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A Novel Approach for Distillation of Hard Water Using Photovoltaic Effect

Ms.P.Vadivu[1], Ms.S.Rubini[2], Dr.S.Hemajothi[3]

***Abstract* - The scope of this system is to use Photovoltaic energy for distillation of water. A solar smokestack distillation system includes the Photovoltaic smokestack, photovoltaic collector, passive condenser, and evaporation system, was designed and constructed. The air in the collector after heating gets released at the base of the smokestack, now this dry air goes upward. By showering saline water into the hot air stream at the middle of smokestack the air is humidified. Now, the remaining vapors contained noticeable all around are dense to give desalinated water. The system is minimal in nature as it is easy to assemble and dismantle. It can be utilized for purifying rain water in summer under rain water harvesting. The cost of this system is low as we use country wood and recycled Aluminum jars.**

I. Introduction

Desalination is a chemical process of converting seawater into fresh water. The two approaches for desalination of water are thermal distillation and membrane processes. The main thermal desalination process are multi-effect distillation, multistage flash distillation, vapour compression distillation and photovoltic distillation. In the last years, an exciting innovation has been introduced by researchers called ― Photovoltaic smokestack. This project is of great significance for the development of new energy resources.

II. Literature Review

The use of advanced water treatment technology to application from research is limited by to implement research concepts prior to full scale design. Twelve key desalination-related papers from seven states outlined some type of state desalination research and implementation priority. Websites also are catalogued where appropriate. On a broad level, Reclamation's desalination investments are guided by institutional knowledge, and by key publications such as the Desalination and Water Purification Technology Roadmap (2003) and Desalination: A National Perspective (2008).

Ms.P.Vadivu[1] *– ECE Department, Assistant Professor, Prathyusha Engineering College – Thiruvallur/ Tamilnadu/ India. – 9940514809. vadivupillai@gmail.com*
Ms. S.Rubini[2]*– ECE Department, Assistant Professor, Prathyusha Engineering College – Thiruvallur/ Tamilnadu/ India. – 9566235854. ecerubini@gmail.com*
Dr.S.Hemajothi[3] *– ECE Department, Professor, Prathyusha Engineering College – Thiruvallur/ Tamilnadu/ India. – 9094768008. hemaselwynj@gmail.com.*

A. Photovoltaic Desalination Methods

Direct and indirect techniques are the two basic methods used for achieving desalination of salt water. Photovoltaic desalination is a method which utilizes solar radiation to produce desalinated water. Based on this method different Photovoltaic desalination plants are developed. The main classifications are direct method and indirect method. A simple cycle that couples a Photovoltaic collector along with a distilling process is the basic mechanism used in direct method.

Photovoltaic desalination is a small-scale operation. Apart from same designs of Photovoltaic distillation (figure 1), the basic principle behind it is similar as such that the heat energy from sun evaporates freshwater from salt water. The water vapour after evaporation process in Photovoltaic distillation condenses on a glass covering and is collected in a condensate trough as freshwater. The covering transmits radiant energy and permits water vapour to condense completely on its inner surface. The brine solution is formed by the left out salt and un-evaporated water in the still basin which must be removed at required timings.

Photovoltaic distillation is frequently used in dry and barren regions where drinking water is less available. Based on the geographic location differing quantity of freshwater is produced by Photovoltaic distillation units. Photovoltaic stills (Figure 2) produced by Unisol Company are employed in many small distillation and desalination system.

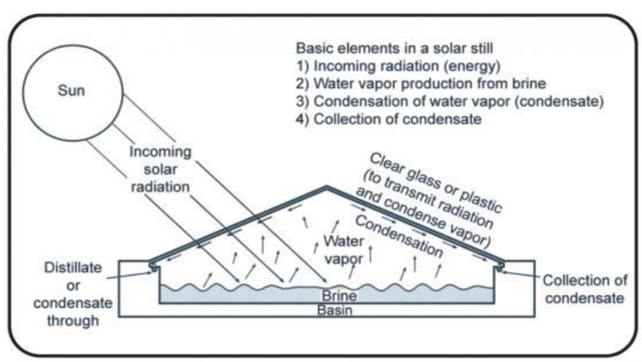

Figure 1: Example of a Photovoltaic distillation process. Source: MECHELL & LESIKAR (2010)

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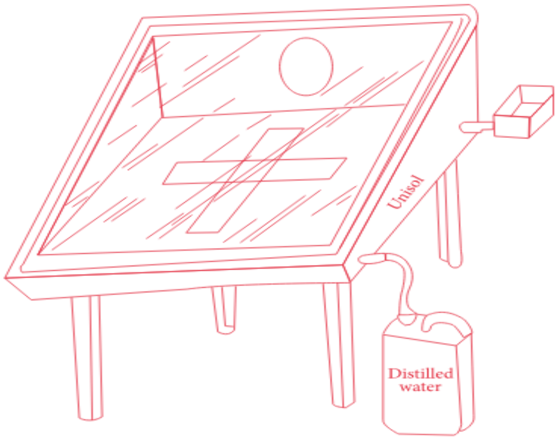

Figure 2: Photovoltaic still

For the direct method, area of the incidence angle to solar surface is directly proportional to solar distillation for water production. According to Pastohr et al. [3] solar productivity of still not only occupies huge space but also comparatively less. Either photovoltaic or fluid based collectors are used in indirect solar desalination process. Water production is dependent on the thermal efficiency of the plant in indirect method and by increasing the scale, the cost per unit for water production is reduced.

B. ***Photovoltaic smokestack Desalination System***

In 1981 at Manzanares, Spain, a pilot Photovoltaic smokestack power system was constructed and from then, more efficiently researchers are showing strong interest in such Photovoltaic smokestack power systems. The warm vitality that is put away at the base of the sun powered lake is utilized as a part of a warmth exchanger to warm up the air. Photovoltaic smokestack for control age and seawater desalination.

Khoo and Lee [12] built up the entire Photovoltaic desalination framework (Figure 3) comprising of Photovoltaic collector, smokestack, desalination framework, and detached condenser framework.

The air inside the Photovoltaic collector is warmed up as the sun oriented radiation strikes the Photovoltaic collector. Thus, the hot air moves from the Photovoltaic collector to the fireplace and ascends to the best because of stack impact. Inside the smokestach, a sprinkler (mistifier) splashes a fine fog of salt water downwards. The hot air ascending the stack would then exchange warm by convection into fine water beads, causing vanishing of the salt water. The water vapor delivered will then be done up and of the smokestack by the wind stream from where it will come into contact with a uninvolved condenser and consolidates to frame new fluid water beads which are gathered in an outside store. Alvarez et al. [13] outlined Photovoltaic collector utilizing reused aluminum jars at a less cost.

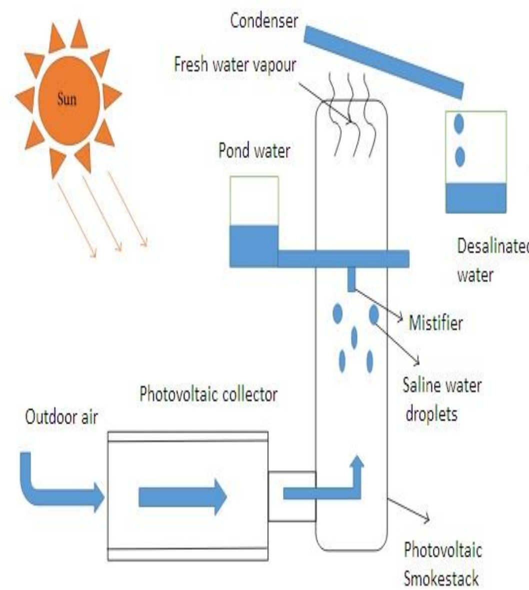

Figure 3: Schematic diagram of Photovoltaic desalination system.

III. Proposed Desalination Plant

In the present work a reused aluminum jar collector was incorporated with a Photovoltaic smokestack. The trial setup essentially includes Photovoltaic collector, smokestack, condenser, sprinkler system, submersible water pump, debilitate fan, Photovoltaic panel for control supply, and stand. A scientific model was created, affectability investigations were directed to improve the framework, and the outline parameters got were then utilized as a part of the dimensioning and estimating of the segments for manufacture. With the comprehension of finish framework each subsystem operation was created and a rearranged rendition was portrayed with the flowchart appeared in Figure (4).

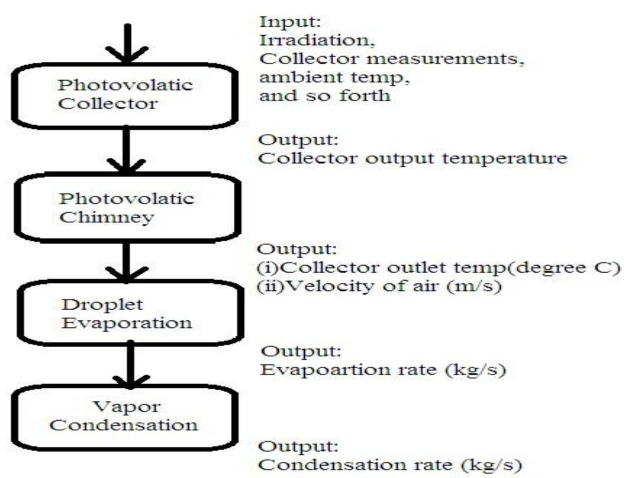

Figure 4: Flow chart of Photovoltaic desalination system.

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A. *Recycled Aluminum-Al Can Photovoltaic Air Collector*

The collector was comprised of reused aluminum soda pop jars to be worked requiring little to no effort. The baffle plate of the collector comprises of 9 roundabout area wind stream channels each made by joining 8 reused Al jars (Figures 5 and 6). Table 1 demonstrates the determinations of the Photovoltaic collector.

S.No	ASSUMPTIONS	SPECIFICATIONSS
1.	Solar Irradiation	1000 W/m^2
2.	Collector area	1.5*0.6 m^2
3.	Base plate temperature	Constant
4.	Absorber plate material	Black paint Al.
5.	Ambient temperature	28^{0}C
6.	Inlet air temperature	32^{0}C
7.	Double glazing	Applied
8.	Wind velocity	2 m/s
9.	Tempered glass emissivity	0.88
10.	Tempered glass transitivity	0.85
11.	Tilt angle collector	80^0
12.	Testing Time	8 hours per day
13.	Black paint absorber plate emissivity	0.09

Table 1: Dimensions and specifications of RAC Photovoltaic collector.

For guaranteeing constrained convection, a debilitate fan, which keeps running with sun powered vitality, was utilized. Tempered glass and Al sheet were utilized at the base of collector to guarantee more warmth retention and reflection. Ideal tilt edge of gatherer is gotten from Ulgen [14].

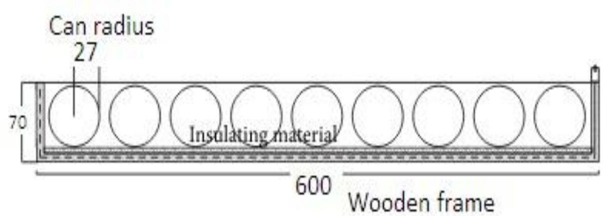

Figure 5: Photovoltaic collector with 9 columns of recycled aluminum cans (front view).

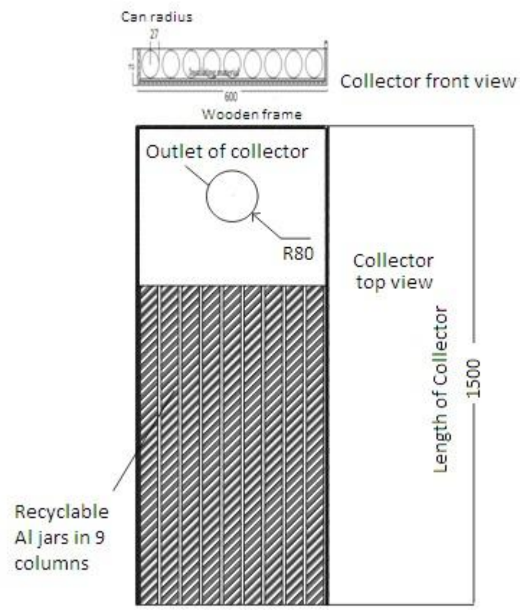

Figure 6: Photovoltaic collector made of recycled aluminum cans (RAC collector).

B. *Smokestack with a Bend*

Smokestack was round in cross segment and made with galvanized sheet (Figure 7) so as to counteract rust development. Height of smokestack (without stand) was 1.5 m and distance across the Smokestack was 0.16 m. The base of the stack was left open to guarantee simple entry into the smokestack during the tests. It was light in weight.

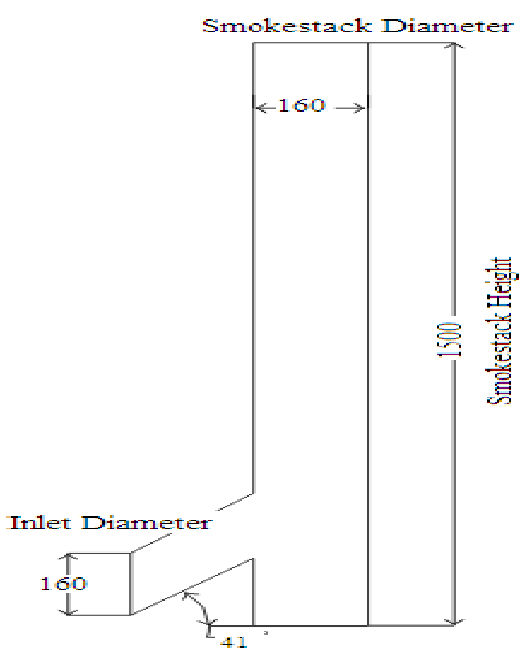

Figure 7: Smokestack made of GI sheet and its dimensions.

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A bend was given toward the finish of the smokestack at an edge of 45° to facilitate assembly with collector. Top end of smokestack was associated with the condenser.

C. ***Construction of Desalination system Using Photovoltaic Smokestack with RAC Collector***

As seen in Figure 8, the collector and Smokestack were fixed together using 4x M8 bolts. The condenser was fixed at the top of the smokestack. Ultimately, the complete system was seated on a stand.

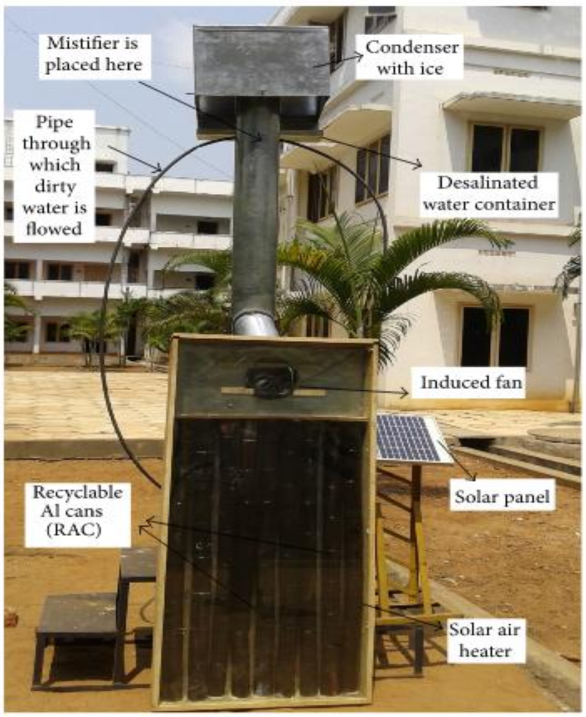

Figure 8: Desalination plant using a Photovoltaic smokestack with RAC collector.

D. ***Condenser***

The condenser was built with measurements of 400 × 450 × 0.5 mm and a 30° slope. For collecting water from condenser surface, a slope was provided. At the top of the condenser it has the facility to store ice.

E. ***Sprinkler System***

For spraying water into the smokestack, a sprinkler was used. This could be vaporized by hot air which comes from smokestack. The sprinkler was placed at the bottom of the smokestack. The saline water was forced into the sprinkler by a small pig boat water pump.

F. ***Experimental Conditions***

The experiment was conducted for 6 hr.

The values were taken at the following conditions. Local time: 11:00 AM to 1:30 PM, on May 9, 2017. Location: kundrathur, Tamil nadu, India. Latitude: 13° 2' 17.0268'' N. Longitude: 79° 56' 28.7880'' E.

Readings for the photovoltaic panel connected are as follows: V = 30 volts; I = 0.028 amp.

The following are Photovoltaic parameters existing in the place of work. Sukhapme and Nayak [15] have given a detailed procedure for calculating solar irradiance of a system at a location:

Latitude (φ) = 16.50deg
Day Number (n) =100 (1)
Array Tilt (Slope) (β)
= 80 deg (but, optimal for that month is at 81 degrees)
Declination angle (δ(in deg))

$$= 23.45 sin\left[\frac{360}{365}(284+n)\right] = 23.08\ deg$$

Hour angle (ω) = $\cos^{-1}$(-tan φ-tanδ)
Monthly avg. radiation (I_o)

$$= I_{sc}\left(1+0.033\cos\left(\frac{360n}{365}\right)\right)\ kw/m^2$$

Solar irradiate on a tilted surface with no atmospheric effects (H_{ot})

$$= \frac{24I}{\pi}\left(\cos(\varphi-\beta)\cos\delta - \cos\omega + \omega\sin(\varphi-\beta\sin\delta)\right)\ kwh/m^2/day. \quad (2)$$

Solar energy with no atmosphere(H_o)

$$= \frac{24I}{\pi}(\cos\varphi\cos\delta\cos\omega + \omega\sin\varphi\sin\delta)\ kwh/m^2/day.$$

The above input values were submitted in (2) and irradiance was calculated as 5.98 kWh/m2. Anyhow, a minimum value of 1.0 kWh/m2 was considered in the calculations.

A analytical model was developed, sensitivity evaluation were done to upgrade the system, and the sketched parameters received were then utilized in the measurement and allocation of the components for fabrication.

G. ***Draught Calculation.***

As per the smokestack height draught calculation equations are

$$\mathbf{h = 353H}\left[\frac{1}{T} - \left(\left(\frac{w+1}{w}\right)\frac{1}{T}\right)\right]$$

$$\mathbf{h'=H}\left[\left(\frac{w}{w+1}\right)\frac{T}{T1} - 1\right] \quad (3)$$

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From the input values, H = 1.3 m; ω= 196 kg of air/hr; and T = 78°C and T_1= 27°C. Draught (h) and draught height (h') are 1.21x10^{-3} mm of water and 3.6 m, respectively.

H. *Performance of RAC Photovoltaic Collector*

The performance of Photovoltaic collector was calculated using the data shown in Table 2. Alvarez et al. [13] calculated RAC Photovoltaic collector thermal efficiency as the ratio of the total useful specific enthalpy flux and the total incident solar radiation flux:

$$\eta = \frac{\int_{t1}^{t2} mCp}{Ac} \frac{T0 - T1dt}{\int_{t1}^{t2} G.dt} \quad (4)$$

S.No	DATA ASSUMED	VALUES
1.	Length of collector	1.5m
2.	Width of collector	0.6m
3.	Length of absorber plate(L_1)	1.5m
4.	Width of absorber plate(L_2)	0.6m
5.	Spacing between absorber plate and bottom plate(L)	1.5cm
6.	Air flow rate(m)	200kg/hr
7.	Air inlet temperature(T_{fi})	30^0C
8.	Ambient temperature(T_a)	28^0C
9.	Solar flux incident on the collector face(I_T)	950 W/m^2-^{0}C
10.	Transmissivity $(\tau_\alpha)_{avg}$	0.85
11.	Top loss coefficient (U_t)	6.2 W/ m^2-^{0}C
12.	Bottom loss coefficient (U_b)	0.8 W/ m^2-^{0}C
13.	Emissivity top plate and bottom plate surfaces(ε_p=ε_b)	0.95

Table 2: Dimensions and specifications of RAC Photovoltaic collector.

I. *Performance of Smokestack*

As the smokestack breadth was kept steady, the speed of the hot air stream which flows through the heat collector increments and the air volume stream rate likewise increments in comparative extent as the smokestack height increments. The pressure contrast which was caused by the air density difference between inside and outside of smokestack was

$$\Delta P = \rho ch.ingH \frac{Tch.in - Ta}{Ta} \quad (5)$$

The pressure difference was proportional to a portion of the elements, such as the density of the air flow at the inlet of the smokestack, the temperature difference ($T_{ch.in}$ - T_a), and smokestack height. This pressure drop would help condensation.

IV. RESULTS AND DISCUSSION

Prior to any water was showered into the framework, the air in the framework was heated through the Photovoltaic collector with least sun based illumination of 1000 W/m2 applied. The temperature conveyances along the collector and smokestack were recorded in Tables 3 and 4 by utilizing research center thermometer.

TIME	INLET TEMPERATURE OF COLLECTOR (^{0}C)	OUTLET TEMPERATURE OF COLLECTOR (^{0}C)
11.00 AM	28	31
11.15 AM	29	38
11:30 AM	30	43
11:45 AM	31	49
12:00 PM	32	53
12:15 PM	32	59
12:30 PM	34	64
1:00 PM	35	74
1:30 PM	36	82

Table 3: RAC collector temperature distribution.

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TIME	INLET TEMPERATURE OF SMOKESTACK (^{0}C)	OUTLET TEMPERATURE OF SMOKESTACK (^{0}C)
11.00 AM	35	33
11.15 AM	38	37
11:30 AM	42	41
11:45 AM	47	45
12:00 PM	52	51
12:15 PM	59	58
12:30 PM	63	61
1:00 PM	73	72
1:30 PM	76	79

Table 4: Smokestack temperature distribution.

From, with an expansion in the sun oriented radiation, the Photovoltaic collector outlet temperature was expanding. The outlet temperature of air in the Photovoltaic smokestack is expanding consistently and this temperature could influence the mist to evaporate and climb. So as to decide the measure of water evaporated, the underlying and last weight of the water tank were estimated with the difference in weight being the measure of water evaporated by the system. The condenser dividers were kept at a consistent temperature of 10°C by utilizing pounded ice. Originally tests were conducted for the sprinkler system mounted close to the Photovoltaic smokestack outlet (0.5 m range from base of smokestack) and each test kept running for 1 hr. Later tests are done at second position 1 m from the base of stack.

Furthermore, temperature estimations along the smokestack were likewise taken to decide the temperature drop in the system as water was infused into the system. Tables 5 and 6 demonstrate the air temperature distributions in smokestack (when water was showered in smokestack). On account of heat and mass transfer in the mist of water and air, the difference in stage from fluid to vapor happens. The drop in temperature with height of the smokestack is because of heat losses over the smokestack divider. It clearly indicates the requirement for a good insulation to be done to the smokestack to minimize convection and radiation. The air rate esteems, in smokestack, estimated utilizing anemometer were classified in Table 7.

It can be seen that air flow rate without mist achieves high at 12.00 noon, which relates to most highest irradiance time. Likewise the air flow rate with mist decrease to minimum around the same time as humidification expands the thickness of air. Air flow rate with mist bend marginally trials behind one without mist.

HEIGHT (m)	INITIAL TEMPERATURE WHEN NO MIST IS SPRAYED (^{0}C)		
	TRIAL 1 AT 11:00 AM	TRIAL 2 AT 01:00 PM	AVERAGE
2.2	60	68	64
2.5	59	66	52.5
2.8	54	63	58.5
3.1	52	57	54.5
3.4	49	56	52.5

Table 5: Temperature distribution of air in Smokestack at different heights (before water is sprinkled in Smokestack).

HEIGHT (m)	FINAL TEMPERATURE WHEN NO MIST IS SPRAYED (^{0}C)		
	TRIAL 1 AT 11:00 AM	TRIAL 2 AT 01:00 PM	AVERAGE
2.2	33	33	33
2.5	32	33	32.5
2.8	31	32	31.5
3.1	29	32	30.5
3.4	29	31	30

Table 6: Temperature distribution of air in Smokestack at different heights (after water is sprinkled in Smokestack).

TRIAL	TIME	AIR FLOW RATE IN CHIMNEY (velocity(m/s))	
		FLOW RATE WITHOUT MIST	FLOW RATE WITH MIST
Trail 1	11:00 AM	0.12	0.08
Trail 2	12:00 AM	0.15	0.06
Trail 3	01:00 AM	0.10	0.07
Average		0.12	0.07

Table 7: Airflow rates in Smokestack.

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The smokestack flow rate with and without mist gives the pressure drop in the smokestack. The impact of smokestack measurement, height, and sun based radiation on the channel water temperature and the glass cover temperature was distinct. Accordingly, the temperature distinction between water vapor and glass inward cover ΔT expanded and hourly freshwater creation expanded in the daytime, while, during the evening, the temperature contrast ΔT reduced by which the freshwater production diminished.

V. CONCLUSIONS

The day by day use of effectiveness of solar energies vitality of the incorporated framework relies upon the heat energy which was picked up from sun based energy to produce freshwater. The essential objective of the work was accomplished through the achievable Photovoltaic smokestack for water desalination. With the predefined design parameters at a minimum solar illumination of 1000 W/m2, experimental testing was done on the model framework, the center of the smokestack being the ideal sprinkler height equipped for condensing and collecting 2.3 L of water by evaporating 3.77 L with the 3.4 m height of whole setup. The achievement of the framework is attributed to the unique design of RAC collector incorporated with the photovoltaic smock stack.

Nomenclature

h : Draught (mm of water)
w : Weight of air (kg/kg of fuel)
T : Mean absolute temperatures of smokestack gas (°C)
T_1 : Outright temperature of air out the smokestack (°C)
H : Height of smokestack above the grate level (m)
$h^{'}$: Draught height of hot gasses (m)
A : Collector area (m2)
N : Incident solar radiation (W/m2)
ƞ : Thermal efficiency of the collector (dimensionless)
C_p : Specific heat (J/kg K)
t : Time (s)
T_o : Mean out passage temperature of the collector (°C)
T_i : Mean inner passage temperature of the collector (°C)
$\dot{m}$: Mass flow rate (kg/s)
ΔP : Pressure difference in smokestack
$\rho_{ch.in}$: Specific density of gasses in smokestack
g : Gravity of earth
$T_{ch.in}$: Inlet temperature of smokestack (°C)
T_a : Ambient temperature around smokestack
ΔT : Temperature difference between lake water and glass internal cover (°C).

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	**Ms.P.Vadivu** received her M.E. degree in Jaya Engineering College, Anna University, Tamilnadu, India., in the year 2010. Now working in Prathyusha Engineering College, Thiruvallur, Tamilnadu, India, as Assistant Professor in Electronics Department. Also Executive research Officer in NanoPV Solar India Pvt. Ltd., Thiruvallur, Tamilnadu, India. She has published 4 papers in national conferences, 2 papers in International conferences, 3 papers in International Journal. Life Member of **ISTE** Professional body**.**
	**Ms. S.Rubini** received the M.E. Degree in Engineering from Prathyusha Engineering College, Anna University, Tamilnadu in the year 2017. Now working in Prathyusha Engineering College, Thiruvallur, Tamilnadu, India as a Assistant Professor. She has published a paper titled “Survival of ICU Patient Health Monitoring Using IoT” in International Conference on Advanced Functional Materials 2017 (ICAFM’17)
	**Dr.S.Hemajothi** received her M.E., degree in Medical Electronics from Anna University, Chennai in 2007 and Ph.D degree from St. Peter’s University, Chennai . Presently, she is working as a Professor at Prathyusha Engineering College, Chennai. Now working in Prathyusha Engineering College, Thiruvallur, Tamilnadu, India as a Professor. She has more than 30 research papers in her credit in National and International Conferences and Journals, Chennai.

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