in different kinds of communities (especially useful for remote communities).This machine will also be capable of being used in any residential, commercial or official building, which produces wastewater. Based on the assessments, manufacturing of this machine is easily reachable.

Keywords: Crisis; Eco-friendly; Sustainable Development; Water Resources

INTRODUCTION

Nowadays there exists an expanded range of sewage systems that can be used for sewage treatment. However, there are major problems with some of the commonly used mechanized systems for sewage treatment, such as high cost of construction, high level of energy consumption, requirement of sludge disposal, and use of high technology for complicated utilization and treatment. Construction of advanced refineries in rural areas aren't welcomed because of lack of specialists for utilization and high cost of construction (Ostad-Ali-Askari *et al*., 2017).

Water reuse simply is the use of reclaimed water for a direct beneficial purpose in various sectors from home to industry and agriculture. For a number of semi-arid regions and islands, water reuse provides a major portion of the irrigation water. In addition, the reuse of treated wastewater for irrigation and industrial purposes can be used as strategy to release freshwater for domestic use, and to improve the quality of river waters used for abstraction of drinking water. Specific water reuse applications meet the water quality objectives. Water quality standards and guidelines which are related to irrigation and industrial water reuse are described in this chapter. Other reuse consumptions such as urban, recreational and environmental are also discussed (Nazari *et al*., 2012).

In future water needs will continue to grow significantly worldwide. Since the

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1980s the increase is estimated at about 1% and will be maintained until 2050. This represents a plus estimated between 20 to 30% comparatively to the current level of water use. Population and economic growth are the main causes. But also, the environmental degradation that induced the global warming and the climate change intensify especially in drier developing and emerging countries which will become even drier (The United Nations world water development report, 2019). Many communities have considered decentralized wastewater systems and their economic and environmental benefits. Nowadays, decentralized wastewater treatment (DWWT) systems can provide the safety and reliability of so-called large-scale treatment, as well as many other benefits to communities. This type of wastewater treatment has a variety of approaches to collection, treatment and reuse. Effluents from houses, industries, organizations, residential and commercial communities. Special site conditions are assessed to calculate the appropriate types of treatment system for each situation. These systems are part of a permanent infrastructure and can be managed as stand-alone facilities or integrated with central wastewater treatment systems. These systems range from simple and passive treatment methods (soil dispersion, commonly used as an internal or septic system) to more mechanized and sophisticated methods such as advanced wastewater treatment plants. Collected and treated from several buildings and discharged into surface water or soil.

So far, decentralized wastewater treatment systems have played a key role in wastewater treatment in small communities and rural areas. Because they are economically feasible, they are easy to work with with a relatively simple configuration and therefore low maintenance requirements (Eggimann *et al*., 2016). To date, a variety of decentralized technologies have emerged, from septic separation systems to advanced treatment systems that are able to meet various emission needs such as drainage or reuse of irrigation (Qadir *et al*., 2010; Negreanu *et al*., 2012). Compared to urban wastewater, rural wastewater has a high variability in intrusive loading (Wang *et al*., 2010), long periods of inactivity (e.g., overnight) and scattered distribution. It is impossible to have enough professional operators to ensure the maintenance of wastewater treatment facilities that prevent the use and development of DWWT systems. For such challenges, discharge standards are increasingly stringent as the need for domestic wastewater treatment plants in rural areas increases. If rural wastewater is not treated effectively, it may pose a threat to aquatic ecosystems and human health (Lehtoranta *et al*., 2014).

Currently, DWWT wastewater treatment facilities are offered efficiently and easily to meet the limitations mentioned above. However, current rural wastewater treatment systems still have problems that are less consistent with the characteristics of rural wastewater emissions, high energy consumption, and operator shortages (Ding *et al*., 2017). Therefore, an efficient, environmentally friendly and sustainable rural wastewater treatment system using renewable energy (e.g., solar and wind energy) is required (Oberholster *et al*., 2019). At the same time, previous researchers in step-by-step biofeed reactors have demonstrated that these systems can increase the efficiency of nutrient and phosphorus removal due to the more efficient use of carbon sources for nitrogen removal (Daw *et al*., 2012). Compared with the traditional activated sludge method, this method is more suitable for the low carbon to nitrogen ratio of rural wastewater (Zhu *et al*., 2009). In addition, the rate of rural wastewater discharge varies slightly during the day (e.g., there may be no effluent release at night) (Han *et al*., 2013). As a result, the traditional continuous operation mode may waste energy at night when wastewater does not enter the reactor or is low. In addition, the removal of nitrogen and phosphorus from wastewater using biological approaches requires anaerobic and aerobic conditions in wastewater treatment plants (García *et al*., 2017). Based on these conditions and at the same time saving more energy consumption, an operational strategy that allows entry and aeration only during the day can be used to treat rural wastewater. Using this mode of operation, the biological reactor alternates between aerobic and anoxic conditions in both spatial and temporal dimensions. To further increase energy savings and use clean energy to reduce maintenance and operation coverage, we recommend the use of solar and wind energy for wastewater treatment.

Currently, the shortage of clean water has become one of the most serious global problems that threatens the continuity of humanity and must be addressed immediately (Haddeland, *et al*., 2014; Mekonnen and Hoekstra, 2016). Countless renewable energies (RE) have been created, such as solar energy (SE), wind energy, geothermal energy, and tidal energy. However, SE is the most abundant source of RE on our planet due to its ubiquity and inexhaustibility. SE-based energy conversion and clean water generation methods seem to be possible ways to solve the current global challenges, which have been over-emphasized by researchers around the world (Fu *et al*., 2018; Wang *et al*., 2017). SE is used in many fields such as photochemical fields , photothermal fields, solar photovoltaic cells, water heating (Yassen *et al*., 2019), air heating (Kabeel *et al*., 2017), drying applications, etc.

Because water itself is a poor absorber of sunlight, photothermal materials must be introduced that can capture a wide range of light and convert that energy into heat. Photothermal materials have been widely used in biomedicine, such as heat therapy, but only in the last few years have they been implemented in solar evaporation. In some early investigations, plasmon nanoparticles were dispersed in a mass solution of solar heating and evaporation (Neumann *et al*., 2013; Zielinski *et al*., 2016). However, most of the heat generated is wasted in raising the temperature, so the evaporation efficiency is relatively low. Instead of heating the whole body of water for purification, energy losses can be minimized by localizing heat at the evaporation interface (air/water). This localization can be activated through the use of nanothermal materials that float above the water (Liu *et al*., 2017; Deng *et al*., 2017; Gao *et al*., 2019; Zhou *et al*., 2019; Zhang *et al*., 2020; Zhao *et al*., 2020). The overall evaporation efficiency can be calculated by detecting the mass change under constant light radiation. Instantaneous efficiency is calculated as $\eta = \dot{m}h / P$, where $\dot{m}$ is the difference between the rate of evaporation in dark and dark environments, h is the specific enthalpy change of liquid water to vapor, and P is the power of light (Li *et al*., 2019). Evaporation efficiency is mainly limited by two factors: the conversion of light to heat, under the influence of reflection, the absorption spectrum, and other processes of energy conversion, and the conversion of water into steam, under the influence of heat loss (ie conduction, convection, and radiation).

Further research in developing affordable modification is warranted to make this technology more widely used in remote arid regions. These may include, suitable application of heat exchangers, improving the effective evaporation and condensation through the addition of thermoelectric heating module at the liner of still basin. Heat storage phase change materials (PCM) can be especially applicable in extending the operability of the still beyond daylight hours through the use of thermal energy during off light or dull light which can be utilized for additional evaporation of basin water, thereby increasing the clean water yield (Matouq *et al*., 2020).

MATERIALS AND METHODS

These systems are usually installed at or near wastewater production sites. Items discharged to the surface of water or soil are required to have an environmental permit. These systems can:

- Used on a variety of scales including private homes, business locations or small communities.
- Treat the effluent until it reaches public health protection levels.

- Comply with city and provincial laws and regulations.
- Work well in rural, suburban and urban areas.

For example, renewable energy sources in Egypt has a remarkable effect for water desalination and benefits as a clean source of energy, cannot be depleted, and don't contribute to global warming or greenhouse gas emissions. Due to these sources are natural, with minimal maintenance and operational procedures costs; they are recently used in water desalination in remote areas. They represent the best option due to the high cost of providing a corresponding conventional facility. Fortunately, Egypt is blessed with good sunshine especially in Upper Egypt and remote areas such as Sinai, Toshka and Owaynat. They receive solar radiation reached 5–8 kWh/m2day. Therefore, the Integrated Solar Green House (ISGH) for water desalination, plantation and wastewater treatment has good potential in these areas of Egypt where other sources of energy may be unavailable or more expensive. Solar water desalination has considered a promising renewable energy-powered technology for producing fresh water. Humidification– Dehumidification (HDH) of solar desalination will increase the overall efficiency of the system. HDH process depends on mixing air with water vapor, and then extracts water from humidified air by a condenser. The amount of vapour that air can hold depends on its temperature. The ISGH is a new development that produces fresh water from sea or saline water, cools and humidifies the plants growing environment, creating an optimum environmental conditions for the cultivation of valuable crops.

According to the treatment scale, the environmental function of the discharged water body, and the local environmental protection requirements, there are three processes which can be selected for water treatment: the first-level strengthening treatment process, the secondary treatment process, and the secondary strengthening treatment process. First-level strengthening treatments usually utilize materialized strengthening treatment methods (Akhoundi and Nazif, 2018), such as the pre-stage process of the adsorption biodegradation (AB) method, the pre-stage process of the hydrolysis aerobic process, the high-load activated sludge process, etc. The secondary treatment process can use the activated sludge process, oxidation ditch process, sequencing batch reactors (SBR) process, hydrolysis aerobic method, AB method, and biological filter method. Secondary strengthening treatment processes can choose the Anoxic Oxic(A/O) method or the Anaerobic-Anoxic-Oxic (A/A/O) method; the goal is to remove carbon source-pollutants while strengthening the function of nitrogen and phosphorus removal (Mehr *et al*., 2018).

According to present surveys, the most widely used treatment process is the ordinary activated sludge method, including the Anaerobic-Anoxic-Oxic, SBR, and oxidation ditch methods in municipal wastewater treatment plants which are already completed and operating in China (Molinos-Senante *et al*., 2018) (Table 1). At present, there are dozens of urban sewage treatment plants with a processing scale of more than 200,000 m3/day in China, and the most common method applied are the activated sludge method and the improved Anoxic Oxic method and Anaerobic-Anoxic-Oxic method (Schopf *et al*., 2018). Large-scale sewage treatment plants in large cities have the advantages of high economic strength, high technical levels, and strong management experience (Di Fraia *et al*., 2018). The larger the scale, the lower the energy consumption and the lower the operating cost. With the development of technology and economic level, the activated sludge process has great potential for developing the collection and utilization of biogas in the anaerobic section (Carstea *et al*., 2018).

If the biogas generated in the sewage treatment process can be utilized, it would inevitably reduce energy consumption. The process flow for a typical wastewater treatment plant (WWTP) is shown in Figure 1. The solid red arrows indicate the process flow of the wastewater treatment process and the orange dotted arrows indicate the process flow of the sludge treatment process.

Table 1. Abatement of physicochemical pollution of municipal and textile wastewaters (S Igoud, 2015)

	Municipal Wastewater				Textile Wastewater			
Parameters	**Raw Wastewater**	**Treated wastewater**	**Abatement rate (%)**	**Standards**	**Raw Wastewater**	**Treated wastewater**	**Abatement rate (%)**	**Standards**
pH	7.51	7.59	-	6.5-8.5				6.5-8.5
BOD (mg/l)	300	30.10	90.1	30	2000	42.2	97.89	500
COD (mg/l)	420	60.26	85.65	90	5502	174.6	96.82	1000
TSS (mg/l)	181 NTU	1.63	99	30	579.6	3	99.55	600
Salinity (g/l)	0.56	0.001	99.99	10	-	-		1
Conductivity (µS/cm)	1590	216	86.5	3 ds/cm	5880	128.7	97.81	5 ds/cm
Mn (µg/cm)	-	-	-	10.0	219.8	28.14	87.19	200
Ni (µg/cm)	0.12	0.05	58.33	2.0	43.95	5.98	86.39	2000
Zn (µg/cm)	0.19	0.15	21.05	10.0	0.618	<0.1	99.83	1000
Fe (µg/cm)	3.87	0.22	94.34	20.0	661.9	87.95	86.71	1000
Cu (µg/cm)	0.02	0.05	85.00	5.0	870.5	105.7	87.85	100
Pb (µg/cm)	-	-	-	10.0	<0.1	<0.1	-	500
Cd (µg/cm)	$4.9\ 10^{-3}$	$11.78\ 10^{-3}$	66.03	0.05	2.66	1.334	49.85	10
Cr (µg/cm)	0.03	0.03	0	1.0	13.32	1.852	86.09	100
Total Coliforms (UFC/100ml)	>3 10^4	2	99	-	-	-	-	-
Fecal Coliforms (UFC/100ml)	>3 10^4	0	100	100-1000	-	-	-	-

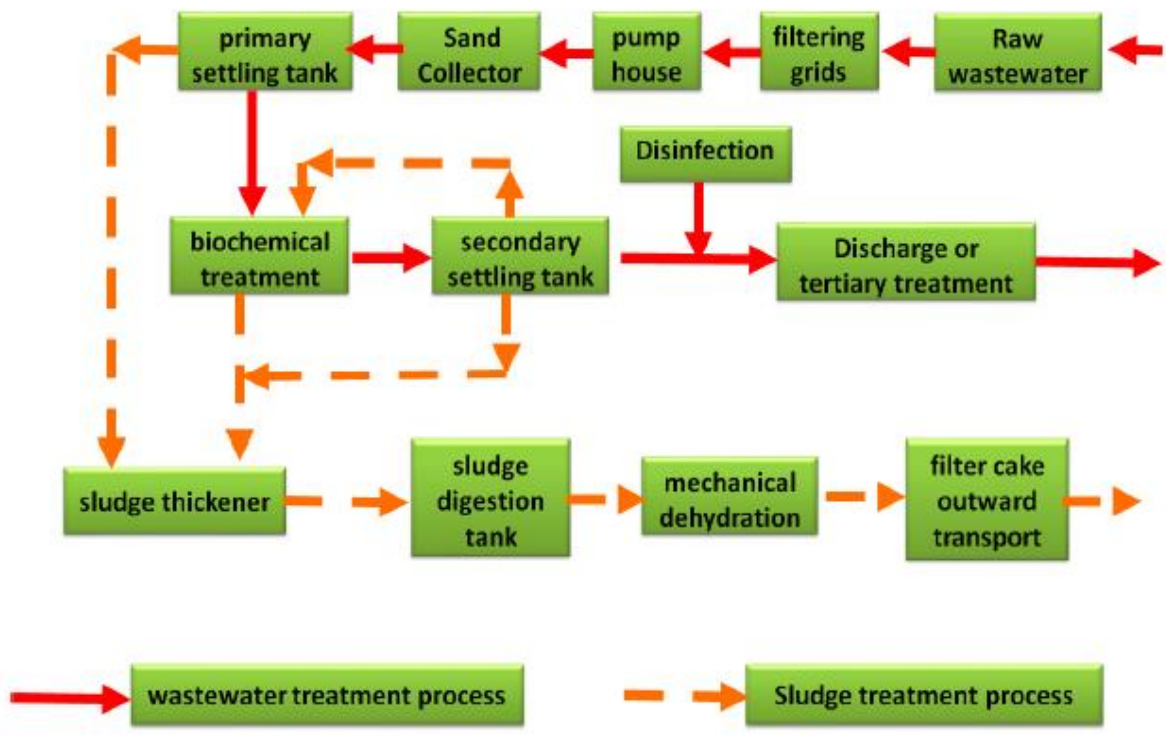

Fig. 1. Typical process flow diagram of a wastewater treatment plant (WWTP) (Guo *et al.*, 2019)

choose the Anoxic Oxic(A/O) method or the Anaerobic-Anoxic-Oxic (A/A/O) method; the goal is to remove carbon source-pollutants while strengthening the function of nitrogen and phosphorus removal (Mehr *et al.*, 2018). According to present surveys, the most widely used treatment process is the ordinary activated sludge method, including the Anaerobic-Anoxic-Oxic, SBR, and oxidation ditch methods in municipal wastewater treatment plants which are already completed and operating in China (Molinos-Senante *et al*., 2018).

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ACCESSIBLE DRINKING WATER

For each 6 people, 1 person do not have access to safe potable drinking water. Additionally, near 2.5 billion people are deprived of potable WC. As a result, these two deprivations have led to spread of diseases which are caused due to potable water shortage and thereupon occurrence of annual fatality of 6 million kids. The importance of access to safe drinking water was reflected in target 7B of the UN Millennium Development Goals (MDGs), which sought to halve the percentage of population (from 1990 to 2015) without sustainable access to an improved drinking water source (United Nations, 2006). According to WHO (World Health Organization, 2006), this goal has been achieved. Furthermore, such efforts to improve access have been credited with reducing drinking water related deaths by 31% (Pruss-Ustun and World Health Organization, 2008). Nevertheless, safe drinking water is not currently accessible to over 780 million people (Weichenthal and Schwarz, 2005). The world has encountered a serious challenge for supplying adequate drinking water for all the population. Till 2015, 40% of the Earth population had been living in communities with scant sources of drinkable water. Despite we assure that usage of green natural energies can guarantee supplying enough potable drinking water for the growing population, we do not exactly know how long it will take to completely cover the nations with new water supplying technologies.

Solar treatment is among the most useful methods to produce clean water from wastewater or even greywater. Solar energy and rays as an accessible free source of energy can be used as a power source of treatment process. Additionally, solar treatment machine can efficiently help removing impurities such as different types of salinity, microorganisms, heavy metals, bacterial infections, Iron, Manganese, and remnants of pesticides and herbicides.

Decentralized wastewater treatment can be a smart alternative for communities, by considering new systems or modifying, replacing or expanding existing wastewater treatment systems.

For many communities, decentralized treatment systems can:

- Be cost-effective and economical
- Avoid high investment costs
- Reduce operating and maintenance costs
- Promote business opportunities
- It is green and stable
- Beneficial for water quality and access
- While maintaining green space, it is responsible for growth and development.
- Safe in environmental protection, public health and water quality
- Protecting the health of communities
- Reduction of common pollutants, nutrients and emerging pollutants
- Reduction of pollutants and health risks related to wastewater

Decentralized wastewater treatment can be used as a reasonable solution for communities of any size and population. Like other systems, decentralized systems need to be properly designed, maintained, and operated to deliver optimal benefits. Decentralized systems help communities achieve threefold sustainability, including being good to the environment, the economy, and the people.

ULTRAVIOLET PROPERTIES

Ultraviolet light penetrates the outer cell membrane of the bacteria or virus and it passes through the cell body, which disrupts its DNA, preventing reproduction of the cells (Weichenthal and Schwarz, 2005). The doze of UV exposure to the water dictates the amount of disinfection of the water. The doze that the water receives is the amount of light intensity and the contact time with the UV radiation. Different dosages are required to disrupt different types of bacteria and viruses since the resistance to UV radiation can vary within different microorganisms. The common wavelength that UV bulbs are designed to emit is 254nm (Daro UV Systems, 2010). This wavelength is at the peak of cell inactivation and therefore is most effective at disrupting the DNA strands of microorganisms. As a result, in this innovation, the major disinfection process has been defined with the absorption of UV254 or shorter wavelengths of UV by vacuumed spiral glass panel (*See* Figures 2-5).

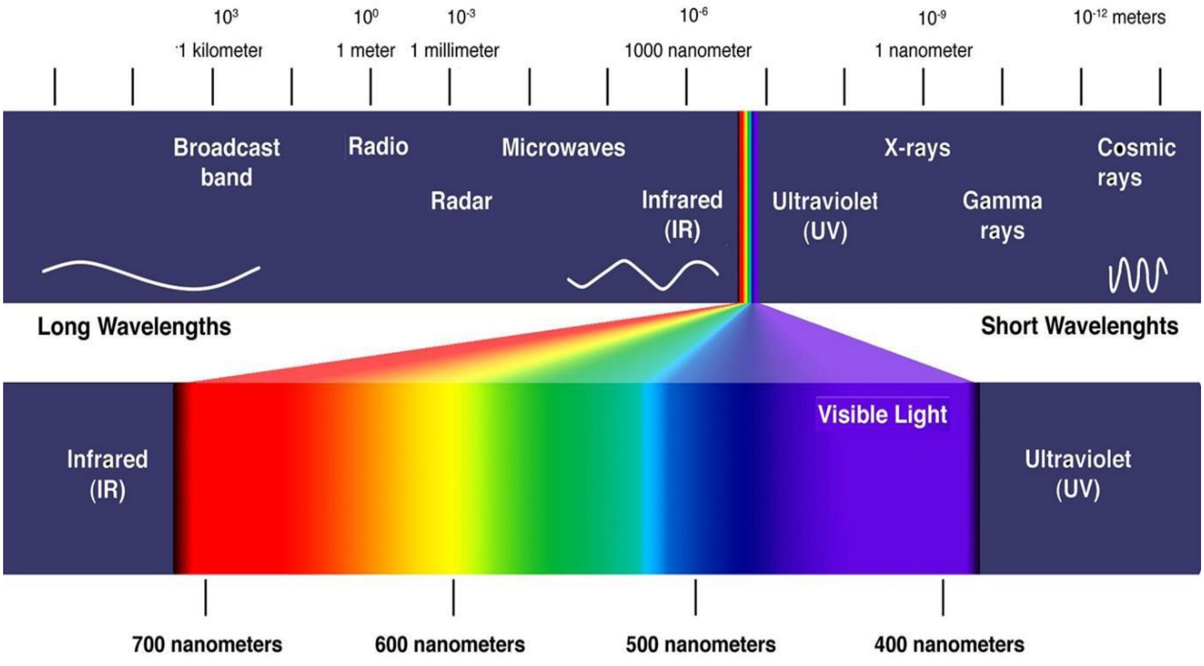

Fig. 2. Electromagnetic spectrum UV rays (https://www.pinterest.com/pin/586382813955458149/visual-search/)

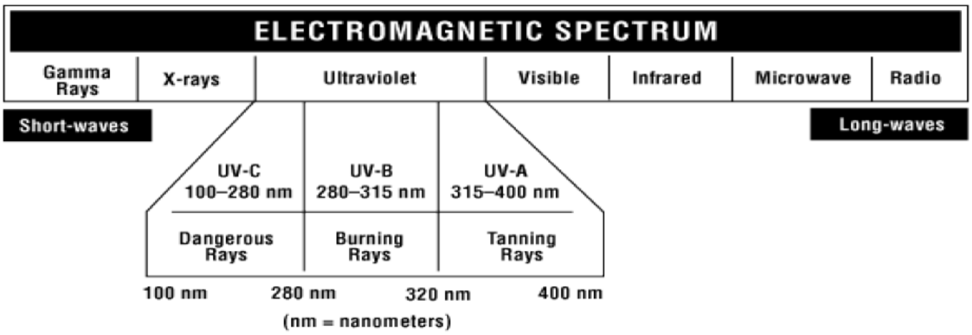

Fig. 3. Detailed electromagnetic spectrum of UV rays (https://www.google.com/url?sa=i&url=https%3A%2F%2Frepository.rmutp.ac.th%2Fbitstream%2Fhandle%2F123456789%2F2763%2FITFD_61_55.pdf%3Fsequence%3D1%26isAllowed%3Dy&psig=AOvVaw0j6k20ZeSG1E435syG1UjC&ust=1600687994132000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCOityM_R9-sCFQAAAAAdAAAAABAD)

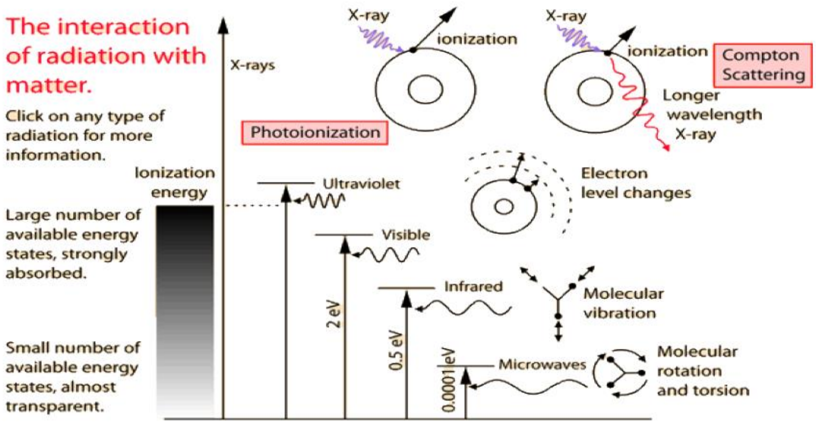

Fig. 4. The interaction of electromagnetic radiation with matter (http://hyperphysics.phy-astr.gsu.edu/hbase/mod3.html)

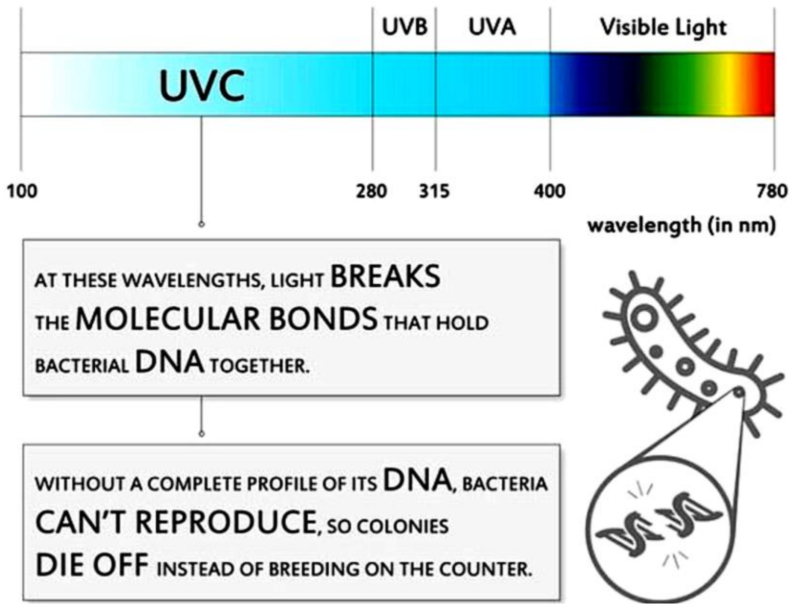

Fig. 5. UV Disinfection: How does it work? (https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.alfaauv.com%2Fblog%2Fuv-disinfection-system-water-treatment%2F&psig=AOvVaw0coHC0jXX6m_7im3ShcwrY&ust=1600688457035000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCPDemvPT9-sCFQAAAAAdAAAAABAD)

WASTEWATER INGREDIENTS

Wastewater or sewage have different kinds of ingredients, including:

1- Over 90% water which is added by flushing water into the toilet.
2- Non-Pathogen compounds such as bacteria, viruses, and infecting organisms like parasite worms and prions
3- Pathogen bacteria (Over 100,000 pathogens in 1 milliliter of sewage)
4- Organic wastes such as hair, food, human and animal excrement, paper fibers, pukes, herbal compounds, etc.
5- Solved organics including urea, fructose, solved proteins, pharmaceutical ingredients, narcotics, etc.
6- Non-organic compounds like Ammoniac, sea salt, baneful toxins, Hydrogen Sulfate, salt (Thiocyanic ester Acids) and Thiourea salt (ester).
7- Gases such as Hydrogen Sulfate, Carbon dioxide, Methane, etc.

USAGES OF PURIFIED WASTEWATER

Reuse of treated wastewater includes urban usages, agriculture, recreation, aquaculture, groundwater recharge and drinking.

The sewage in the environment has not been affected due to environmental pollution, because there is not unpleasant products, especially flies and mosquitoes, which these insects provide themselves for the transport of pathogenic microbes. It pollutes the environment. Therefore, the effluent must be partially treated before entering the environment.

Wastewater pollution is further due to the presence of their organic matter, which enables these substances to be converted to nitrites, nitrates and phosphates, etc., by means of oxygenation and oxidation, and then is separated from the wastewater as a sediment.

RESULTS AND DISCUSSION

The usages of purified wastewater can be used in:

- Building washing and cleaning
- Storing water for urgent water demands
- Landscape Irrigation
- Carwash
- Recycling water for toilets
- Recycling water for heating systems
- Recycling water for pools and fountains

ELEMENTS OF SOLAR WASTEWATER TREATMENT MACHINE

1- Photovoltaic panel, 2- Vacuumed spiral glass pipes panel, 3- Spiral Copper pipes panel, 4- Condenser panel, 5- 3 pumps including 2 eccentricity pumps and one sludge pump, 6- Potable water storage tank, 7- Portable septic tank, 8- 2 cylinders for inlet and outlet streams for wastewater and clean water, 9- Disk Filter, 10- Chlorinator and Ozone generator

SOLAR WASTEWATER TREATMENT MACHINE MECHANISM

After collecting raw sewage of the building or house, the outlet stream of the sewage will fall into the portable septic tank of the treatment machine. During discharging sewage to the septic, coarse particles will be settled down due to their weight in comparison with water, and light wastes will float on the surface of septic. Afterwards, physically filtered water flows through the first cylinder and by the time the cylinder gets full, the floater starts the pump (which uses electricity, generated by photovoltaic panel of the machine) and the pump inserts water to disk filter in order to filter fine and dissolved particles.

After the second stage of physical filtration, filtered water will flow into the vacuumed spiral glass pipes panel. During this process, UV200 and beneath wavelengths will be absorbed by the spiral glass panel and consequently UV disinfection process starts and after 30 minutes, all microbes and bacteria of water will be removed.

Filtered disinfected water flows into the spiral copper pipes panel at the 3rd step. High thermal conductivity of copper causes high temperature of copper pipelines when sunshine occurs. Hot pipeline of copper spiral panel is now ready to apply thermal disinfection to water. By increasing the water temperature and reaching to the boiling point, any probable remained infections will be removed and we can assure that all bacteria and infectious elements have been eliminated. Then, Evaporated water, made in this step goes through the condenser panel and vapor condenses into water. Boiling is very important that it makes all impurities of water be removed and lets the water get cleaned and potable. Now, potable clean water is ready to be pumped through the potable water storage tank to be injected to water network of house or building for different types of demands. If the user plans to make the produced water, drinkable, the machine has the capability of increasing water quality to potable drinking water by inserting water to the chlorinator and ozonator.

With regards to the sedimentation in septic tank, after several cycles of machine working, sediments volume will increase and therefore lower the efficiency of septic, so that the sludge pump depletes the sediments out of the septic tank and discharges them to the sewage network of the region.

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CONCLUSIONS

The concept of this patent as a modern DWWT system is based on recycling water in a local site which in turn lowers the costs of wastewater gathering network, construction of expensive centralized wastewater treatment plant, etc. Regarding the climate change and global warming, green buildings especially net zero water and energy buildings are going to become the first priority in our next imminent generation of green construction. This machine which is also capable of being portable would be a useful asset to make a building independent in the annual water consumption. What makes this machine distinguished compared with the other similar prototypes is its small scale, affordability, mobility, high-grade outlet water quality and the lowest carbon and methane producer system ever built.

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