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Initial investigations of a combined photo-assisted water cleaner and thermal collector

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A B S T R A C T

Efficient solar thermal collectors incorporate thermosiphon effect to rid the costs associated with force flow systems, yet they lack the functions of solar photocatalytic collectors for water cleaning. The combination of hot and clean water from one collector is demonstrated in the present study by utilizing two chambers under Mirotherm® solar selective absorber. Top glazing has a transmittance of 71%. One chamber was closed and transports captured heat to the mixture chamber, which is open to a cold reservoir in a loop method. MB dye in water and AEROXIDE TiO2 P90 were utilized as the reagents. It has been observed that 1.2 ppm of MB dye can be cleaned using 127.4 mg*L-1 suspended UV-activated AEROXIDE TiO2 P90 that exhibits no sedimentation in the collector with thermosiphon flow. Thermal analysis was performed using ten thermocouples within the collector and non-contact temperature sensors above. The analysis of water heating thermal collector was studied for two modes; one with a controlled cold inlet and other with rising temperature inlet. We recommend that a controlled inlet temperature of 21.5 °C be utilized to acquire 40.1 °C increase in temperature, at which point the thermal efficiency of the collector is 67%.

1. Introduction

The natural resource of solar light can provide a large alternative from the immense expenditure on earth extraction mechanism by means of innovative renewable technology [1]. There exists no method to combined two popular renewable energy devices; solar thermal collector and solar photocatalytic collector. Recent literary surveys emphasize to significantly increase the efficiency of energy usage by maximizing the conversion of alternative natural resource, such as solar light to electrical power and for hot water/air heating purposes over more conventional methods that deploy coal and fuel resource utilization [2]. Approximately 1.08×10^{18} kWh of solar energy reaches the surface of the Earth and thus it is essential that its exploitation be maximized by the industry. Solar light exploitation has succumbed to profitable happenings and yielded solutions to obligatory provisions of reduced hunger, safe drinking water, improved health measures and security of environmental sustainability in the most recent times, owing to decades of efforts priory [3,4]. The most prominent technologies that have been successfully implemented to ease the burden on natural resource extraction are; (i) photovoltaic modules for electric power generation (ii); solar thermal collectors/solar water heaters for efficient hot water production (iii), solar photocatalytic collectors to decontaminate water and (iv), hybridized photovoltaic/thermal collectors [5–9]. A combination device for solar thermal collection and solar photocatalytic water cleaning has not been created and studied. Advanced oxidation process using suspended Titanium (IV) Oxide irradiated with UV light, or simply termed photocatalysis of water pollutants has become a support method alongside conformist techniques by these photocatalytic collector [10,11]. These systems are not house hold conducive as the solar thermal collectors have now become. . The advanced oxidation mechanism under solar light has been appraised to decompose various organic pollutants in water, ranging from dye waste from textile industries

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Nomenclature

A	Area (m^2)
C	Initial concentration of MB dye (ppm)
c	Specific heat capacity (kJ kg^{-1} K^{-1})
e	Experimental error
F	Normalized percentage
G	Irradiance magnitude (W m^{-2})
g	Acceleration due to gravity (m s^{-2})
h	Heat transfer coefficient (W m^{-2} K^{-1})
H	Height of collector
h	heat transfer coefficient (W m^{-2} K^{-1})
I	Measured Spectral intensity (a.u)
k	thermal conductivity (W m^{-1} K^{-1})
L	Characteristic length of heat transfer (m)
M	Mass (kg)
$\dot{m}$	Mass flow rate of mixture (kg s^{-1})
η	Efficiency
Nu	Heat transfer Nusselt number
Pr	Fluid Pradtl Number
Q	Heat transfer rate (W)
q''	Heat flux (W m^{-2})
Ra	Rayleigh's Number
t	time (second or minutes)
T	Temperature (°C)
U_L	Over all heat loss coefficient (W m^{-2} K^{-1})
x	Longitudinal distance (m)
y	Transverse distance (m)

Greek Symbols

τ	Transmittance
η	Efficiency
β	Volumetric expansion coefficient (K^{-1})
Δ	Change in quantity
ε	Emissivity
γ	Independent variable
φ	Dependent variable
θ	Inclination from the ground (°)
λ	Wavelength (nm)
ν	Fluid Kinematic viscosity (m^{-2} s)
ρ	Fluid Density (kg m^{-3})
σ	Stefan-Boltzmann constant (W m^{-1} K^{-4})

Subscripts

a	ambient
abs	Absorber
abs-glass	Absorber to glass
conv	convection
cr	critical
el	electrical
f	Front
g	Glass
in	Inlet
i	Initial
out	outlet
o	Final
rad	Radiation
th	thermal
w	Water

Abbreviation

a.u	Arbitrary Units
AMBI	5-amino-6-methyl-2-benzimidazolone
CPC	Compound Parabolic Collector
DAQ	Data Acquisition
DASC	Direct Absorption Solar Collector
DSSR	Double-skin-sheet-reactor
ETC	Evacuated Tube Collector
FPC	Flat-Plate Collector
MB	Methylene blue
P25	Grade 25
P90	Grade 90
PVC	Poly Vinyl Carbonate
TiO_2	Titanium (IV) Oxide
TFFBR	Thin-falling-film-bed-reactor
TPTC	Two-chamber Photocatalytic Thermal collector
UV	Ultra-Violet light

as well as *Escherichia coli* bacteria in drinking water and there is certainly a need to explore their potential with house hold water cleaning in one assembly [12–17].

This study aims to create a functional solar collector that shows photocatalytic decomposition of a model pollutant and efficient solar thermal collection. In accord with the literature review preceding this section, the new collector should provide $\eta_{the} > 0.6$ and a high-temperature gain of 40–60 °C with respect to other thermal collectors. It is imperative that a new collector design provides solar water cleaning, without the falsifying results from other phenomena that lead to decrease of dye in water such as photolysis and pollutant adsorption on catalyst surface, so that it may be investigated by researchers in future work.

2. Literature review

Solar photocatalytic and solar thermal collectors utilize specific and different electromagnetic radiations of natural solar light. UV light comprises of approximately 2–3% of the magnitude natural solar light [18], VIS light is 54.2% and NIR radiation is 26.4% [19] as reported for the AM 1.5 solar spectra. Solar photocatalytic collectors make use of UV light only that initiates advanced oxidation processes to photo-degrade a model pollutant in the water. The process involves the generation of hydroxide ions on the surface of the photo-activated catalyst leading to the oxidation-reduction of the organic pollutant. TiO_2 P25 semiconductor has been most profoundly used in these collectors. This catalyst is either suspended in the water or coated on the surface of transparent glazing of the collectors entailing water cleaning only and availing UV light [10,20,21]. Experimental work on the performance of solar water cleaners has constituted monitoring decreasing concentrations of Azo-dyes against TiO_2 P25. Pollutant MB dye in water is still prevalent to numerous contamination studies globally and has shown 100% degradation via photocatalysis in indoor work only [22,23]. MB dye has been subjected to various photocatalytic degradation experiments in outdoor solar photocatalytic collectors, with the inclusion on oxygenation and hydrogen peroxide to assist in its oxidation-reduction. It is one of the best pollutants to demonstrate photocatalytic reactions with various TiO_2 catalyst grades in natural solar light. The advanced oxidation of MB dye via photocatalysis harnesses UV and VIS light. Two distinct sub-processes occur; photocatalysis (under UV light) and photosensitization (under VIS