Pilot Scale Wastewater Treatment Unit Using Fresnel Lens Solar Concentrator

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Abstract

Many municipalities across the world confront a major problem with waste water treatment. However, Tier-1 and Tier-2 cities have good infrastructure to treat the wastewater, but most of the villages are still facing the problem, because of less resources, the untreated waste water is left to flow on the ground, while travelling it merges with the fresh water bodies, and results in surface and ground water pollution in nearby villages. The development of a pilot size waste water treatment system that efficiently produces water by evaporation and condensation in conjunction with a Fresnel lens solar concentrator is discussed and analysed in this experimental investigation.. Solar radiation setup for waste water treatment consists of Fresnel lens which help in achieving the temperature up to 400°C and then wastewater is being converted into vapour form due to this solar radiation. The evaporated vapour condenses on the surface of the glass and collects in a collecting tank. When compared to a typical wastewater treatment plant, this environmental friendly and sustainable procedure removes organic and bacteriological contaminants from wastewater and, moreover, this chemical-free treatment converts wastewater into reusable form of water with less sludge. The main advantage of this treatment method is, simple to construct and no skilled manpower is required to operate it. Since solar radiation is used as a power source to achieve high temperature therefore, no external power source is required to operate this unit. Results indicate that strength of waste water is reduced by 87%, TDS reduced by 82% as compared to sewage water and Ca, Mg, N, P, Chlorides and Sulphates are reduced by 87%, 91%, 66%, 42%, 92% and 80% respectively. However, the main challenge of this method is low output, but can be improved by various techniques mentioned in the study.

1. Introduction

Water is an essential element for existence of life on the earth. With the arising amount of water demand and at risk of water pollution, water has changed from one of the relative abundances to one of the relative scarcities. The depletion of underground water and freshwater resources would pose a far greater threat to our future. As water resources become more limited and waste discharge becomes increasingly problematic, the concept of water reuse is becoming important (Ree-Ho Kim et al. 2007). The effectiveness of wastewater treatment systems is being examined because of rising problem posed by the increase of industrial activities, and a requirement for low-cost and low-impact treatments is increasing (Bettonte M et al. 2019). A huge quantity of wastewater is generated due to an increase in population which leads to the pollution of surface and groundwater bodies. Solar radiation and condensation are one such type of technique used for the treatment of saline water (E Delyannis 2003). In contrast, (Claire Debroux et al. 2019) replaced saline water with the waste water then integrated Fresnel lens with single basin, single sloped solar still for increasing the evaporation rate. The setup consists of Fresnel lens, stand, evaporating tank, transparent glass cover, and collecting basin. Since the Fresnel lens is used to achieve a maximum temperature of nearly 400°C by mechanism of converging all the solar rays that falls on the flat sheet (H Zhai et al 2010 and Sales M T B F 2016), due to the intensity from the solar radiation water starts boiling, and the evaporated water is condensed on the glass surface, then the droplets will

slides along the glass surface and falls on the open pipe channel which is fixed at the edge of the transparent glass cover, inside the evaporation tank, now, the collected water travels through the sloped pipe and collected in a trough placed outside the evaporation tank (Dev R and Tiwari G 2011).

The depth of water in the storage tank, the surface area of the glass, the structure of the solar still and storage tank, material used, colour, insulation material, surrounding environmental conditions such as solar radiation, wind velocity and ambient temperature, absorbing area, temperature of wastewater, glass inclination angle and type of water are some of the common factors that influence the efficiency of this system (A E Kabeel et al 2014; A Muthu et al 2014; A S Abdullah et al 2021; Bai Y et al 2021; Basharat Jamil et al 2017; D. Dsilva Winfred Rufuss et al 2016; Hiroshi Tanaka 2009; and Hitesh N et al 2016). Table 1 gives consolidatation of the literature review of various solar still systems for desalination of water.

Table 1
Literature review

Reference	Model Studied
Apurva A Patil et al (2018)	Review various solar distillation systems
Ahmed M et al (2017)	Single basin solar still using radiating surface and convex lens. Efficiency of proposed unit was 63.64%
Ahsan, A. et al (2013)	From a solar water distillation device, several numerical models were compared and water production was estimated.
Dev, R. and Tiwari, G. (2010)	Hybrid photovoltaic/ thermal (PV/T) system's performance was studied.
Ebaid, M.S.Y. et al (2015)	A computer simulation model of a single slanted solar powered still was proposed to examine the unsteady-state thermal performance.
Hidouri, K et al (2017)	The heat transfer coefficients were examined with three different correlations, available in the literature later compared, theoretical results with the experimental work in terms of hourly yield.
Johnson et al (2019)	When an external solar enhancer is applied, a theoretical model is used to mimic the temperatures and productivity of a single-slope, single-basin solar still.
Kumar, S. et al (2010)	In a basin type hybrid (PV/T) active solar still, an empirical relationship was developed to evaluate heat transfer coefficients and fractional energy.
Murilo Alexandre Fendrich et al (2018)	Reviews various technologies and materials required for wastewater treatment using solar concentrator
Murugavela, K.K. et al (2013)	To improve the effectiveness of the inclined solar still, various methods were reviewed and compared the performance of each method.
Rajesh V R et al (2016)	Proposed water desalination unit using Fresnel lens with yield of 30.8 liters with efficiency of 55%
Sanchez Vega, L.R (2016)	Proposed low cost, small scale solar concentrator using Fresnel lens having 50 % efficiency.
Velmurugan, V et al (2011)	Experimental as well as numerical investigations on types of solar still was presented.

In this experimental study the proposed ecofriendly pilot scale wastewater treatment unit is a new solution that may be easily applied with less manpower, land requirement, and low sludge generation, especially in rural locations where waste management is not so popular. This is cost effective method in terms of energy requirement as solar energy is a source of energy.

2. Experimental Setup And Material Required

Fresnel lens, trapezoidal evaporation tank with basin, supporting platform, transparent glass cover, and collecting tank were the main materials utilized for the treatment of wastewater using solar radiation and condensation technology.

2.1. Fresnel Lens

Fresnel lenses are made up of a series of concentric grooves etched on a lightweight, thin plastic sheet that comes in a variety of shapes and sizes. Fresnel lenses are beneficial in a range of applications due to their high light gathering capacity. Fresnel lens improves the distillate production output and efficiency of a single slope solar still. There are two types of Fresnel lenses: Spot and Linear; for this experiment linear Fresnel lens are used. The linear Fresnel lens with dimensions 135 cm × 100 cm as shown in Fig. 1.

2.2. Trapezoidal Evaporation Tank

Trapezoidal Evaporation tank is nothing but a solar still, which is used to collect the evaporated water as shown in Fig. 2, is a single sloped solar still with inclination of 30° is used for the experiment. In detail, the water basin of dimension 90 cm × 57 cm × 3 cm was made using galvanized steel for storage of waste water. The interior surface of the water basin was painted black to improve sunlight absorption capacity. The water basin is placed inside a thick wooden as shown in Fig. 3. The space between the water basin and the wooden box is 100 mm. For inlet and outlet, PVC pipes are used. A tempered glass of dimensions 100 cm × 70 cm was used as a transparent cover and placed at an inclination of 30°. To achieve solar input amplification, aluminium foil was applied between the glass cover and the water basin for sealing. A Fresnel lens aids in focusing sunlight into the basin through the tempered glass. The contemplated wastewater treatment was meticulously planned so that the Fresnel lens' focus point was always on the basin's bottom. Inside the evaporation tank, water vapours are formed.

2.3. Supporting Stand

Its purpose is to keep the Fresnel lens at a specific distance from the ground. The focal length of the Fresnel lens determines the height of the stand. The stand is made of iron bars to support the weight of the lens while also resisting wind forces. The stand may be raised to a height of 2m, with holes for the Fresnel lens anchors starting at 1m from the bottom and spacing of 10cm between each hole.

Because in experiment a 1.5 m focal length lens was used, the Fresnel lens is anchored at a height of 1.66m as shown in Fig. 4 from the bottom. The stand is set up such that the focused light falls on the glass plate with maximum concentrated spot. Figure 5 show the supporting stands used in this experiment.

2.4. Transparent Glass Cover

A piece of tempered glass having dimensions 100 cm × 70 cm was employed at a 30° angle used as transparent cover. A Fresnel lens directs sunlight into the basin through tempered glass. It is used to concentrate refracted solar energy as well as to condense water vapours. Condensed water droplets fall down to a corner, where they are attached to a slanted PVC pipe. The condensed water droplets travel

down to a corner, where they are connected to a slanted PVC pipe. The glass must be able to endure the heat generated by the Fresnel lens. Temperatures of around 500°C to 800°C are produced. Evaporation tank with transparent glass cover is shown in Fig. 6.

2.5. Collecting Tank

A tank is used to collect the condensed water droplets which are condensed on the glass plate and collected in a slightly inclined pipe and flowed to the collecting tank. The volume of the collecting tank depends upon the rate of evaporation and condensation per day. This collected water is tested and knowing the parameters present in water, we can use it for domestic purposes and further disinfecting it we can use for drinking. Collecting tank unit used for collection of condensed water is shown in Fig. 7.

3. Methodology And Procedure

- i. For experimental analysis sewage water sample from MVSR engineering college in Nadargul was collected.
- ii. After that, the sewage water was screened for plastic debris and other solid particles present in sample.
- iii. The amount of condensate is directly proportional to the amount of water present in the solar still (Bhambare et al. 2021). On the first day of the experiment, approximately 5-6 liters of waste water was added. The equipment was then oriented to face the sun, and the Fresnel lenses was placed above the container to receive direct sunlight. Concentrated rays from the Fresnel lens began to boil the waste water.
- iv. The vapors from the sewage water condensed on the glass surface, and water was collected at the tip of the glass surface due to the slope of the glass. Water was then channeled to the collecting tank, which was kept outside the single sloping container, via outlet pipe.
- v. For 5 days, same technique was followed, adding 1-2 liter of waste water daily, considering evaporation losses, as the production rate of basin type solar still is limited (D Dsilva et al 2016). The water sample is collected, tested, and analyzed in the laboratory.
- vi. The flow of entire methodology and procedure is shown in Fig. 8 and Fig. 9. The entire experimental setup for treatment of waste water using solar radiation and condensation is shown Fig. 8

4. Results And Discussion

For this experiment the sample was collected from MVSR Engineering college and was analysed and compared for various physio-chemical properties of treated water with drinking water is given in Table 2. However, the water quality parameters and BIS standard for various chemical and biological constituents is given in Table 3.

The key conclusions from the study are:

Table 2
Comparison of physio-chemical properties of raw water, treated water and drinking water

Parameters	Sewage Water	Treated Water	Drinking Water
pH	8.55	6.82	6.5–8.5
Calcium as CaCO ₃	180mg/l	24mg/l	75mg/l
Magnesium as CaCO ₃	92mg/l	8mg/l	30mg/l
Turbidity (NTU)	28.2	4.5	1–5
Nitrogen	5.60	1.90	10
Total Dissolved Solids	916mg/l	163mg/l	500 mg/l
Phosphorous	0.14mg/l	0.08mg/l	0.05 mg/l
Chlorides as CaCO ₃	243mg/l	19mg/l	250 mg/l
Sulphates as SO ₄	115mg/l	22mg/l	200 mg/l
BOD	84mg/l	11mg/l	< 5mg/l _a
Total coliforms	32 CFU	8 CFU	< 50 CFU
Faecal coliforms	Present	Present	Absent

Table 3
Water quality parameters and BIS Standards for various chemical and biological constituents

Parameters	Drinking Water (ISO 10500:2012)	
	Permissible Limit	Maximum Limit
Odour	Agreeable	Agreeable
Taste	Agreeable	Agreeable
pH	6.5 to 8.5	No relaxation
TDS (mg/l)	500	2000
Hardness (as CaCO ₃) (mg/l)	200	600
Alkalinity (as CaCO ₃) (mg/l)	200	600
Nitrate (mg/l)	45	No relaxation
Sulphate (mg/l)	200	400
Fluoride (mg/l)	1	1.5
Chloride (mg/l)	250	1000
Turbidity (NTU)	5	10
Arsenic (mg/l)	0.01	0.05
Copper (mg/l)	0.05	1.5
Lead (mg/l)	0.01	No relaxation
Iron (mg/l)	0.3	No relaxation
Zinc (mg/l)	5	15
Faecal Coliform (CFU)	0	0

- i. Eco-friendly and sustainable process removes the organic and bacteriological impurities in the wastewater
- ii. Less quantity of sludge compared to conventional wastewater treatment plant. This sludge can be used as a manure for fields.
- iii. This treatment method is simple to construct and no skilled manpower is required to operate it.
- iv. Solar radiation is used as power source to achieve high temperature more than 400⁰C which is used for evaporation therefore, no external power source is required to operate this unit.
- v. The parameters of the treated water are comparatively closer to the standard parameters of domestic water usage. As from the results obtained it is suitable for domestic usage and further treatment it can be used for drinking.

- vi. Some parameters of the treated water are in the range of standard fresh water like BOD, turbidity, pH, coliforms, etc and due to some faecal content, it is fit for domestic use but not for drinking.
- vii. This pilot scale unit can be installed in every individual house, especially in rural areas as a small-scale treatment unit to eradicate the water problem, thus preventing the wastewater being mixed with the fresh water bodies.
- viii. As compared to sewage water the treated water has 86.67 %, 91%, 66%, 42.8%, 92.18% and 80.86% percentage removal efficiency for calcium as CaCO_3 , magnesium as CaCO_3 , nitrogen, phosphorous, chlorides as CaCO_3 and sulphate as SO_4 respectively.
- ix. Turbidity of treated water improved to 84% while the percentage removal of TDS was 82%.
- x. BOD of treated water improved to 86.9% as compared to sewage water.

Graphical comparison of various physio-chemical properties of raw water and treated water is shown in Fig. 11 and Fig. 12. Figure 13 shows fluctuation in water collection with respect to time.

4 Future Prospects

The throughput from the solar still is our main challenge, as the evaporation and condensation are two significant factors for increasing the efficiency of waste water treatment. So, there are few techniques which worked on desalination process using solar still can be used here. However, these techniques are new and in developing stage, but can be implemented to maximize the efficiency.

4.1 Enhancing the evaporation rate

Using various types of wick materials in the still, we can improve the rate of evaporation to nearly 180% as compared to the conventional solar still (A S Abdullah et al 2021). By simple modification using internal/ external reflectors increases the daily productivity of basin type solar still, about 70–100% (Hiroshi Tanaka 2009). The distillate output of solar still is very low, due to less sunshine hours in a day, so to increase the efficiency of solar still, the thermal energy storage materials have to be used, since they release the heat during off-sunshine hours (Hitesh N Panchal 2016). Coupling solar still with flat solar collector increases the productivity by 36%, also increasing the water depth will reduce the rate of evaporation, in contrast reducing the thickness of water film and increasing the surface area will increase the productivity of condensate, because the intensity of solar radiation is directly proportional to the rate of evaporation (O. O. Badran and H A Al-Tahainch 2005). Integrating the conventional solar still with external condensator increases the rate of productivity by 53%, and using both nanofluids and condensator improves the solar still productivity by 116% (A E Kabeel et al 2014). Reducing specific height (the average gap between basin and glass cover) increases the daily efficiency of solar still (Basharat Jamil and Naiem Akhtar 2017).

4.2 Enhancing the condensation rate

The superhydrophobic coating on the glass cover surface is considered a new method to improve the anti-fogging and anti-corrosive properties of the glass surface and this increases the rate of condensation

(Bai Y et al 2021). South oriented double sloped solar still and glass cover tilted with an angle of 35° performs better than single slope solar still (Ibrahim Altarawneh et al 2017). The rate of condensation not only depends on the temperature difference of the glass surface but also on the sidewalls, so by water circulation through tubes along the sidewalls, will cooldown the temperature, which results in enhanced condensation rate (K Vinoth Kumar and R Kasturi Bai 2008).

5 Conclusion

In the context of global water scarcity and future energy crisis, water treatment technologies driven by solar energy are sustainable alternatives to address the worldwide water problem, the various applications of solar energy are disinfection, detoxification and desalination. The selection of solar water technologies can be very site specific. Among the various technologies, there is a simple, economical technology such as solar still using Fresnel lens, which is suitable for remote regions especially in developing nations which lack financial support. In this study, the fabrication of pilot scale waste water treatment unit is designed which provide reusable water by evaporation and condensation by integrating Fresnel lens with solar still. The water collected from this process is tested for various parameters and compared with the standard drinking water parameters from IS 10500: 2012. As compared to sewage water the treated water has 86.67%, 91%, 66%, 42.8%, 92.18% and 80.86% percentage removal efficiency for calcium as CaCO_3 , magnesium as CaCO_3 , nitrogen, phosphorous, chlorides as CaCO_3 and sulphate as SO_4 respectively. Turbidity of treated water improved to 84% while the percentage removal of TDS was 82%. BOD of treated water improved to 86.9% as compared to sewage water. This pilot scale unit can be installed in every individual house, especially in rural areas as a small-scale treatment unit to eradicate the water problem, thus preventing the wastewater being mixed with the fresh water bodies. Also when compared to conventional waste water treatment plant this technique requires less area to install and cost of laying sewer or drainage pipelines from city to wastewater treatment plant is not required.

Declarations

All the authors approved the manuscript and this submission. This manuscript having an original work, which has not been published before and is not under consideration by any other journal.

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Figures

Figure 1

Linear Fresnel lens with dimensions

Figure 2

Trapezoidal evaporation tank with tray

Figure 3

Trapezoidal evaporation tank

Figure 4

Sketch of supporting stand

Figure 5

Supporting stand

Figure 6

Transparent glass cover

Figure 7

Collecting tank unit

Figure 8

Flow chart representation of methodology

Figure 9

Flow chart representation of entire procedure

Figure 10

Experimental setup for treatment of waste water

Figure 11

Comparison of physio-chemical properties of raw water and treated water

Figure 12

Comparison of physio-chemical properties of raw water and treated water

Figure 13

Fluctuation in water collection

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