

Performance improvement of single and double effect solar stills with silver balls/nanofluids for bioactivation: An experimental analysis

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ABSTRACT

The implementation of bioactivation nanofluid in single and double slope solar stills (SDESS) is an important aspect from thermo-economic point of view. Based on efficient thermal modelling, a comparative analysis of nanofluids is also suggested for design optimization of solar stills. To develop SDESS observations, the data is taken for the period from January 2021 to April 2022, at KLEF in India. To create green TiO₂ nanoparticles using eco-friendly bleaching chemicals and jackfruit peel (Bioactivation), a green nanoscale approach is used. The performance of the double-effect solar distiller (DESD) is demonstrated using various TiO₂/Jackfruit peel nanofluids (TJPN) (5%, 10%, 15%, 20%, 25%, and 30%) with silver colour balls. The SDESS results are presented as energy (41%) and exergy (5.63%), with the TJPN having the highest efficacy (20%) based on water depth of 0.8 cm. With a water depth of 0.8 cm over the course of a 12-hour observation period, the total SDESS efficiency result is 7.35 kg/m² per day and TJPN for 30%. An economic analysis of SDESS is found with the cost of concentration that portable water (per litre) and appraised around 0.0726\$ by reimbursement term of 14 months. The average thermo-enviro-economics analysis of SDESS is 3.35 (exergy) and 4.71% (Energy). For 0.8 cm of water depth and an analysis of the weather for good life cycle units, SDESS concentrates 7.97 tonnes of CO₂ emissions. Additionally, the analysis of TJPN optimization by the SDESS is done for 5%, 10%, 15%, 20%, 25%, and 30% and is based on the theoretical yield at the maximum water temperature and water depths of 0.6, 0.8, 1 and 1.2 cm.

1. Introduction:

Water is one of the primary essentials of soil and is necessary for human survival. Human uses water to maintain the health and need 20 to 50 L per day for drinking, cooking, bathing, and other needs depending upon geographical conditions. Sangeetha et al. [1] investigated the activated carbon nanoparticles (ACNPs) with fixed ZnO nanoparticles from *Mangifera indica* (M) and *Celostia argentea* (C) at various ratios of 5, 10, 15, 20, and 25 wt%. Utilizing silver-colored steel

balls (SBs) and the Gibbs free energy equation, which promote convective heat transfer and absorb solar radiation, the thermodynamic analysis of the samples is calculated for an entropy change. The study concluded that BPACNP-SB boosted daily efficiency by 38.73% while the DUSS improved by 14.92 L/m²/day. Shanmugan et al. [2] have experimented to construct sessions for the yield of winter is 5.39 L/m², and in summer is 7.89 L/m² per day. In addition to significant uses nanoscience applications. Sangeetha et al. [3] reviewed DSSS and improvements in effectiveness Phase Change Materials (PCMs), and Nano-Fluids (NFs) based on thermal energy storage materials. It focused on

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Nomenclatures			
A_{sb}	SDESS has used that area of the silver balls (m^2)	h_{sbb}	The overall heat transfer coefficient of silver balls towards the basin region is calculated using SDESS. (W/m^2K)
A_b	SDESS has used an area of the basin (m^2)	h_{wsb}	The total heat transfer coefficient of saline water towards silver balls is calculated using SDESS. (W/m^2K)
A_{gsn}	Area glass cover in South and north facing (sn) (m^2)	m_y	cumulative yield (L/m^2)
A_0	Initially from methyl orange absorptions	L	SDESS has used evaporation process (latent heat) (J/kg)
A_t	Subsequent degradation	k	SDESS has used the glass wool insulation (thermal conductivity) (W/mK)
I_E	East side absorbed by solar radiations (W/m^2)	$P_w \& P_G$	As a measurement tool for partial vapour pressures ranging from temperatures of glass covers to salty water (Nm^{-2})
I_s	Solar radiations (W/m^2)	$\dot{Q}_u$	Total heat transfer of the distillers (W/m^2K)
L	Latent heat (joules)	$\dot{q}_{ewE}$	East side evaporative heat transfer rate (W/m^2K)
$\dot{m}_E$	The evaporation of water (mass) (Kg/m^2h)	$\dot{q}_{ewW}$	West side evaporative heat transfer rate (W/m^2K)
M_{EW}	Total mass production of west and east side glass output (Kg/m^2h)	U_{ba}	Side wall loss from bottom to ambient
M_{sb}	Mass of the silver balls (Kg/m^2h)	U_{bw}	Side wall loss from bottom to west
M_w	Mass of the water (Kg/m^2h)	U_{EW}	Side wall loss from east to west
M_b	Mass of the basin area (Kg/m^2h)	U_L	Side wall loss
T_m	Moist air used in DESD ($^{\circ}C$)	η_0	Efficiency solar distillers (%)
T_{gsn}	Temperature of glass covers in South & North facing ($^{\circ}C$)	$\dot{E}x_{evap}$	SDESS exergy output
T_a	Ambient temperature ($^{\circ}C$)	$\eta_{passive}$	Thermal efficiency (%)
T_{sb}	Silver balls temperature ($^{\circ}C$)	n	lifetime (s)
$T_b \& T_w$	Basin and water temperature ($^{\circ}C$)	i_{er}	Effective interest rate
$T_w \& T_{sb}$	Water and silver balls temperature ($^{\circ}C$)	t	Number of combining periods (s)
T_b	Basin (bioactivation) temperature ($^{\circ}C$)	i_{br}	Bank rate annual interest rate
T_{sw}	Saline water temperature ($^{\circ}C$)	i_{erc}	Effective interest combination rate
T_s	Sky temperature ($^{\circ}C$)	e^i	An effective annual and continuous combination interest rate
T_m	Moist air temperature ($^{\circ}C$)		
T_{sw0}	Initial condition designs ($^{\circ}C$)		
T_{sb}	SDESS has used the temperature of the silver balls ($^{\circ}C$)		
h_{gsna}	SDESS used for an overall heat transfer coefficient as of glass covers (South & North facing = sn) to ambient air (W/m^2K)		
h_{sbg}	Total heat transfer coefficient from silver balls to glass covers (sn) (W/m^2K)		
h_{gsb}	SDESS is used the total heat transfer coefficient of glass covers (sn) to silver balls (W/m^2K)		
h_{sbm}	SDESS is used as the total heat transfer coefficient of silver balls toward moist air (W/m^2K)		
h_{tE}	Total heat transfer coefficient as of east side glass cover (W/m^2K)		
h_{cwE}	Heat transfer coefficient as of convective from water to east side glass cover (W/m^2K)		
h_{ewE}	Heat transfer coefficient as of evaporative from water to east side glass cover (W/m^2K)		
h_{rwE}	Heat transfer coefficient as of radiative from water to east side glass cover (W/m^2K)		
h_{cW}	Heat transfer coefficient as of convective water (W/m^2K)		
h_{aW}	Heat transfer coefficient as of ambient to water (W/m^2K)		
h_{tW}	Heat transfer coefficient as of bottom to water (W/m^2K)		
h_{cwW}	Heat transfer coefficient as of convective from water to west side glass cover (W/m^2K)		
h_{ewW}	Heat transfer coefficient as of evaporative from water to west side glass cover (W/m^2K)		
h_{rwW}	The rate of heat transfer from water to the west side of the glass cover (W/m^2K)		
h_{sbm}	The overall heat transfer coefficient of silver balls towards wet air is calculated using SDESS. (W/m^2K)		
		Greek Symbol:	
		α'_g	Absorptivity of the glass cover
		τ_g	Transmittivity glass covers
		α_{gsn}	DESD is absorptivity by glass covers (sn)
		α_{sb}	DESD is absorptivity by silver balls
		ε	DESD is used in glass covers emissivity values
		σ	DESD is used in Stefan – Boltzmann constant values
		η_e	The system's daily thermal efficiency (%)
		τ_w	Sun radiation absorbs to salt water at JPTSB's surface.
		$\tau_{g(sb)}$	A glass cover absorbs solar radiation, increasing its intensity in the south-north direction.
		Abbreviations:	
		C C_1	Capital cost
		FA C_1	First Annual Cost
		ASV ₁	Annual Salvage Values
		SV ₁	The Value of Salvage
		SFF ₁	Fund Sinking for the Factor
		SFF ₁	The sinking Fund Factor
		CO ₂	Carbon dioxide
		AMCO	value of an annual maintenance coefficient.
		PWC	Current cost value
		PWB	The value of a benefit today
		UAC	Uniform annual cost
		EEP _{En}	Exergo-economic parameters based on energy
		EEP _{Ex}	Exergy based on exergo-economic parameter values
		EP _{CO₂}	Enviro-economic parameter
		IN _{CO₂}	International carbon cost.

predictions by applying publicity creativities of the PCMNf employed in DSSS. The impact of passive units investigated by Shanmugan et al. [4] was the outcome with a material yield of 7500 ml/m²/day and Al₂O₃ nanofluids without PCM, on the other hand, it produced 4200 ml/m²/day. Using absorber liners for coating materials of TiO₂/Cr₂O₃. A study on stepped basin solar still (SBSS) coated with energetic SiO₂/TiO₂

nanolayers was also analyzed experimentally by Shanguman et al. [5]. Janarthanan et al. [6] proposed in-depth analyses of review article based on indium-doped tin oxide (ITO) thin-film coating methods. It was discovered that the lowest resistivity is 0.7–12 104 cm for the evaporation approach and the maximum gearbox is 90–95% for the CVD process. ITO films are being created for TCO applications. Based on a

review of the fundamental elements of a dye-sensitive solar cell, Ruba et al. [7] examined PV via thin-film technologies. The numerous metals nanomaterials encapsulated photo anodes and counter electrodes are taken into consideration for the review as an ideal material for a pronounced performance highlighted and addressed. Sowmya, et al. [8] have studied the dye-sensitized solar cells (DSSCs) using *Amaranthus* and *Henna* leaves by nano-sized TiO_2 after got good absorption range and functional groups result. The fresh and dried leaves of *Lawsonia inermis* (*Henna*) have been developed by Sowmya et al. [9]. They are made from the solvent used to extract the henna dye that is utilized in dye-sensitive solar cells (DSSCs) as a sensitizer. Consequently, acetone was used to extract the dye from the dried leaves, and the efficiency was greater at 0.351% with a fill-factor of 0.3765. Omar Baitha [10] studied recent research on nanoparticle-based direct and indirect desalting systems and examined how the presence of nanoparticle suspension significantly increased the distillation performance of a mechanism. Omar Baitha [11] conducted research on a tubular solar collector that improved energy efficiency, solar still performance as well as environmental outcomes. It was determined that the traditional and modified solar stills had annual yields of 405.04 and 549.77 kg/m^2 , which are both achieved by the passive system's hourly exergy efficiency and global exergy efficiency of 7 and 30%, respectively, thereby the active system's exergy efficiency of 11 and 41%. Dunkle's approach was used by Omar Bait and Mohamed Si-Ameur [12] to incorporate a straight forward distiller into a cylindrical solar collector that can forecast temperatures in various still sites. For the passive and active targets, the respective distillate volumes and instantaneous efficiencies were (2.77 kg/m^2 , 4 kg/m^2), with an augmentation rate of yield of 44.40% and (40%, 80%). The complete function of nanofluids in many domains, particularly solar desalination machineries expending nano-fluids to boost thermal performances of metal or metal oxide nanoscale particles, was evaluated by Omar Bait and Mohamed Si-Ameur [13]. The effects of nanoparticle size, shape, quantity, and stability technique were concluded for those solar configurations that are still functioning.

Double distiller studied by Rajamanicham et al. [14] cylindrical charcoal as an energy storage medium with different water depths. They concluded that a minimum water depth of 0.01 m gives a maximum yield of 3025 ml/day/m^2 . Still With Cylinder Vertical Position (SWCVP) attained the maximum efficiency of 49.47% compared to Still with Cylinder Horizontal Position (SWCHP). Joe Patrick Gnanaraj and Vel-murugan [15] have analyzed the protectivity of a double distiller with the inner amendment of the corrugate basins area (2995 $\text{ml/m}^2\text{.day}$), the black granites (3210 $\text{ml/m}^2\text{.day}$), still with wick (2690 $\text{ml/m}^2\text{.day}$) external modification of still with external reflectors (3655 $\text{ml/m}^2\text{.day}$) and both internal and external modification (5130 $\text{ml/m}^2\text{.day}$). Love-deep Sahota and Tiwari [16] have verified the simulation model of DSSS with different concentrations of Al_2O_3 (0.4%, 0.8%, 0.12%). The results indicated that 30 kg and 80 kg of base fluid achieved 12.2% and 8.4% at 0.12% concentrations. They proved that an increase in nanoparticle concentrations increases the desalination yield. The double distiller is fabricated and tested using energy-storing resources like iron scraps, washed stones, etc., by Kalidasa Murugavel et al. [17]. Daily maximum production of 3.66 L was achieved by $\frac{3}{4}$ quartz rock. The double distiller was manipulated using absorbing materials (wick materials of black cotton, jute cloth, sponge sheet, and coir mate), and distillate yield obtained of 3.58 kg/day from the distiller as an aluminum fin lengthwise by cotton material has been investigated by Kalidasa murugavel and Sridhar [18]. A single slope single basin solar still (SBSS) was created by Rajesh Kumar et al. [19] utilising silicon dioxide (SiO_2) nanoparticles (NPs) and *Jatropha curcas* L. (JCL) leaf extract. They produced a total distillate output for the summer that was 8.79 L/day (SiO_2 NPs / JCL) and for the winter that was 6.49 L/day (SiO_2 NPs) for the entire system during a 24-hour cycle. Due to an increase in energy absorption brought on by the night time performance procedure and distillation is improved. The outcomes are then recognized temperature by utilisation fresh-lime action result in basin area. Jani and Modi [20] have examined

the effect of hollow fins with square and circular shapes at different water depths (10 mm, 20 mm, 30 mm) of the double distiller. The minimum basin water depth of 10 mm to circular the hollow fins distillate result is obtained of 1.4917 kg/m^2 per day and compare the square hollow fins is 0.9672 kg/m^2 per day. Piyush pal et al. [21] developed a modified double slope multi-wick distiller performed with a water depth of 1 cm – 2 cm. The black cotton wick was obtained by the maximum yield of about 9012 ml/day , compared to the water depth (2 cm) jute wick of 7040 ml/day . The analysis of basin water depth is most significant for maximum mass output. Elango and Kalidasa Murugavel [22] experimented with various water depths of single and double distiller effects using with insulated and without insulation; both environments reported for insulations at 1 cm water depth achieved of 4.401 $\text{L/m}^2\text{.day}$ by the single basin design. Dwivedi and Tiwari [23] compared the HTC of passive solar stills based on Dunkle models. They observed that 0.01–0.03 m water depth variation occurs in the heat transfer modes. Double slope solar still output is 464.64 L/yr . With a water flow rate of 0.050, 0.10, and 0.20 kg/min . Ghandourah et al. [24] created a double slope wick type solar distiller (DSWSD) by covering it with lanthanum cobalt oxide (LaCoO_3) nanoparticles. Therefore, the proposed DSWSD's daily productivity was 5.40 and 3.85 kg/m^2 per day for coatings with and without 20 wt% LaCoO_3 /black paint, respectively. Margarita Castillo Tellez et al. [25] experimentally verified that wind velocity double distiller efficiency concluded that up to 2.5–6.9 m/s wind velocity, 3.5 m/s is considered an optimum value of solar still. NPCM ($\text{MgAl}_2\text{O}_4/\text{Ni}/\text{Fe}_2\text{O}_3\text{-PCM}$) constructed in solar box cooker analyzed with fuzzy logic and Cramer's rules by Palanikumar et al. [26]. It was concluded in NPCM, PCM, and without NPCM, individually, temperatures of 163.74 °C, 147 °C, and 113.34 °C were reached bar plate absorber. Lawrence et al. [27] constructed solar distiller included performance investigation of the local climate at 11° N. It showed that the same product performed better with solar still values in Coimbatore's coastal districts. Nijmeh et al. [28] tested various absorbing materials by the solar distiller, like salts, violet dye, charcoal, etc. They concluded that violet dye increased protectivity by up to 29% compared with other materials. Jackfruit peel/ TiO_2 (JPT) was studied by Asha et al. [29] in green TiO_2 nanoparticles coating a solar still. It produces 4.96 L/m^2 without coating and 6.12 L/m^2 with coating were the main subjects of its findings. A test run on the average increase with a productivity of about 102.64%. In the sand heat reservoir of solar protection by Farshad and Ashkan [30], the researchers examined the four double slope stills with a constant depth of water and water surface cover distance. They identified that distillate affects up to 26%, so Mehrzad Feilizadeh et al. [31] concluded that water depth is one of the key factors for boosting distillate production. Zeroual et al. [32] investigated DSSS with a partially cooled condenser. They improved it by 11.82% (north glass cover - water flow) and 2.94% (north glass cover - intermittent shading). Morad et al. [33] studied the double distiller active/passive based on with and without cooling glass cover and obtained the production as 10.06 L/m^2 per day by FPC joined refrigeration glass cover at flash mode.

Various research methods have increased the productivity of SDESS by combining with numerous kinds of TJPN (nanofluid) ratio concentrators such as 5%, 10%, 15%, 20%, 25%, 30%, and based on water depth of 0.6 cm, 0.8 cm, 1 cm, 1.2 cm by units. However, relatively limited study has been conducted by coupling with thermo-enviro-economics analysis of concentrator with TJPN used the system. This study's primary goal is to determine, how the yield varies when the water death diameter changes while keeping the basin's other characteristics constant. According to thermal modeling performed by Tiwari and Dwivedi [34], thermo-enviro-economics equations for balancing have been created for SDESS coupled with TJPN ratio with water depth concentrator. Unlike previous research, no external working TJPN is used as a water depth to circulate between the basin and receiver to minimize heat loss.

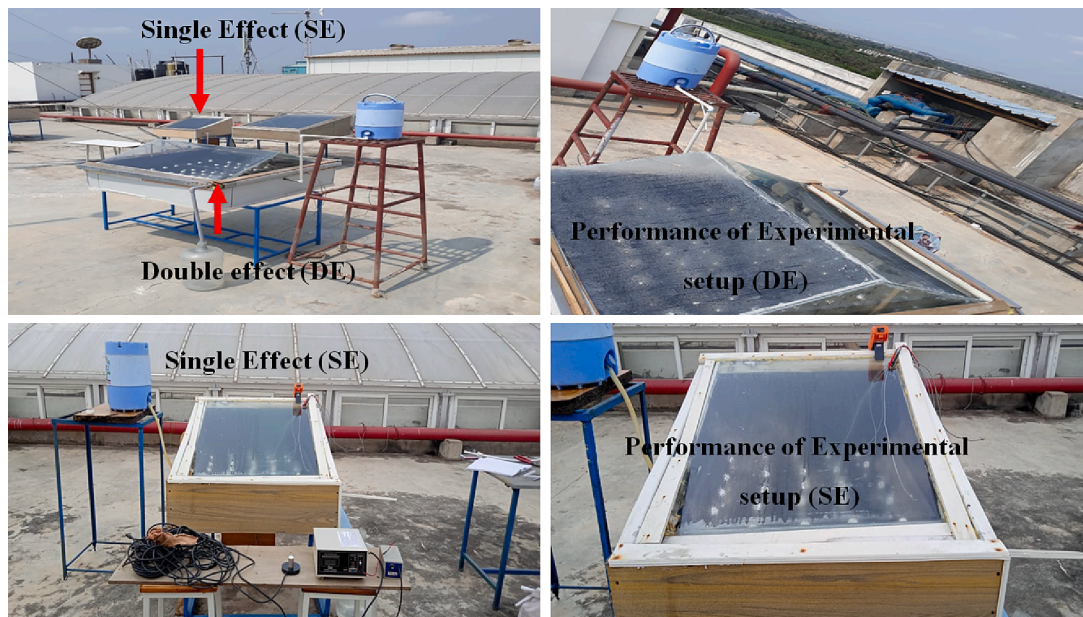


Fig. 1. SDESS in passive mode and performance of Experimental setup.



Fig. 2a. On January 2, 2022, fresh No. 1 Jackfruits (3 no., 10 kg each) displayed on the KLEF campus.

2. Material and methodology

2.1. SDESS setups:

Fig. 1 represents a new single and double-effect solar still (SDESS) experimental analysis of bioactivation nanofluids with silver color balls. The basin area is $1\text{ m} \times 1\text{ m}$, and the water depth is 1 cm for the dimension of the solar still. Therefore, the basin internal dimensions were $1\text{ m} \times 1\text{ m} \times 0.1\text{ m}$. Glass wool sheets with a 5 mm thickness are walls and function as insulation. 4 mm thick glass covered at the top of the basin angled 16° from the horizontal. PVC pipe collects the solar still's distilled water, which is then sent into a beaker jar. Nanofluid

temperature, water temperature, basin, and glass cover temperature (G1 & G2) are all measured using thermocouples. A scale is set up to record the water depth taken. The glass cover of the still is sealed to it using silicone adhesive and M-seal to prevent leaks. Furthermore, DE has been coupled with SE for comparative analysis, as shown in Fig. 1.

2.2. Bioactivation nanofluids material Collection:

The bioactivation materials for No. 1 fresh jackfruits (3nos. – 10 kg for each) were expressed in Fig. 2(a) after the fresh ripe jackfruits were separated to remove the peel, pulp, flake, and seed at the Koneru Lakshmaiah Education Foundation (KLEF) campus in Green City at



Fig. 2b. Shown in silver balls.



Fig. 2c. TiO_2 synthesis and jackfruit peel extraction.

Vaddeswaram, Vijayawada. These materials underwent a very brief procedure of freeze-drying, grinding, and deposition at 30°C for seven hours. TiO_2 is purchased by Anil Scientific Company in Vijayawada, Andhra Pradesh, followed by acetonitrile, formic acid, and ethylene glycol. Vasa Scientific Company in Malleswaram, Bangalore, Karnataka, has sold HPLC quality products. The analytical grade of reagents were purchased from Scientific Engineering Company, Hyderabad, Telangana, using a Millipore water purification system that uses ultra-pure water that was collected from the Shastra Scientifics, Kolathur, Chennai, Tamil Nadu. The silver ball materials for 100Cr6 (ISO 3290 grades) with descriptions that addresses of Aadi-Siddharta, Erandwana Pune. Fig. 2(b) shows the silver ball diameter range is 0.5 mm of nanofluids.

2.3. JPT process

The new materials of bioactive nanofluids have been collected in the KLEF campus for no. 1 fresh Jackfruit Peels (JP) thoroughly prepared, which is washed employing double filtered water. It is milled after being dehydrated in an air heater. At room temperature and 31°C , 5 g of powdered jackfruit peels are blended with 40 ml of double-distilled water. The extract-containing samples were sieved through Spectrum (nylon mesh) and then through Millipore hydrophilic filter with size $0.22\ \mu\text{m}$, which is used for further research. It was proposed to extract of jackfruit peel (JPT) covering 10 mM TiO_2 . It is used in agitation for 3 hours with 200 ml of ionized water. A sample is provided using the direction of below- 31°C agitation conditions instead of 8 hours, as shown in Fig. 2(c).

2.4. Preparation and modification of JPTN using hydrothermal methods

The world's energy demands now need eco friendly methods process, which has synthesized to advance useful material for large-scale manufacturing, considered the synthesis process for bioactivation. The carbon materials were hydrothermal carbonization with an approach of low temperature with low pressure. JPT has used the lowers working temperatures of 210°C as a method of the synthesis process. These processes were auto-generated reactions lowest 1 MPa. JPT has resulted in low-temperature and low-pressure hydrothermal synthesis controlled to simple, green, provide great added value, which is reduced by CO_2 [35], to the specific study of low temperature is 210°C obtained for JPTN by a small particle size of 2.37 nm. It can be used in solar still by nanofluids used in silver balls. A hydrothermal method is used in JPT achieved through an autoclave at 210°C for a short period of 5 hour, as represented in Fig. 2(d). This process is more time-consuming than environmentally eco-friendly [36]. Rapid methods have affordable and green factors are developed the materials made of carbon with the necessary qualities as microwave with the help of hydrothermal/solid-state carbonization [37,38,39].

2.5. Analysis of developing thermal SDESS

Successive statements were prepared for the SDESS modules, which is again energy balance when coupled with ratios for silver balls nanofluid concentrators:

- For the basin, a water temperature gradient is not considered.
- Glass covers and wall material's thermal capacities are not considered.
- The silver balls connecting the nanofluids concentrator ratios are fully insulated units.
- SDESS of the silver balls-nanofluids top and bottom average water temperatures equal the water column's average temperature in the unit's basin.
- Wind speed is not taken continuously during the day but as fluctuating values.

The equation of east condensing glass covers an energy balance: SDESS for inner surface

$$\alpha'_g I_E + h_{tE}(T_{sw} - T_{sciE}) - U_{EW}(T_{sciE} - T_{sciW}) = \frac{K_g}{L_g}(T_{sciE} - T_{scoE}) \quad (1)$$

SDESS for the outer surface

$$\frac{K_g}{L_g}(T_{sciE} - T_{scoE}) = h_{aE}(T_{scoE} - T_a) \quad (2)$$

$$h_{tE} = h_{cwE} + h_{ewE} + h_{rwe}$$

West condensing glass cover of SDESS:

The inner surface of SDESS:

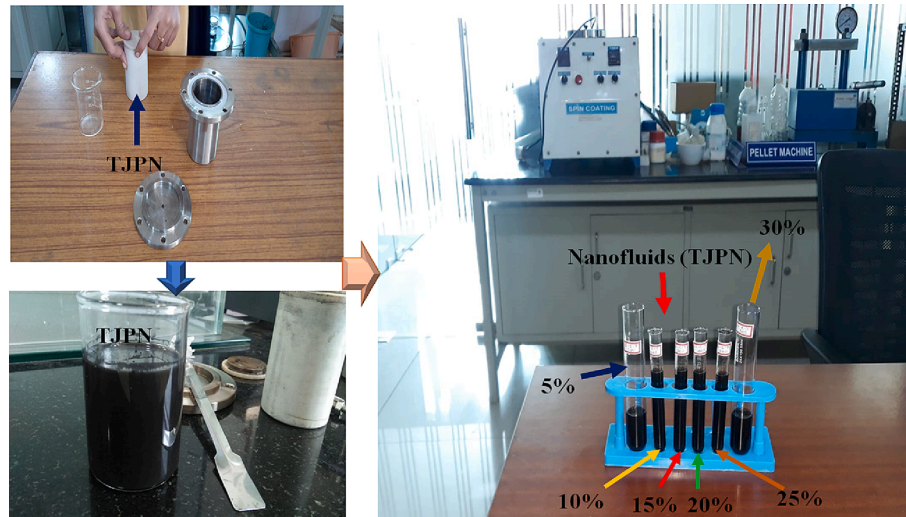


Fig. 2d. TJPN different ratios.

$$\alpha'_g I_w + h_{cW}(T_{sw} - T_{sciW}) + U_{EW}(T_{sciE} - T_{sciW}) = \frac{K_g}{L_g}(T_{sciW} - T_{scoW}) \quad (3)$$

DSESS for the outer surface

$$\frac{K_g}{L_g}(T_{sciW} - T_{scoW}) = h_{aW}(T_{scoW} - T_a) \quad (4)$$

where, $h_{tW} = h_{cwW} + h_{ewW} + h_{rwW}$

DSESS for the bottom of the basin

$$\alpha'_b \tau_g (I_E + I_w) = 2U_{bw}(T_{sb} - T_{sw}) + 2U_{ba}(T_{sb} - T_a) \quad (5)$$

DSESS for the mass of the water:

$$(MC_w) \frac{dT_{sw}}{dt} = (I_E + I_w) \tau_g \alpha'_w + 2U_{bw}(T_{sb} - T_{sw}) - h_{tE}(T_{sw} - T_{sciE}) - h_{tW}(T_{sw} - T_{sciW}) + \dot{Q}_u \quad (6)$$

where

JNPT thermal energy is:

$$\dot{Q}_u = F_R A_a \left[I_s \eta_0 - \frac{A_r}{A_a} U_L (T_{sw} - T_a) \right] \quad (7)$$

The first differential order equation is solved in the above equations from 1 to 7 as

$$\frac{dT_{sw}}{dt} + aT_{sw} = f(t) \quad (8)$$

$$\text{where, } a = \frac{1}{(MC_w)} \left[\frac{2U_{bw}U_{ba}}{U_{bw} + U_{ba}} + \frac{(p-B_2)h_{tE}}{p} + \frac{(p-B_2)h_{tW}}{p} + A_w F_r U_L \right]$$

$$\text{And } f(t) = \frac{1}{(MC_w)}$$

$$\left[\left(\alpha'_w \tau_g + \frac{\alpha'_b \tau_g U_{bw}}{U_{bw} + U_{ba}} \right) (I_E + I_w) + A_a F_r I_s \eta_0 + \frac{h_{tE} A_1 + h_{tE} B_1}{p} + A_w F_r U_L T_a + \frac{2U_{bw}U_{ba}}{U_{bw} + U_{ba}} T_a \right]$$

A first-order differential equation is reduced from equation (8); we are using the initial condition as $T_{sw} = T_{sw0}$ by $t = 0$, develops

$$T_{sw} = \frac{f(t)}{a} [1 - \exp(-a\Delta t)] + T_{sw0} \exp(-a\Delta t) \quad (9)$$

From equations (1) to (7) given by the inner glass, then the outer glass cover based on temperature (east and west sides) as

$$T_{scoE} = \frac{\frac{K_g}{L_g} T_{sciE} + h_{aE} T_a}{\frac{K_g}{L_g} + h_{aE}}$$

$$T_{scoW} = \frac{\frac{K_g}{L_g} T_{sciW} + h_{aW} T_a}{\frac{K_g}{L_g} + h_{aW}}$$

$$T_{sciW} = \frac{B_1 B_2 T_{sw}}{p}$$

$$T_{sciE} = \frac{A_1 A_2 T_{sw}}{p}$$

The DSESS calculations follow the initial temperature performance of water, and the inner glass temperature following a sequence of temperatures is computed similarly.

DSESS has used the glass cover focused on the east and west sides formed the evaporative heat transfer rate is:

$$\dot{q}_{ewE} = h_{ewE}(T_{sw} - T_{sciE})$$

$$\dot{q}_{ewW} = h_{ewW}(T_{sw} - T_{sciW})$$

After that, the equation can be used to determine the DSESS's hourly yield.

$$\dot{m}_E = \frac{q_{ewE} \times 3600}{L}$$

and,

$$\dot{m}_W = \frac{q_{ewW} \times 3600}{L} \quad (10)$$

DSESS total production has

$$\dot{m}_{EW} = \dot{m}_E + \dot{m}_W$$

24 hours production of the solar still is

$$M_{EW} = \sum_{i=8}^{17} \dot{m}_{EW} \quad (11)$$

2.6. Performance of DSESS assessment for overall thermal efficiency:

The performed DSESS feasibility solar energy efficiently operated for purifying the brackish water during a specific period and ordered to properly measure the parameters frequently operated to define as DSESS performed with hourly variation to the water yield per day to calculate (transferred thermal heat for water evaporation) thermal efficiency.

$$\eta_{passive}(\%) = \frac{\sum m_{ew} \times L}{(\sum (I(t))_t \times A_s \times 3600)} \quad (12)$$

2.7. Exergy efficiency of DSESS:

DSESS, the exergy input is calculated as equal to the exergy as

$$\dot{E}x_{in} = \dot{E}x_{sun} \\ = A_s \times 0I(t) \times [01 - \frac{04}{03} \times \left(\frac{0T_a + 0273}{T_s} \right) + \frac{01}{03} \times \left(\frac{0T_a + 0273}{T_s} \right)^{04}]$$

DSESS exergy output is

$$\dot{E}x_{evap} = A_s \times h_{ew}(T_{sw} - T_{scie}) \times \left[1 - \frac{T_a + 273}{T_{sw} + 273} \right] \quad (13)$$

2.8. Economic analysis of DSESS:

DSESS analysis of economical sources of water production, benefit-cost ratio, exergo-economic, and enviro-economic is involved in assessing the cost and investigating the powerful factor affecting the price of producing water by the units. The lifetime analysis of DSESS has been obtained to assess the CO₂ extenuation (carbon credit produces -enviro-economic analysis) interest rates.

2.8.1. Water production of DSESS assessment cost analysis:

The freshwater yield of DSESS is an important point for reducing the cost, which necessitates showing a cost connected and scheming the cost of manufacturing at 1L of freshwater. The current price of a sequence and equivalent annual payments in cash have used the ratio to determine the Capital recovery factor. An effective costs analysis of the parameter is working to agree to the achievement through the savings in the lifetime (n) of DSESS can be written by the formula [40,41]:

$$\text{Capital recovery factor} = \frac{i_{br}(1 + i_{br})^n}{(1 + i_{br})^n - 1} \quad (14)$$

Instead of annual interest rate performance, the interest rate is measured to physical return on saving accounts investments. The compounding over time is appealing, showing the percentage rate in real terms payable for the loan or any other interest and arrears. The resulting effective relation evaluates yearly notice rates as [42]:

$$i_{er} = l + \frac{i_{br}}{t} - l \quad (15)$$

The steady combination of interest rates is limited to the mathematical complex concentration formula, which is interesting annually combined an immeasurable number of times obtained by the resulting formulation parameters [42] as depends on the laws each country follows on the conditions of the lending bank.

$$i_{erc} = e^i - 1$$

DSESS is commercially operable standing take to the total cost needed by capital cost (C C₁) used for the First Annual Cost (FA C₁).

The overall analysis of DSESS entries lifespan for the cost per year is gained for resulting relative [43] as

$$\text{First Annual Cost (FAC}_1) = \text{capital cost (CC}_1) \times \text{CRF} \quad (16)$$

DSESS has been estimated by salvage value (SV₁), which is completed depreciation through the end of the unit's useful life. Annual salvage values are dependent on components for the DSESS lifetime [44] relation is.

$$\text{Annual Salvage Values (ASV}_1) = \text{Salvage Value (SV}_1) \times \text{Sinking Fund Factor (SFF}_1)$$

The sinking Fund Factor (SFF₁) represents an equal annual cash flow (interest bank rate). It is calculated future ratio value (CRF) as [45]:

$$\text{Sinking Fund Factor (SFF}_1) = \frac{i_{br}}{(1 + i_{br})^n - 1} \quad (17)$$

DSESS is gained for the Annual Maintenance Cost (AM C₁), components destruction, repair, and operation as [46]:

$$\text{AM C}_1 = \text{AMCO} \times \text{FA C}_1$$

The maintenance of the DSESS cost coefficient annual costs of mechanisms destruction is quantified as repair and operation. It is a uniform annual cost (PWC) as [47]:

$$\text{PWC} = \text{FA C}_1 + \text{AMC}_1 - \text{AS V}_1$$

DSESS is produced freshwater dependent on the annual distillate water (DW). The freshwater cost per liter (ACPL) [48] is.

$$\text{ACPL} = \frac{\text{PWC}}{\text{DW}}$$

Economic analysis of DSESS has benefited cost ratio (BCR), which has been calculated as [48]:

$$\text{BCR} = \frac{\text{PWC}}{\text{PWB}}$$

DSESS can be calculated by the present worth of benefit as [32]:

$$\text{PWB} = \text{DW} \times \text{PAPF} \quad (18)$$

DSESS presents the annual productivity freshwater (PAPF). The buying price of one-liter water is varied in every country benefit-cost ratio might be greater than the agreement asset is an effective process.

2.8.2. Exergo-economic analysis of DSESS

Exergy and economic analysis of cost-effective by the exergo-economic parameter for the DSESS is a useful combination for the annual output uniform cost of energy and exergy [49] as

$$\text{EEP}_{Ex} = \frac{(E_{en})_{out}}{\text{UAC}}$$

$$\text{EEP}_{En} = \frac{(E_{ex})_{out}}{\text{UAC}}$$

DSESS has been produced as an annual to calculate exergy out (E_{ex}), energy out (E_{en}):

$$(E_{en})_{out} = \frac{\text{DW} \times h_{fg}}{3600} \quad (19)$$

$$(E_{ex})_{out} = \frac{\text{DW} \times h_{fg}}{3600} \left(1 - \frac{T_a}{T_w} \right)$$

2.8.3. Environmental cost analysis of DSESS

2.8.3.1. *Enviro-economic analysis.* During the DSESS, a lifetime analysis of enviro-economic parameters has been obtained to equal the cost by CO₂ reduction. The enviro-economic parameter [50] is

$$\text{EP}_{CO_2} = \text{IN}_{CO_2} + \emptyset_{CO_2} \quad (20)$$

2.8.3.2. *Exergo-environmental analysis.* Fossil fuels are required for energy consumption for water production pollutes the environment. Renewable sources have reduced this level of pollution. Exergy is produced to decrease Exergo-environmental parameters to evaluate based on the CO₂ equation [51] is

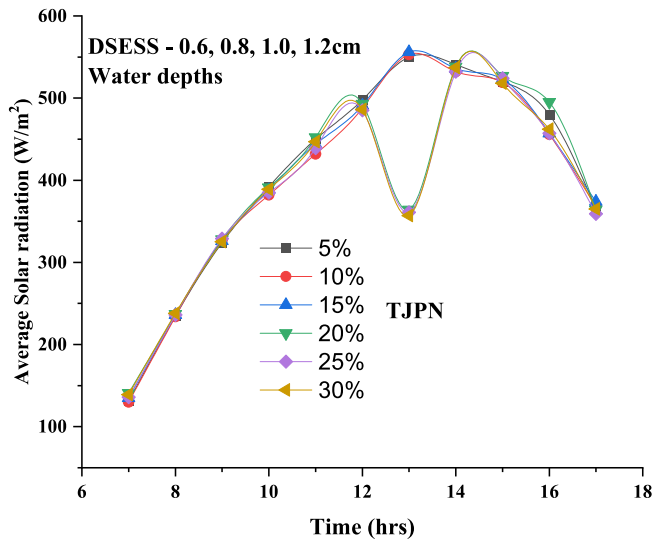


Fig. 3a. DSESS with different weather conditions for hourly variation of solar intensity of KLEF location.

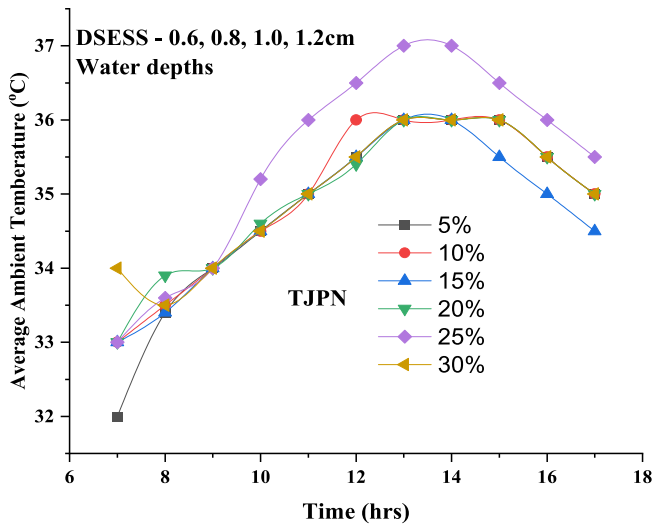


Fig. 3b. DSESS with different weather conditions for hourly variation of ambient temperature of KLEF location.

$$\phi_{exCO_2} = \frac{2((E_{ex})_{out} \times n - E_{in})}{1000} \quad (21)$$

Energy and exergy of the DSESS for the CO₂ reduction has evaluated by total CO₂ mitigation

$$\text{Total CO}_2 \text{ mitigation} = \phi_{exCO_2} + \phi_{CO_2}$$

2.8.4. 3 Exergo-enviroe-conomic analysis

Exergo-enviroe-conomic parameters (EP_{exCO_2}) [52] are evaluated cost of CO₂ reduction created on exergy as

$$EP_{exCO_2} = IN_{CO_2} + \phi_{exCO_2} \quad (22)$$

3. Results and discussion

India Meteorological Department, Shivajinagar, Pune-411 005, India, uses the DSESS approach to collect climatic data for Vijayawada, Andhra Pradesh, for a range of meteorological conditions from April 2021 to April 2022. The ambient temperature and solar radiation absorb the glass covers (east - west sides) were taken times for fluctuation by the

DSESS. 'C' language lineups have created anticipate hours fluctuations of water temperature, glass temperature, distillate output, and the several heat transfer coefficients of DSESS. Computation of all performance parameters is done by theory prototypical using updated standards the convective heat transfer coefficients together the inner and outer glass temperatures. Percentage divergence between the experimental and theoretical outcome is then calculated by comparing the results to the experimental data. Fig. 3 (a & b) represents the average solar radiation and ambient temperature with different ratios base into glass cover in DSESS. As a computed immediate exergy with energy using DSESS, productivity has improved as follows methodology.

The peel of the jackfruit includes a lot of cellulose, which can be used in the creation of antimicrobial packaging sheets and solar desalination procedures as well as solar energy absorber plates with a higher energy plays surface area and purity. According to research, jackfruit's thick peel can be used to extract biofuel, make nano-porous adsorbent materials. JPTN temperature yield of the DSESS is given hour data for the thermophysical characteristics and temperature-based determination before that specific hour. Assessment of different desired outputs is 8.00 am to 9.00 am, thermophysical characteristics evaluated at temperature JPNT consistent to 8 am. The performance of DSESS has been analyzed for the variation of maximum temperature difference (ΔT) max 5%, 10%, 15%, 20%, 25%, and 30% among nanofluid assisting TiO₂/Jackfruit peels nanofluids (TJPN) and based on water depth of mass at four different concentrations of 0.6 cm, 0.8 cm, 1 cm, 1.2 cm for the units are presented in Fig. 4. For all six ratios, as the nanofluids of JPTN occur at optimized 0.6 cm, 0.8 cm, 1 cm, 1.2 cm, the water depth of the mass of DSESS was that peak value of the maximum temperature (ΔT) difference to interesting result perceived in Fig. 4. DSESS was experimental that the value of (ΔT) maximum is perceived for a higher 20% ratio of JPTN with a water depth of 0.8 cm based on nanofluid, which JPTN follows for each concentration of 5%, 10%, 15%, 20%, 25%, 30% as shown in Fig. 4. DSESS has been used for the metallic-green High concentrations of nanoparticles spread more before that specific time assumed volume of the JPTN. The systems might enhance the basin region for nanoparticle heat transfer to JPTN internal heat, increasing the temperatures. The result detected a significant (ΔT) maximum increase to the rising concentration JPTN only up to 20% as concentration ratio with a water depth of 0.8 cm, and it starts decreasing for typical days other JPTN with based on water depth in Fig. 4 and Table 1. The different concentration ratio increases JPTN with aquatic depth has reduced in value (ΔT) max beyond 30% because JPTN with water depth is also 1.2 cm. Therefore, increasing the temperature of JPTN requires more thermal energy transferred from a functional nanofluid essential in improving heat transfer rate as a JPTN based on thermal conductivity increases. The JPTN of the DSESS is evaluated based-on water depth; an important development of thermal conductivity for the JPTN is got in Table 2. JPTN performed of DSESS has been perceived that correlation stretches an augmentation of 10.12%, 12.41%, 12.91%, 17.58%, 16.23%, 15.74% for 5%, 10%, 15%, 20%, 25%, 30% that of JPTN based on water depth (0.6 cm, 0.8 cm, 1 cm, 1.2 cm), respectively. Other businesses, such as those concerned with biofuel, paper, paint, and optics, have also made use of the characteristics of jackfruit peel. On the extraction of several compounds utilized in the paper, textile, and biofuel industries, published materials have been discovered. While 85% of the jackfruit peel is organized into crystalline sections with a fully developed crystal surface based on TiO₂, only 15% of the peel absorbs solar radiation to attract a crystalline structure. Therefore, DSESS can be utilized to focus on the different TiO₂/Jackfruit peels nanofluids (TJPN) ratios and show that components degrade due to jackfruit peel. The JPT nanocomposite was found to have a porous structure, 85% crystallinity, and grain sizes between 40 and 60 nm.

Fig. 5 thermal energy efficiency detected the highest standards immediately; the heat energy productivity of JPTNs was much more than DSESS performance gained using water depth. Table 3 enhanced the JPTNs that thermo-physical properties are higher for the JPTN

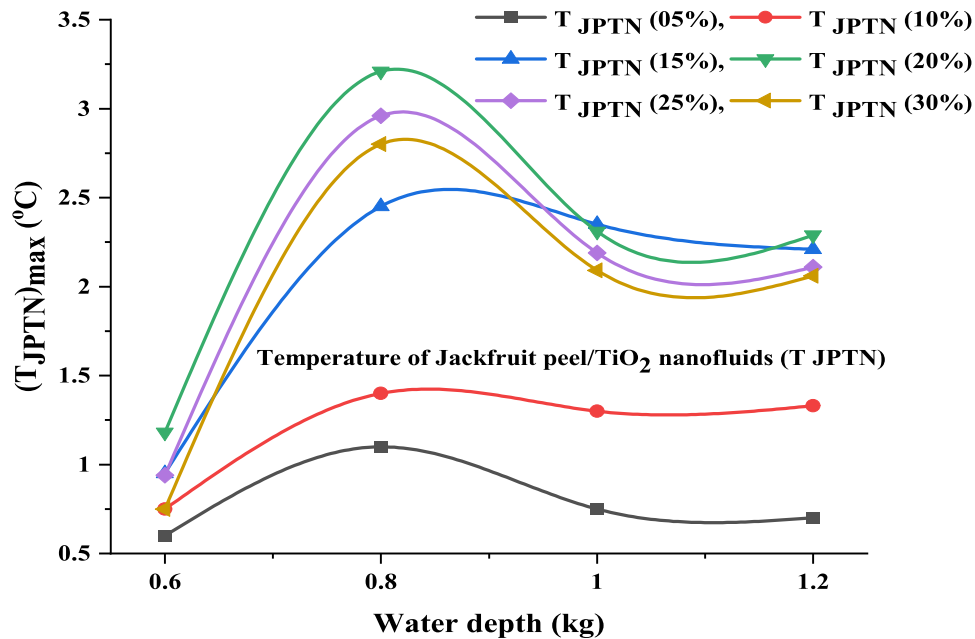


Fig. 4. JPTN variation of ratio (05%, 10%, 15%, 20%, 25%, 30%) with different water depth (06 cm, 0.8 cm, 1.0 cm, 1.2 cm) for DSESS average temperature.

Table 1

The difference ratio of JPT nanofluid with water depth is based on the higher value of the maximum temperature concentrations for DSESS.

S. no	JPTN Concentration of different ratio	Different Water depth				ΔT °C
		0.6	0.8	1.0	1.2	
1	05%	1.812	1.942	1.924	1.901	
2	10%	1.912	2.097	2.064	2.014	
3	15%	2.126	2.364	2.314	2.982	
4	20%	2.312	2.657	2.556	2.401	
5	25%	2.214	2.516	2.414	2.313	
6	30%	2.104	2.114	2.109	2.099	

Table 2

DSESS used in JPTN with Improvements for thermal conductivity different concentration ratio

S. No	JPTN Concentration of different ratio	The thermal conductivity k_{JPTN} (W/mK)	Improvements (%)
1	05%	0.7352	10.12
2	10%	0.7358	12.41
3	15%	0.7371	12.91
4	20%	0.7379	17.58
5	25%	0.7380	16.23
6	30%	0.7381	15.74

(20%) with comparing lowest for all ratios with compared to water depth is 0.8 cm. The heat transfer coefficients for JPTNs have been attributed to the higher the DSESS. It is necessary to include JP sources in our faster evaporation process because JP plays a crucial role in DSESS in the development of the energy absorber plate. JPTNs have a crucial mineral that can be found naturally in drinking water more products and is used in daily products as a stabilizer and some beer brewing processes. The heat flow rate curve shows the thermal rate of decomposition, and the midpoint and inflection point temperature values are similar cellulose models. Higher onset temperatures were linked to develop thermal stability. Due to cellulose's high degree of crystallinity, this behaviour may have occurred.

The water depth of 0.8 cm using system thermal exergy efficiency

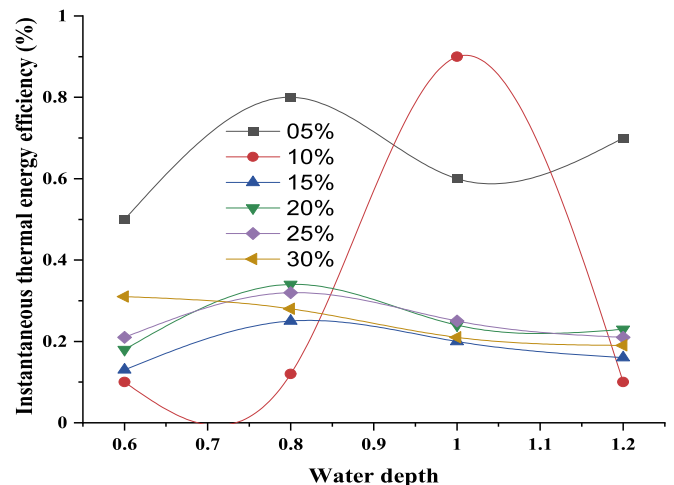


Fig. 5. Variation of instantaneous thermal efficiency of DSESS.

Table 3

The concentration of ratios by the JPTN of the DSESS is used in 08 cm water depth to get highest thermal energy (TEE), exergy efficiency (TEX.E), thermal energy (TE), exergy (TEX) of an ordinary day from April 2021 to April 2022.

DSESS water depth is performed of 08 cm					
S No	JPTN of DSESS effects	TEE (%)	TEX.E (%)	TE (kWh)	TEX. (kWh)
1	05%	25.36	3.54	1.560	0.122
2	10%	31.41	7.41	1.630	0.164
3	15%	33.45	9.12	1.243	0.175
4	20%	50.12	11.21	1.546	0.214
5	25%	46.24	10.24	1.234	0.198
6	30%	41.24	9.56	1.124	0.164

with the highest values has been observed in Fig. 6 to be considerably more than the DSESS performance achieved by JPTN. The reason for this is discussed in the context of DSESS, which is the highest value of instantaneous thermal energy efficiencies for different focus on JPTN

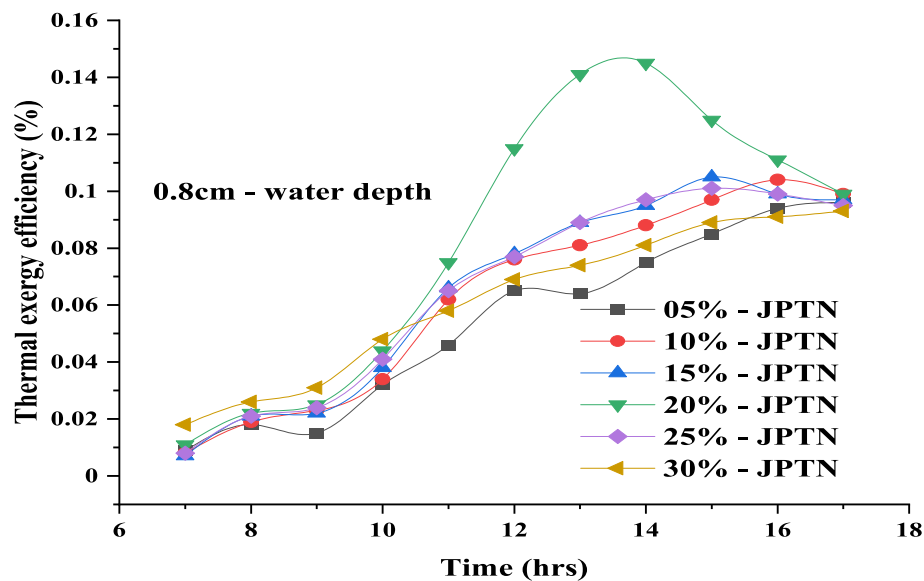


Fig. 6. With the hourly variation of thermal energy efficiency and concentration of water depth of 0.8 cm, several JPTN ratios are employed in DSESS.

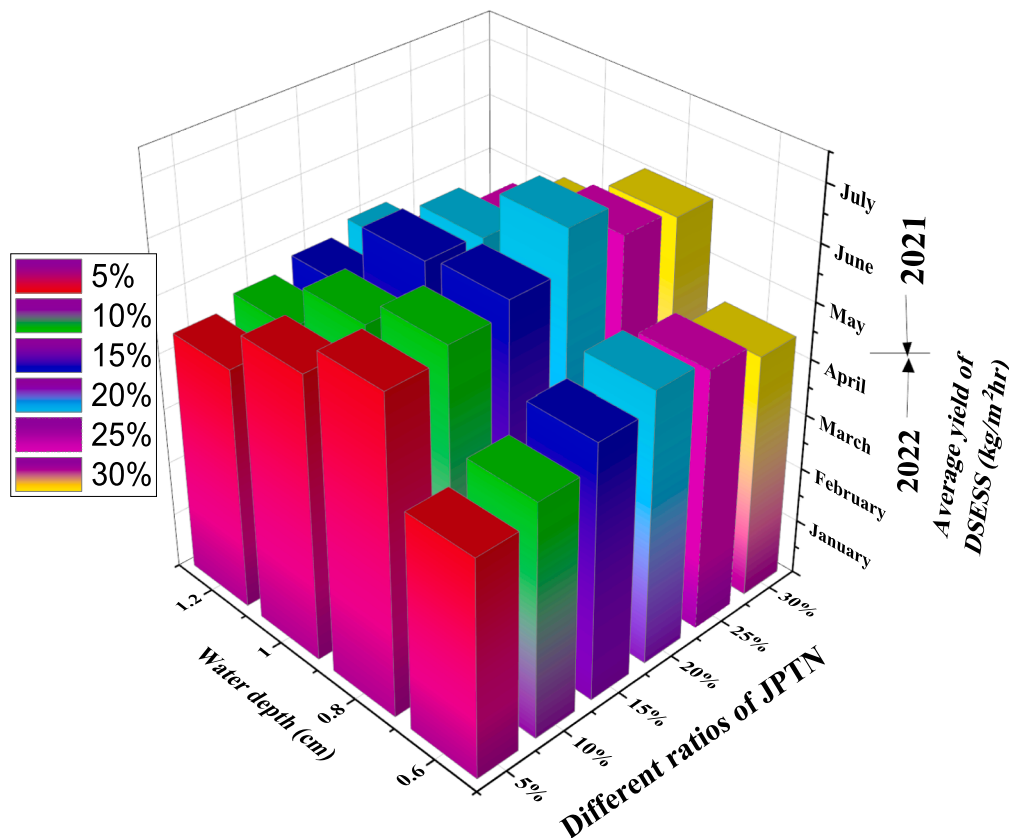


Fig. 7. DSESS average productivity for different ratios of JPTN with water depth for weather conditions in KLEF from April 2021 to April 2022.

based on water depth 0.8 cm has 37.21%, 41.78%, 44.65%, 49.24%, 47.21%, 42.54% and thermal exergy efficiency of the DSESS was 11.21%, 12.14%, 13.54%, 14.25%, 14.01%, 11.54% for those JPNT ratios of 05%, 10%, 15%, 20%, 25%, 30%, respectively. The average thermo-environment-economics analysis of the SDESS is 4.71% (energy), and simulation models of ΔT based on parameters by theoretical and experimental values have been discussed the internal heat transfer modes working the basin area to glass cover in between to develop the

saline water molecules with transfer (evaporation) process. However, there are numerous other factors that can impact how much an SDESS generates. The measured site meteorological data and temperature entering SDESS are first entered into the computer programme in order to simulate the functioning of the SDESS.

The output of the simulation Programme includes the temperatures of the still water, glass, and basin, as well as the temperatures and relative humidity of the air that leaves the still, the condenser, and the

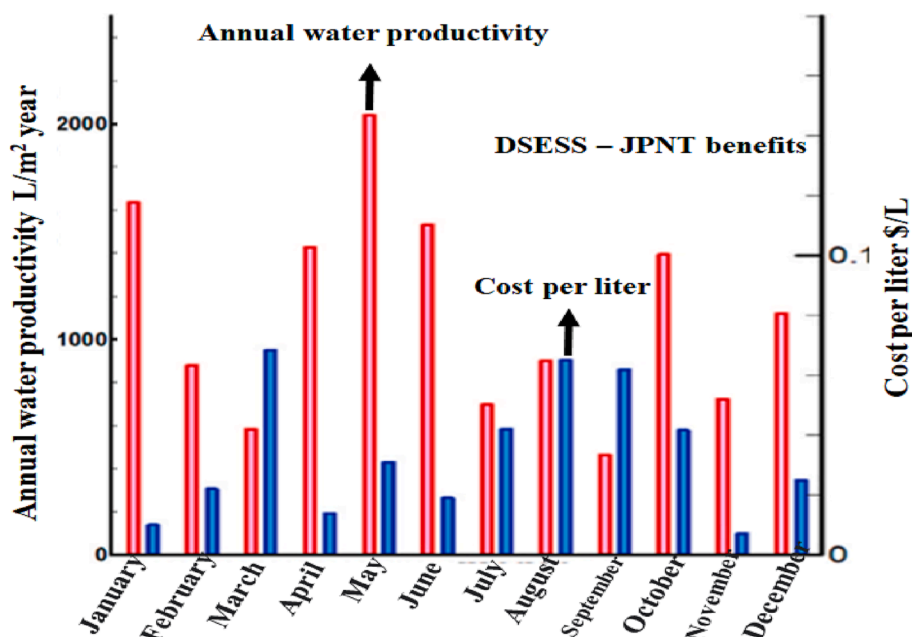


Fig. 8. DSESS benefits for Annual water productivity and cost per liter.

heat recovery system. It also includes the temperatures and relative humidity of the air that leaves the still and the production of distillate from the glass and the condenser. The India Meteorological Department, Shivajinagar, Pune-411 005, India, uses the DSESS approach to collect climatic data for Vijayawada, Andhra Pradesh, for a range of meteorological conditions from April 2021 to April 2022. With maximum values up to 20% (JPNT), the relative humidity calculation's energy averages out at around 4.71%. The DSESS values is highest more than the highest efficiency gained for thermal energy/exergy by a water depth of 0.8 cm, as shown in Table 3.

DSESS is used in JPNT based on a water depth of 0.8 cm for different weather conditions obtained from the systems, as shown in Fig. 7. The west side compares higher than the single slope side. The different ratio of JPNT is perceived as the highest yield and obtained for the weather conditions JPNT of 20% because there were more days than the other concentration ratios based on 0.8 cm water depth.

Higher yearly productivity is attained in the DSESS utilizing JPNT with a water depth of 7234L/m²year. DSESS has provided the yearly yield and cost per liter, as shown in Fig. 8. The annual production of the DSESS was inversely proportional to the cost per liter. According to the findings, the greatest and lowest CPL systems have 0.31 and 0.007 dollar bills for each liter. Additionally, water production cost was decreased by the longer lifespan of JPNT utilized in DSESS and reduced the interest rate.

4. Conclusion

Double and single-effect solar still average thermal efficiency is 18.06% and 22.20%, individually. Double-effect and single-effect distiller units exergy efficiency evaluated as 2.4% and 3.5% respectively. The total daily yield obtained experimentally for the Double effect and single-effect distiller units are 01.74 kg/m² and 02.505 kg/m² designed at 0.8 cm water depth. The DESD is fabricated and verified using different TiO₂/Jackfruit peels nanofluids (TJPN) (5%, 10%, 15%, 20%, 25%, 30%) with silver ball performance. DSESS consequences are presented to maximum efficiency of 41% (energy) and 5.63% (exergy) are detected that TJPN for 20% based on water depth is 0.8 cm. An overall result for DSESS productivity is 7.35 kg m⁻²/day, and TJPN at 30% with a water depth is 0.8 cm during 12 hours of observation. The average thermo-enviro-economics analysis of DSESS is 3.35 (exergy),

and 4.71% (Energy), an economic analysis of DSESS discovered with the cost of concentration that portable water (per liter) and appraised about 0.0726\$ by reimbursement period of 14 months.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Sangeetha, A., Shanmugan, S., Gorjian, S., 2022. Experimental evaluation and thermodynamic Gibbs free energy analysis of a double-slope U-shaped stepped basin solar still using activated carbon with ZnO nanoparticles. *J. Clean. Prod.* 380, 135118.
- [2] Shanmugan, S., Essa, F.A., Gorjian, S., Kabeel, A.E., Sathyamurthy, R., Manokar, A.M., 2020. Experimental study on single slope single basin solar still using TiO₂ nano layer for natural clean water invention. *J. Storage Mater.* 30, 101522 <https://doi.org/10.1016/j.est.2020.101522>.
- [3] Sangeetha, A., Shanmugan, S., Alrubaie, A.J., Jaber, M.M., Panchal, H., El Hadi, M., Attia, A.H., Elsheikh, D.M., Essa, F.A., 2023. A review on PCM and nanofluid for various productivity enhancement methods for double slope solar still: Future challenge and current water issues. *Desalination* 551, 116367. <https://doi.org/10.1016/j.desal.2022.116367>.
- [4] Shanmugan, S., Palani, S., Janarthanan, B., 2018. Productivity enhancement of solar still by PCM and Nanoparticles miscellaneous basin absorbing materials. *Desalination* 433, 186–198. <https://doi.org/10.1016/j.desal.2017.11.045>.
- [5] Mohandass Gandhi, A., Shanmugan, S., Kumar, Ravinder, Elsheikh, Ammar H., Sharifpur, Mohsen, Bewoor, Anand K., Bamisile, Olusola, Hoang, Anh Tuan, Ongar, Bulbul, 2022. SiO₂/TiO₂ nanolayer synergistically trigger thermal absorption inflammatory responses materials for performance improvement of stepped basin solar still natural distiller. *Sustain. Energy Technol. Assess.* 52 (Part A) <https://doi.org/10.1016/j.seta.2022.101974>.
- [6] Janarthanan, B., Thirunavukkarasu, C., Maruthamuthu, S., Manthrammel, M.A., Shkir, M., AlFaify, S., Selvakumar, M., Reddy, V.R.M., Park, C., 2021. Basic deposition methods of thin films. *J. Mol. Struct.* 1241, 130606.
- [7] Ruba, N., Prakash, P., Sowmya, S., Janarthanan, B., Prabhu, A.N., Chandrasekaran, J., Alshahrani, T., Zahran, H.Y., Yahia, I.S., 2021. Recent advancement in photo-anode, dye and counter cathode in dye-sensitized solar cell: A review. *J. Inorg. Organomet. Polym. Mater.* 31 (5), 1894–1901.
- [8] Sowmya, S., Prakash, P., Ruba, N., Nagamani Prabhu, A., Janarthanan, B., Reddy, V.R.M., Hegazy, H.H., 2021. Fabrication of natural dye-sensitized solar cells with bulk TiO₂ instead of nano-size. *Optik* 242, 166205. <https://doi.org/10.1016/j.ijleo.2020.166205>.
- [9] Sowmya, S., Ruba, N., Inbarajan, K., Prakash, Pooja, Janarthanan, B., 2021. Dye-sensitized solar cells concocted with dyes extracted from fresh and dried leaves of Henna using different solvents. *Opt. Quant. Electron.* 53, 274. <https://doi.org/10.1007/s11082-021-02953-5>.

- [10] Bait, O., 2020. Direct and indirect solar-powered desalination processes loaded with nanoparticles: A review. *Sustain. Energy Technol. Assess.* 37, 100597 <https://doi.org/10.1016/j.seta.2019.100597>.
- [11] Bait, O., 2019. Exergy, environ-economic and economic analyses of a tubular solar water heater assisted solar still. *J. Clean. Prod.* 212, 630–646. <https://doi.org/10.1016/j.jclepro.2018.12.015>.
- [12] Bait, O., Si-Ameur, M., 2017. Tubular solar-energy collector integration: Performance enhancement of classical distillation unit. *Energy* 141, 818–838. <https://doi.org/10.1016/j.energy.2017.09.110>.
- [13] Bait, O., Si-Ameur, M., 2018. Enhanced heat and mass transfer in solar stills using nanofluids: A review. *Sol. Energy* 170, 694–722.
- [14] Rajamanickam, M.R., Velmurugan, A., Ragupathy, P., Sivaraman, E., 2021. Use of thermal energy storage materials for enhancement in distillate output of double slope solar still. *Mater. Today: Proc.* 34 (2), 416–419. <https://doi.org/10.1016/j.matpr.2020.02.203>.
- [15] Gnanaraj, J.P., S., Velmurugan, V., 2019. An experimental study on the efficacy of modifications in enhancing the performance of single basin double slope solar still. *Desalination* 467, 12–28. <https://doi.org/10.1016/j.desal.2019.05.015>.
- [16] Sahota, L., Tiwari, G.N., 2016. Effect of Al_2O_3 nanoparticles on the performance of passive double slope solar still. *Sol. Energy* 130, 260–272. <https://doi.org/10.1016/j.solener.2016.02.018>.
- [17] Kalidasa Murugavel, K., Sivakumar, S., Riaz Ahmed, J., Chockalingam, K.K.S.K., Srihar, K., 2010. Single basin double slope solar still with minimum basin depth and energy storing materials. *Appl. Energy* 87 (2), 514–523.
- [18] Kalidasa Murugavel, K., Srihar, K., 2011. Performance study on basin type double slope solar still with different wick materials and minimum mass of water. *Renew. Energy* 36 (2), 612–620. <https://doi.org/10.1016/j.renene.2010.08.009>.
- [19] Rajesh Kumar, T., Shanmugan, S., Sunita Sundari, G., Latha Devi, N.S.M.P., Abhiram, N., Palanikumar, G., 2022. Experimental Investigation on the Performance of a Solar Still Using SiO_2 Nanoparticles / *Jatropha curcas* L. *SILICON* 14, 3501–3514. <https://doi.org/10.1007/s12633-021-01119-y>.
- [20] Hardik, K., Jani, K., Modi, V., 2019. Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins. *Sol. Energy* 179, 186–194. <https://doi.org/10.1016/j.solener.2018.12.054>.
- [21] Pal, P., Yadav, P., Dev, R., Singh, D., 2017. Performance analysis of modified basin type double slope multi-wick solar still. *Desalination* 422, 68–82. <https://doi.org/10.1016/j.desal.2017.08.009>.
- [22] Elango, T., Kalidasa Murugavel, K., 2015. The effect of the water depth on the productivity for single and double basin double slope glass solar stills. *Desalination* 359, 82–91. <https://doi.org/10.1016/j.desal.2014.12.036>.
- [23] Dwivedi, V.K., Tiwari, G.N., 2009. Comparison of internal heat transfer coefficients in passive solar stills by different thermal models: An experimental validation. *Desalination* 246, 30–318. <https://doi.org/10.1016/j.desal.2008.06.024>.
- [24] Ghandourah, E.I., Sangeetha, A., Shanmugan, S., Zayed, M.E., Moustafa, E.B., Tounsi, A., Elsheikh, A.H., 2022. Performance assessment of a novel solar distiller with a double slope basin covered by coated wick with lanthanum cobalt oxide nanoparticles. *Case Studies in Thermal Engineering* 32, 101859. <https://doi.org/10.1016/j.csite.2022.101859>.
- [25] Castillo-Téllez, M., Pilatowsky-Figueroa, I., Sánchez-Juárez, Á., Fernández-Zayas, J.L., 2015. Experimental study on the air velocity effect on the efficiency and freshwater production in a forced convective double slope solar still. *Appl. Therm. Eng.* 75, 1192–1200. <https://doi.org/10.1016/j.applthermaleng.2014.10.032>.
- [26] Palanikumar, G., Shanmugan, S., Chithambaram, V., Gorjian, S., Pruncu, C.I., Essa, F.A., Kabeel, A.E., Panchal, H., Janarthanan, B., Ebadi, H., Elsheikh, A.H., Selvaraju, P., 2021. Thermal investigation of a solar box-type cooker with nanocomposite phase change materials using flexible thermography. *Renew. Energy* 178, 260–282. <https://doi.org/10.1016/j.renene.2021.06.022>.
- [27] Lawrence, A., Hariharan, C., Shanmugan, S., Janarthanan, B., 2021. Performance of single slope solar still for socio-economic development in coastal locations in India. *Int. J. Ambient Energy* 43 (1), 5175–5183. <https://doi.org/10.1080/01430750.2021.1927838>.
- [28] Nijmeh, S., Odeh, S., Akash, B., 2005. Experimental and theoretical study of a single-basin solar still in Jordan. *Int. Commun. Heat Mass Transfer* 32 (3–4), 565–572. <https://doi.org/10.1016/j.icheatmasstransfer.2004.06.006>.
- [29] Asha, S., Shanmugan, S., Srinivasa prasad, M.V.V.K., Venkateswarlu, M., Meenachi, M., Sangeetha, A., Rao, M.C., 2022. Thermal potential porous materials and challenges of improving solar still using TiO_2 /Jackfruit peel-enhanced energy storage material. *Mater. Today: Proc.* 66 (Part 8), 3616–3625.
- [30] Tabrizi, F.F., Sharak, A.Z., 2010. Experimental study of an integrated basin solar still with a sandy heat reservoir. *Desalination* 253, 195–199. <https://doi.org/10.1016/j.desal.2009.10.003>.
- [31] Feilizadeh, M., Karimi Estahbanati, M.R., Ahsan, A., Jafarpur, K., Mersaghian, A., 2016. Effects of water and basin depths in single basin solar stills: An experimental and theoretical study. *Energy. Conver. Manage.* 122, 174–181. <https://doi.org/10.1016/j.enconman.2016.05.048>.
- [32] Zerouala, M., Bouguettaia, H., Bechki, D., Boughali, S., Bouchekima, B., Mahcene, H., 2011. Experimental investigation on a double-slope solar still with partially cooled condenser in the region of Ouargla (Algeria). *Energy Proc.* 6, 736–742. <https://doi.org/10.1016/j.egypro.2011.05.083>.
- [33] Morad, M.M., El-Maghawry, H.A.M., Wasfy, K.I., 2015. Improving the double slope solar still performance by using flat-plate solar collector and cooling glass cover. *Desalination* 373, 1–9. <https://doi.org/10.1016/j.desal.2015.06.017>.
- [34] Dwivedi, V.K., Tiwari, G.N., 2010. Experimental validation of thermal model of a double slope active solar still under natural circulation mode. *Desalination* 250 (1), 49–55. <https://doi.org/10.1016/j.desal.2009.06.060>.
- [35] Ye, H., Chen, J., Hu, Y., Li, G., Fu, X.-Z., Zhu, P., Sun, R., Wong, C.-P., 2020. One-pot synthesis of two-dimensional multilayered graphitic carbon nanosheets by low-temperature hydrothermal carbonization using the in situ formed copper as a template and catalyst. *Chem. Commun.* 56, 11645–11648. <https://doi.org/10.1039/D0CC03010D>.
- [36] Yuan, M., Zhong, R., Gao, H., Li, W., Yun, X., Liu, J., Zhao, X., Zhao, G., Zhang, F., 2015. One-step, green, and economic synthesis of water-soluble photoluminescent carbon dots by hydrothermal treatment of wheat straw, and their bio-applications in labeling, imaging, and sensing. *Appl. Surf. Sci.* 355, 1136–1144. <https://doi.org/10.1016/j.apsusc.2015.07.095>.
- [37] Zhang, J., An, Y., Borrión, A., He, W., Wang, N., Chen, Y., Li, G., 2018. Process characteristics for microwave assisted hydrothermal carbonization of cellulose. *Bioresour. Technol.* 259, 91–98.
- [38] Ruba, N., Sowmya, S., Prakash, P., Janarthanan, B., Nagamani Prabu, A., 2021. Dye-Sensitized Solar Cells Using a Cocktail of Synthetic (Eosin Y) and Natural (Beetroot, Pomegranate, and Kumkum) Dyes. *Braz. J. Phys.* 51, 1459–1465. <https://doi.org/10.1007/s13538-021-00970-z>.
- [39] Sowmya, S., Inbarajan, K., Ruba, N., Prakash, P., Janarthanan, B., 2021. A novel idea of using dyes extracted from the leaves of *Prosopis juliflora* in dye – Sensitized solar cells. *Opt. Mater.* 120, 111429. <https://doi.org/10.1016/j.optmat.2021.111429>.
- [40] Singh, D.B., Tiwari, G.N., 2017. Energy, exergy and cost analyses of N identical evacuated tubular collectors integrated basin type solar stills: a comparative study. *Sol. Energy* 155, 829–846. <https://doi.org/10.1016/j.solener.2017.07.018>.
- [41] Shoeibi, S., Rahbar, N., Abedini Eshfahani, A., Kargarsharifabad, H., 2020. Application of simultaneous thermoelectric cooling and heating to improve the performance of a solar still: an experimental study and exergy analysis. *Appl. Energy* 263, 114581. <https://doi.org/10.1016/j.apenergy.2020.114581>.
- [42] Newnan, D.G., Eschenbach, T.G., Lavelle, J.P., Lewis, N.A., 2020. Engineering economic analysis. ISBN 0-19-517149-7. 2004 – 292.
- [43] Agrawal, A., Rana, R.S., 2019. Theoretical and experimental performance evaluation of single-slope single-basin solar still with multiple V-shaped floating wicks. *Heliyon* 5 (4), e01525.
- [44] Saini, V., Sahota, L., Jain, V.K., Tiwari, G.N., 2019. Performance and cost analysis of a modified built-in-passive condenser and semitransparent photovoltaic module integrated passive solar distillation system. *J. Storage Mater.* 24, 100809. <https://doi.org/10.1016/j.jest.2019.100809>.
- [45] Omidli, B., Rahbar, N., Kargarsharifabad, H., Rashidi, S., 2020. Combination of a solar collector and thermoelectric cooling modules in a humidification–dehumidification desalination system-experimental investigation with energy, exergoeconomic and environmental analysis. *Energy. Conver. Manage.* 225, 113440. <https://doi.org/10.1016/j.enconman.2020.113440>.
- [46] Dumka, P., Jain, A., Mishra, D.R., 2020. Energy, exergy, and economic analysis of single slope conventional solar still augmented with an ultrasonic fogger and a cotton cloth. *J. Storage Mater.* 30, 101541. <https://doi.org/10.1016/j.jest.2020.101541>.
- [47] Rastegar, S., Kargarsharifabad, H., Rahbar, N., Behshad Shafii, M., 2020. Distilled water production with combination of solar still and thermosyphon heat pipe heat exchanger coupled with indirect water bath heater - experimental study and thermoeconomic analysis. *Appl. Therm. Eng.* 176, 115437. <https://doi.org/10.1016/j.applthermaleng.2020.115437>.
- [48] Kosmadakis, G., Manolakos, D., Kyritsis, S., Papadakis, G., 2009. Economic assessment of a two-stage solar organic Rankine cycle for reverse osmosis desalination. *Renew. Energy* 34 (6), 1579–1586. <https://doi.org/10.1016/j.renene.2008.11.007>.
- [49] Singh, A.K., Paonia, S., Jain, D., Mishra, D., 2019. Performance evaluation and economic analysis of solar desalination device made of building materials for hot arid climate of India. *Desalination Water Treat.* 141, 36–41. <https://doi.org/10.5004/dwt.2019.23480>.
- [50] Yousef, M.S., Hassan, H., Sekiguchi, H., 2019. Energy, exergy, economic and enviroeconomic (4E) analyses of solar distillation system using different absorbing materials. *Appl. Therm. Eng.* 50, 30–41. <https://doi.org/10.1016/j.applthermaleng.2019.01.005>.
- [51] Rajaseenivasan, T., Srihar, K., 2016. Performance investigation on solar still with circular and square fins in basin with CO_2 mitigation and economic analysis. *Desalination* 380, 166–174. <https://doi.org/10.1016/j.desal.2015.11.025>.
- [52] Elbar, A.R.A., Yousef, M.S., Hassan, H., 2019. Energy, exergy, exergoeconomic and enviroeconomic (4E) evaluation of a new integration of solar still with photovoltaic panel. *J. Clean. Prod.* 233, 665–680. <https://doi.org/10.1016/j.jclepro.2019.06.111>.