Heliyon 7 (2020) e05793

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

An inclusive study on new conceptual designs of passive solar desalting systems

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ARTICLE INFO

Keywords:
New conceptual design solar desalting systems
Novel solar desalting systems
Efficiency
Productivity

ABSTRACT

Potable water is one of the vital necessities for the society. The assurance of availability of clean water to society is a big confront due to restricted accessibility of clean water on planet Earth. Solar desalting systems can be used for justifying the appropriate supply of fresh water in distant localities by the use of ample sunlight. In spite of conventional solar desalting systems, various other designs of solar desalting systems are used to boost the overall performance of the system. In this work, various new conceptual designs of passive solar desalting systems have been reviewed to understand better, efficient and productive performing system along with various novel solar desalting systems that can inculcate the real feeling of performing information among the researchers. An overview has also been established for better utility indications and comparative performances among all solar desalting systems. The interpretations have been accomplished with the better results and some favor has also been recommended for the future betterment and building novel designs to meet the feasible hurdles.

1. Introduction

Desalted water is the primary source of mineral water or fresh water and the consumers of fresh water are indeed to have adequate water for now and then. Potable form of water is utilized in a variety of areas like kitchen, to drink water, agriculture, industries, etc. Brackish water is not in the position to use because of many health issues such as skin cancer, black foot disease etc. [1, 2, 3], hence the assurance of neatness of available water is quit necessary before use. In view of water decontamination, various techniques are there like multi-effect desalination and flash removal, vapor compression, RO, membrane refinement, etc. nevertheless it also consumes conventional resources of power to run the above systems which are not fit in distant localities [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

Otherwise, solar desalting systems are self sustainable and having simple working principle to clean brackish water. Solar distillation systems are based on simple working principle as still basin water receives solar irradiant energy which converts basin water into vapor and finally vapor get condensed into water also called as distilled water (the freshest water). These solar distillation systems are broadly classified into passive (no any external power source consuming or producing devices are integrated with it) and active type (there are one or many external power source consuming or producing devices such as PVT, electric pump etc. are integrated with it). Many researchers have been done by different researchers such as experimental and theoretical investigations as well as reviews on passive and active solar desalination units [15, 16, 17, 18, 19, 20, 21, 22, 23]. The distilled water from solar desalting unit presents the purest form of water than water accessible from rain [24, 25]. The concentration levels of primary metals such as Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, B^{3+} etc. which are initially present in the sea water or brackish water, significantly reduced below the values typically obtained through membrane based filtration i.e. up to 10–500 ppm and solar still based distillation i.e. up to 1–50 ppm [98]. As, the distilled water has almost nil amount of minerals and the suggested amount of minerals and contaminants as per World Health Organization (WHO) and Environmental Protection Agency (EPA) are 1 mg/l, 0.3 mg/l, 0.05 mg/l, 5 mg/l, 0.2 mg/l for copper, iron, manganese, zinc and aluminum respectively, hence for best quality drinkable water, it should be further treated and follow the guidelines of WHO and EPA [26, 27, 28, 29, 30]. The yield has 7–8 pH with 200ppm that represents good quality of water suggested by WHO and BIS [31].

In the present work, specially designed passive type single basin solar desalting systems have been considered. The term 'specially designed' refers systems with customized top basin cover or basin liner, special

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https://doi.org/10.1016/j.heliyon.2020.e05793
Received 29 November 2018; Received in revised form 29 March 2019; Accepted 17 December 2020

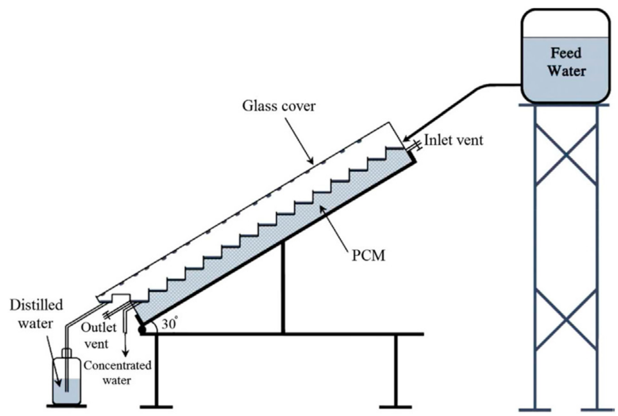


Figure 1. Line diagram of Weir solar desalting system cascade type with PCM which improves the solar radiation absorption capability [68, 89].

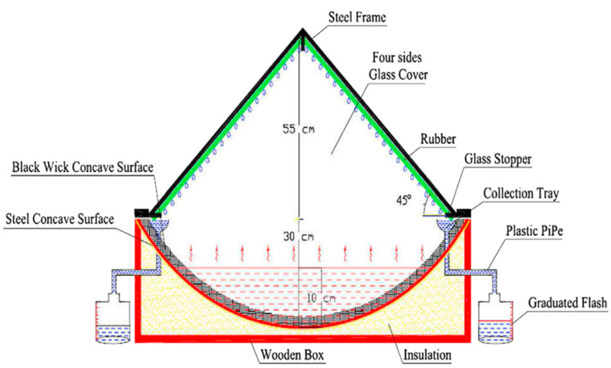


Figure 2. Line diagram of concave wick type PSDS with variable water depth have better condensation rather than evaporation except sides of the wick material [73].

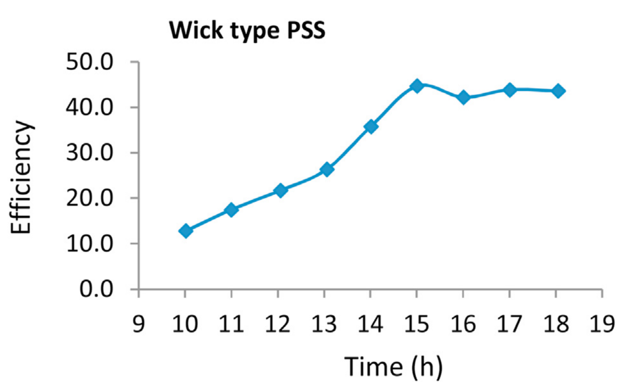


Figure 3. Efficiency variation with respect to Time of concave wick type pyramid solar still (PSS) [103].

arrangements into basin unit, multi-still coupled to each other or novel in terms of newness in design, transportation considerations, flexibility in design and moreover, the term ‘novel’ referred by various researchers have been considered. The performances of these stills focused on its specialty, efficiency and productivity. The related parameters considered are design specialty, work regime, basin area, distillate output for unit area in a day with maximum solar radiation available and maximum temperature conditions at various parts in solar distillation systems for throughout study in the whole review work. This study tried out to identify the most effective, economic and self-sustainable solar desalting

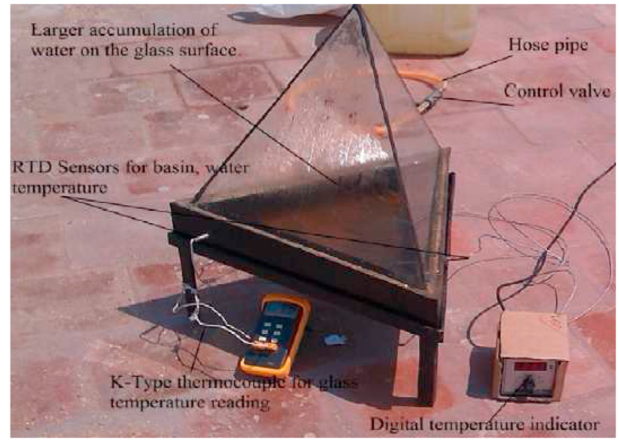


Figure 4. Photographic view of triangular pyramid solar still (PSS) have more evaporation area compared to conventional solar distillation systems [74].

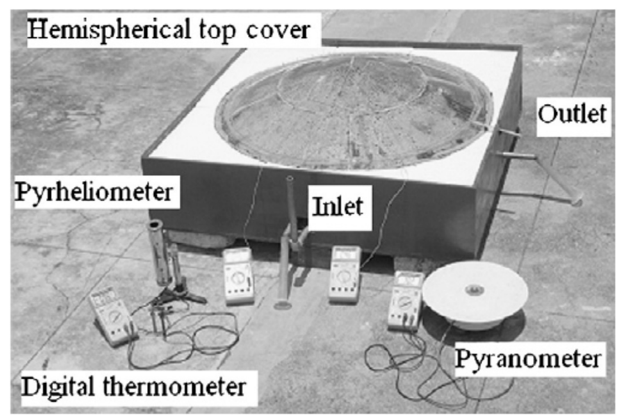


Figure 5. Pictorial view of hemispherical solar still (HSS) has better overall solar absorption and condensation [79].

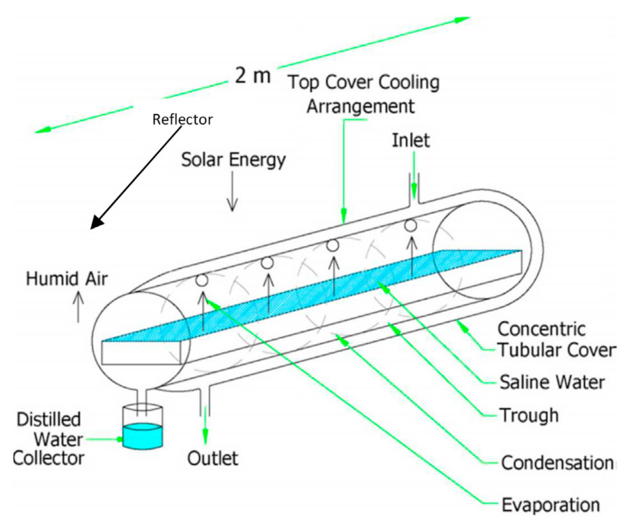


Figure 6. Line diagram of tubular solar still (TSS) with reflector and rectangular tray maintains thin layer of water in basin liner which improves its performance [80].

system among all focused units. In this current work, the identification and promotion of marketable, household and transportable novel solar desalting systems have been presented.

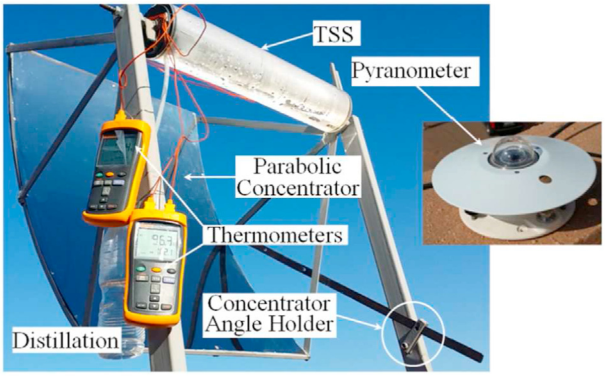


Figure 7. Photographic view of tubular solar still (TSS) with parabolic concentrator which improves diffused solar irradiative energy and performs better [81].

2. Outline of new conceptual design solar desalting systems

Liberally available rich quantity of solar energy i.e. used to clean brackish water through desalting process firstly with the help of solar desalting systems. Later on, conventional stills are refined in terms of design, working principle and integration of different elements in it and called specially designed solar desalting systems which are good performance. As this study is based on specially designed single basin passive solar desalting systems which have special designs as well as attached with other elements with distinguished resource type i.e. waste heat recovery source through PCM, wicks, weir steps, fins, thermal concentrators, etc. So, the enhanced and superior evaporation and condensation in a solar desalting system makes it higher yield producing unit [32]. Such types of different solar desalting systems with new conceptual designs have been reviewed and a short literature survey discloses the versatile effectiveness of these systems as follows.

2.1. Solar still with pyramidal top cover (pyramid solar desalting system)

Hamdan et al. [33] presented the recital of solar desalting system with paramedic top cover for single, double or triple basin type system in the climatic conditions of Jordan. The result with better efficiency and yield was found for triple basin type unit. Later on, Fath et al. [34] represented a assessment between pyramid solar desalting system (PSDS) and single slope solar desalting system (SSSDS). The result showed as PSDS behaves slightly better performance than SSSDS i.e. 3% more efficient due to corresponding larger condensing area in that unit. Mahian et al. [35] presented study of exergy and economic parameters for active & passive PSDS and found that active unit produces 20% more distillate. Al-Hassan and Algarni [36] experimented to reveal the effects of water level and mass in still basin for three models of PSDS and found corresponding result but best with the lesser water mass and water level. Sathyamurthy et al. [37] showed triangular PSDS incorporated with PCM that was responsible for better yield. Kabeel et al. [38] exposed the consequence of top cover direction and shape in which square PSDS performs better with 4.13 l/m^2/day yield) in Egypt). Then, Nayi and Modi [39] presented different types of PSDS systems and compared with conventional SSSDS systems in which previous found better and economic than next. After that Taamneh and Taamneh [40] presented an experimental study and analyze active and passive square PSDS and found the first system having fan performs 25% better than next in terms of yield.

Various sets of pyramid solar desalting systems under different climatic conditions represent variable results. For the establishment of better relationship between all setups, productivity is represented by yield per unit area per day. It has shown that PSDS always better than SSSDS and triple basin type better than simple PSDS whereas active PSDS performs well than any other system. It is due to the larger effective condensation area availability with effective evaporation as well as condensation in the presence of suitable active medium.

2.2. Spherical combination of still top cover and basin liner (spherical solar desalting system)

Dhiman [41] presented a spherical solar desalting system and studied with the help of mathematical modeling, also compared with SSSDS in which offered system reported 30% more yield than SSSDS because of proposed system doesn't have need of any solar tracking device but receives solar irradiant energy. Later on, Basel [42] performed an experimental analysis for mutable hemispherical solar desalting system (HSDS) and found up to 5.7 l/m^2/day with 33 % efficiency. Both systems are free from solar tracking except the portability benefit of the second system also have output for unit area per day.

2.3. Rectangular tray as still basin in a tube as its covering (tubular solar desalting system)

Tiwari and Kumar [43] considered the tubular solar desalting system (TSDS) especially performing with no night conditions and found better for longer TSDS as it facilitates larger basin area which supports better evaporation as a result higher distillate in comparison with SSSDS. Kumar and Anand [44] offered a model of TSDS having multi wick in place of rectangular basin. In this way, this desalting system offers more area for condensation hence better result than SSSDS. After that TSDS was further improved and presented by Ashan et al. [45] in the form of a new design that have metal body as a basin and covered with thin film (vinyl chloride). The desalinization was followed by the simple or conventional TSDS. In this set-up, yield was better due to larger temperature variation between basin water to thin film tubular covering. Then, Arunkumar et al. [46] experimented on TSDS with PSDS and CPC along with cooled or not cooled conditions and the favorable results came out with 7.77 l/m^2/day yield. It was also concluded by them that high initial setup cost with overall high efficiency and corresponding distillate that compensates the investment value of system. Later on, Arunkumar and Kabeel [47] introduces PCM with TSDS-CPC and analyzed TSDS-CPC with PCM and compared for without PCM and the result confers higher performance for TSDS-CPC with PCM as 5.78 l/m^2/day yield in comparison with TSDS-CPC as 5.33 l/m^2/day yield only. The higher

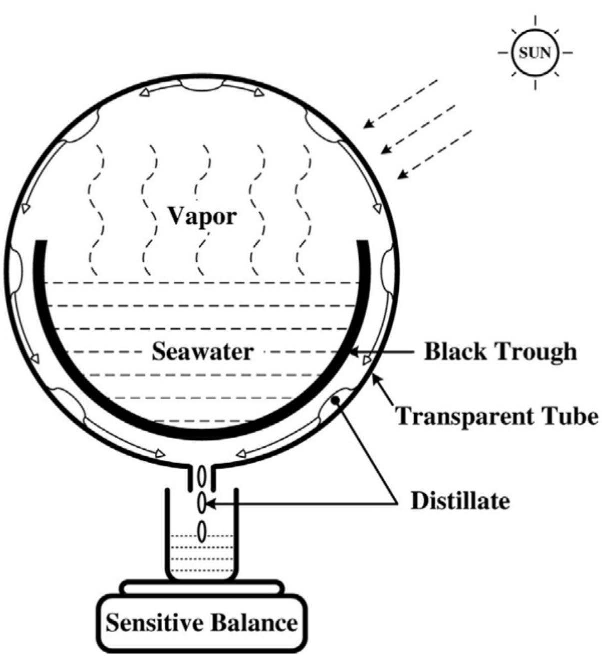


Figure 8. Schematic view of tubular solar still (TSS) [81].

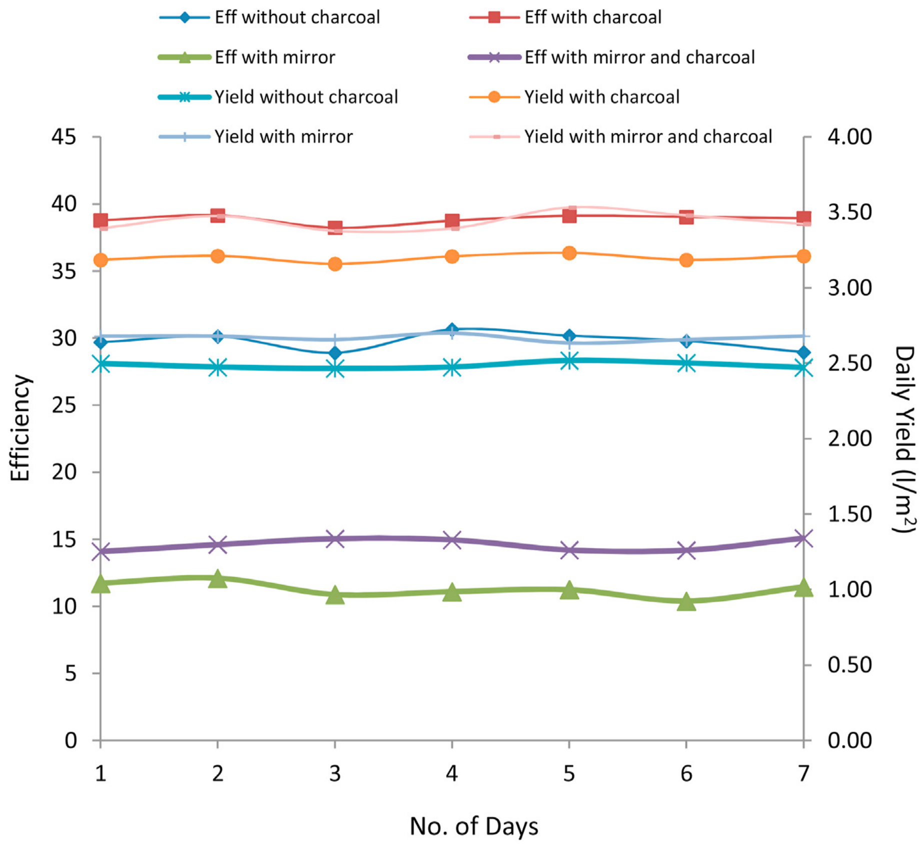


Figure 9. Efficiency and Daily yield variation with respect to No. of days for solar still with 'V' top cover (VSS) system based on the experimental data taken for with and without charcoal, with boosting mirror and with boosting mirror along with charcoal. Boosting mirror improves diffused radiation, whereas charcoal acts as phase change material [103].

performance of the system was due to the application of PCM which supplies continuous heat as a supplementary thermal energy due to changing its phase and hence latent heat of PCM was provided to the basin liner in between cooling hours. Recently, Jing et al. [48] studied on concentric TSDS which has two layers in that outer layer contains wet wick and inner as usual. The result found better as distillate output than the previous TSDS system.

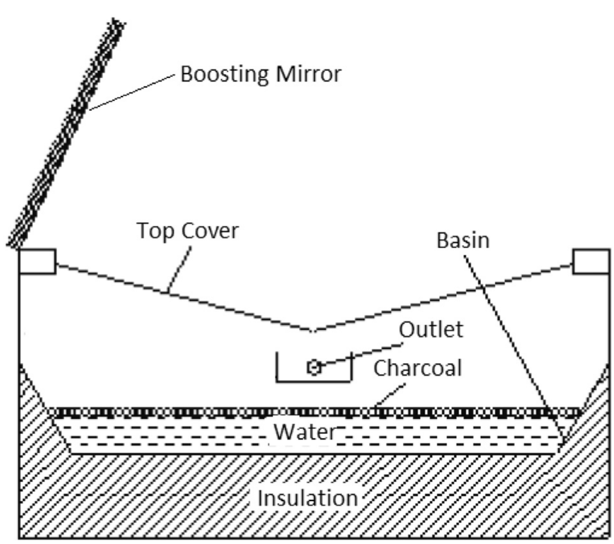


Figure 10. Line diagram of solar still with 'V' top cover (VSS) and with boosting mirror accompanied with charcoal [82].

TSDS has better usability solar radiation because of thinner layer of basin water mass as compared to other systems and his capability is increased by the application of PCM. Hence, better output results with suitable PCM for TSDS-CPC systems.

2.4. Multiple wicks with different orientations in a still (multi wick solar desalting system)

One of the earlier studies related to dual slope multi wick solar desalting system (MWSDS) was presented by Tiwari and Selim [49] and reported higher yield but also have higher investment value because of materials utilized have higher costs in this system. Further, Singh and

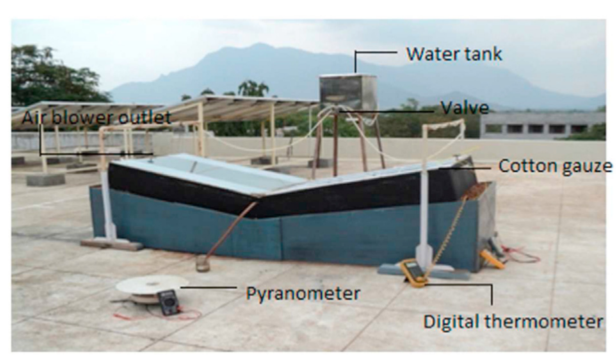
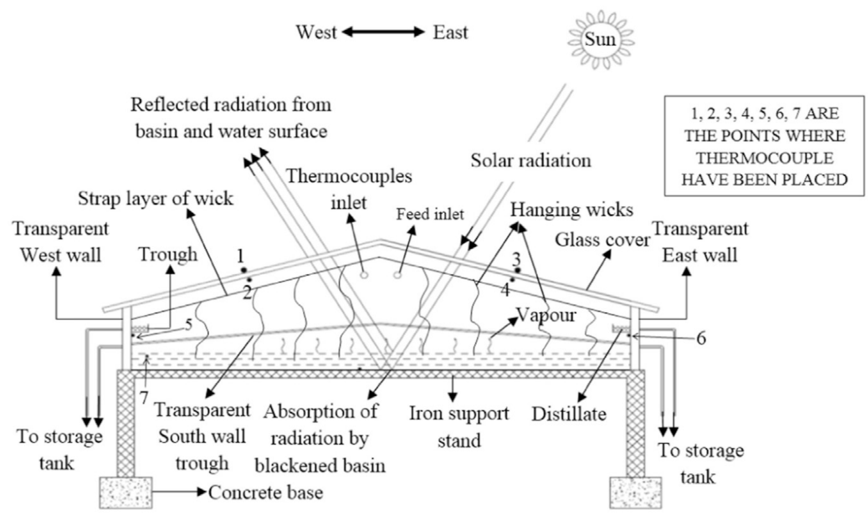


Figure 11. Photographic view of solar still with 'V' top cover (VSS) with cotton gauze which acts as wick material for cooling down the top cover temperature. Hence, it maintains greater temperature difference between inner glass temperatures to outer glass temperature [83].



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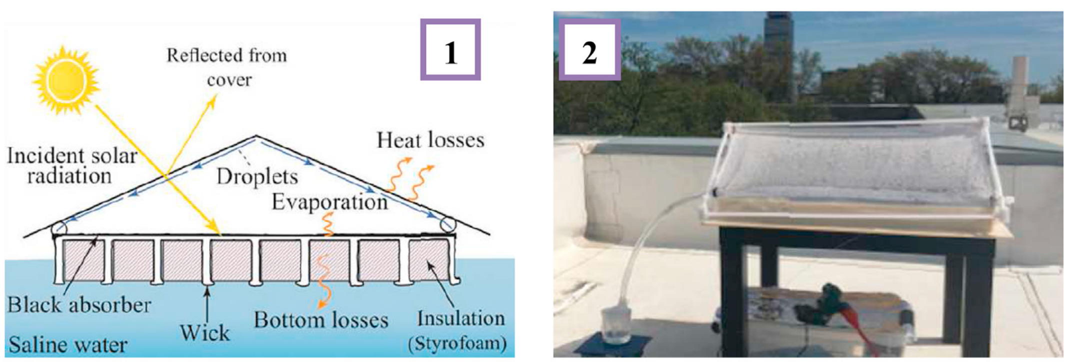

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Figure 12. a. Line diagram of multiple wick solar desalting system and these vertically oriented wicks exposes more evaporation area [84]. b. Wick solar desalting system (floating type). (1) System mechanism, different elements and working principle displayed schematically. (2) Picture of actual testing set up being installed at the roof top [85].

Tiwari [50] presented multi effect MWSDS having better efficiency due to the incorporation of wick which maintains a thin layer of water mass. Mahdi et al. [51] experimented on tilted WSDS in addition with charcoal cloth as a thermal energy storing medium also reported the results with better appreciation. Further, the contribution of Pal et al. [52] was also well recognized in the field of MWSDS that was presented with some amendments into conventional solar desalting units, also reported considerably high performance. Then, Pal and Dev [53] presented some modifications in double slope conventional solar desalting system which was efficiently converted into MWSDS that shows appreciable efficiency and distillate output than straight distillers. These systems have multiple wicks but the efficient system has better wick material associated with better thermal storage materials having better performance for the same basin area.

2.5. Multiple diffused channels in still (diffusion solar desalting system)

Various types of diffusion solar desalting systems (DSDS) mainly multi-effect horizontal, vertical or inclined type DSDS have been studied by various scholars before theoretically or experimentally [54, 55, 56, 57, 58, 59, 60]. Later on, new concept of designs are constantly evolved

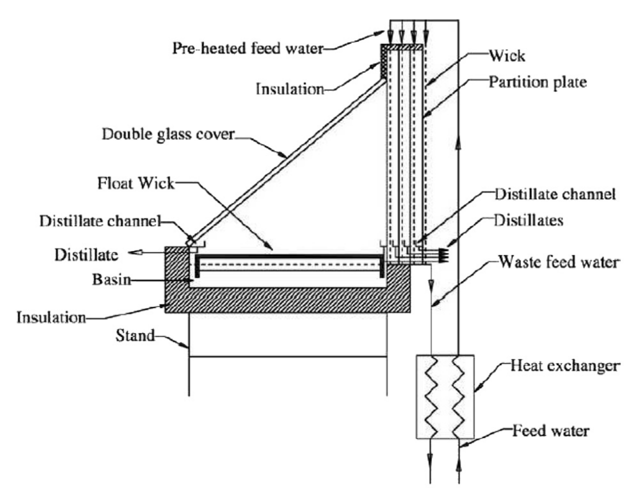

Figure 13. Line diagram of diffusion solar still (DSS) with floating wick and heat recovery through heat exchanger which enable preheat to feed water, ultimately performance results better [87].

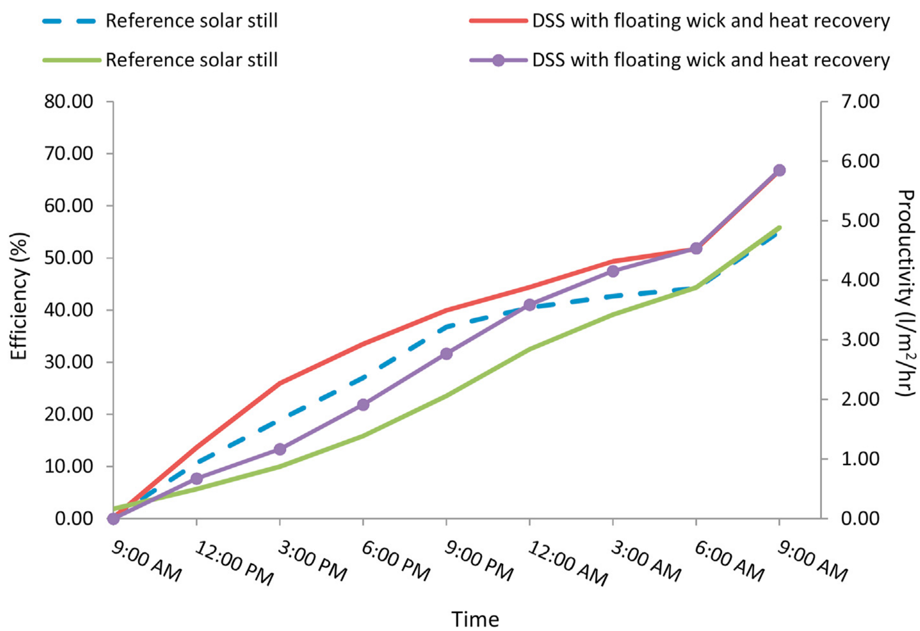

Figure 14. Variation of efficiency and productivity with respect to time of diffusion solar still (DSS) with floating wick and heat recovery in between reference solar still and diffusion solar still [103].

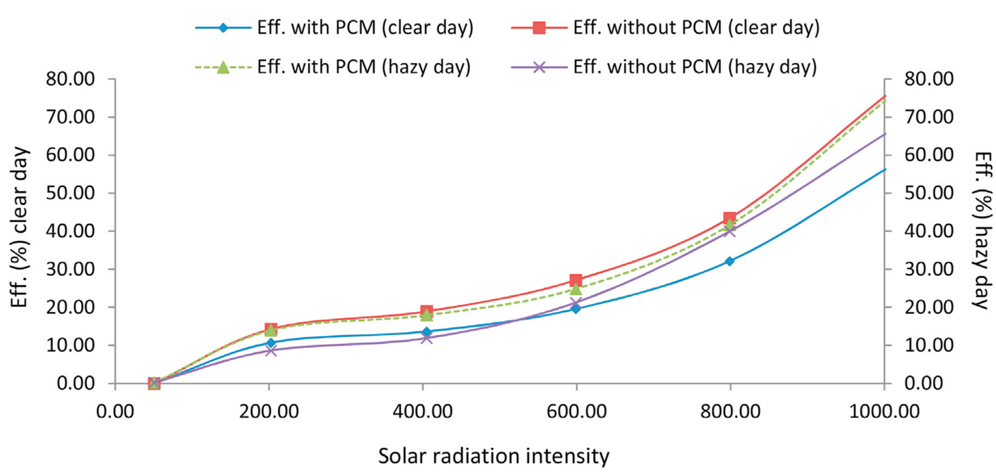

Figure 15. Efficiency variation with and without PCM for weir solar still cascade type in clear and hazy day which shows changes in results as per solar intensity varies up to one sun solar intensity [103].

now a days as the earlier works was affected by several deficiencies reveled by continuous evaluation done by researchers. Hiroshi Tanaka [61] offered the extension in previous work and experimented on multi-DSDS coupled with FPC. It was marked as good result with 13.3 $l/m^2/day$ yield in his study for the particular type of DSDS for the maximum solar intensity conditions. Chong et al. [62] expressed multi-DSDS along with heat exchanger and connected with vacuum type solar spiral collector. In it water recovers excess heat hence temperature of water enhances more and correspondingly more evaporation so higher condensation and larger yield up to 23.9 $l/m^2/day$. Further Huang et al. [63] introduces improved by applying spiral type multi-effect DSDS having similar specifications as used in [62] and reported improved maximum distillate production of 40.6 $l/m^2/day$ based on solar absorber area only under standard test conditions as it used directional as well as lateral diffusion at the same time that improves overall performance in terms of yield. Hiroshi Tanaka [64] considered the multi-effect with vertical type DSDS coupled with slanted wick that performed well from previous work like [61] and the result was reported as 15.9 $l/m^2/day$ yield. Hiroshi Tanaka [65] presented study based on various parameters like dimensional ratio etc. and optimized it to get better results after that this model was rechecked through experiments by Tanaka et al. [66] and recorded considerable yield.

DSDS systems are well efficient due to its diffusion channels (horizontal, vertical, inclined or spiral multi-effect etc.). Spiral solar collectors shows better performance and furthermore spiral multi-effect DSDS with additional evaporation and condensation in longitudinal and lateral directions will improve the performance up to next level.

2.6. Multiple steps in basin forming multiple weir type channel (weir type solar desalting system)

Solar desalting weir type system was studied by Sadineni et al. [67] theoretically and experimentally and recorded well correlation coefficient along with 20% improved performance in comparison with conventional distillers due to having larger surface area for evaporation with a reduced amount of glazing and due to smaller

Figure 16. Photographic view of Novel portable pyramid solar still (PSS) which is a portable and flexible solar still and can be inflated wherever required [90].

Figure 17. Photographic view of Novel portable Triangular prism solar desalting system with portability benefits which is one of the novel approaches [90].

water depth in basin along with continuously flowing of water recovers more and more heat. After that Tabrizi et al. [68] presented solar desalting weir cascade type system assisted with PCM. The study was revealed with low mass flow rate with and without PCM in hazy days and clear days, ultimately result favored clear day without PCM with higher distillate. Zoori et al. [69] represented study with a comparison for the same model as shown in Figure 1 with no PCM. This study was simulated and validated with experimental study also, and found well matching. Weir solar stills work based on thin water layer maintained at basin liner are responsible for better production whereas weir stills assisted with PCM and water loop minimizes heat loss ultimately, results a much better yield.

2.7. Superheated steam generation and distillation with contactless distiller (contactless solar steam generation and desalting system)

Cooper et al. [70] has presented a unique concept for superheating the steam. In this experimental work solar absorber is not in the contact with water directly but filled with solar irradiative energy which is utilized further for superheating the steam with 38% efficiency (lab conditions) and can distillate water up to 2.5 l/m^2/day. On the other hand, Kashyap et al. [71] showed a cyclic CO_2 capture into grapheme aero gel material for corresponding conversion into water and $CaCO_3$ with the help of solar localized heating for 1000 W/m^2 (one sun) solar intensity at laboratory conditions.

The overall work represents various solar desalting systems in which diffusion solar stills and weir type solar stills perform well. It has larger effective evaporation and condensation area with minimum water mass at basin liner or at diffusion surface which directly reflects the corresponding result. Stills with PCM, FPCs, CPC or additional condenser etc. directly reflect the distillate production output under the same basin area (converted into unit area wherever necessary).

3. Favored new conceptual designs of latest solar desalting systems

Conventional solar desalting units represent simple design of construction and needs many improvements further because it has high heat losses and less efficient. So these systems need additional designs with special features like that performed with maximum efficiency up to 40% and yield up to 6 l/m^2/day, disclosed by Kunze [72]. Thus, these modified designs with improved performances are called as specially designed single slope passive solar desalting system.

The responses of results for all the specially designed single slope solar desalting systems are based on the still design specialty, additional

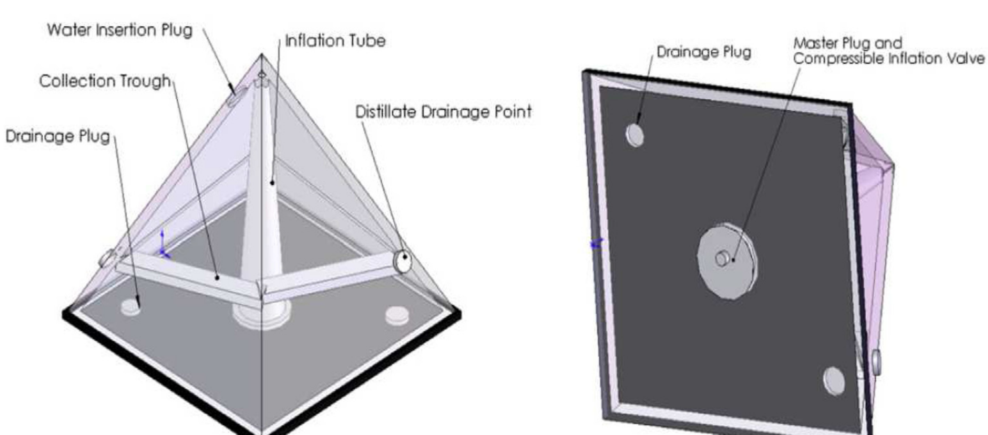

Figure 18. Constructional features of Novel portable pyramid solar still (PSS) [90].

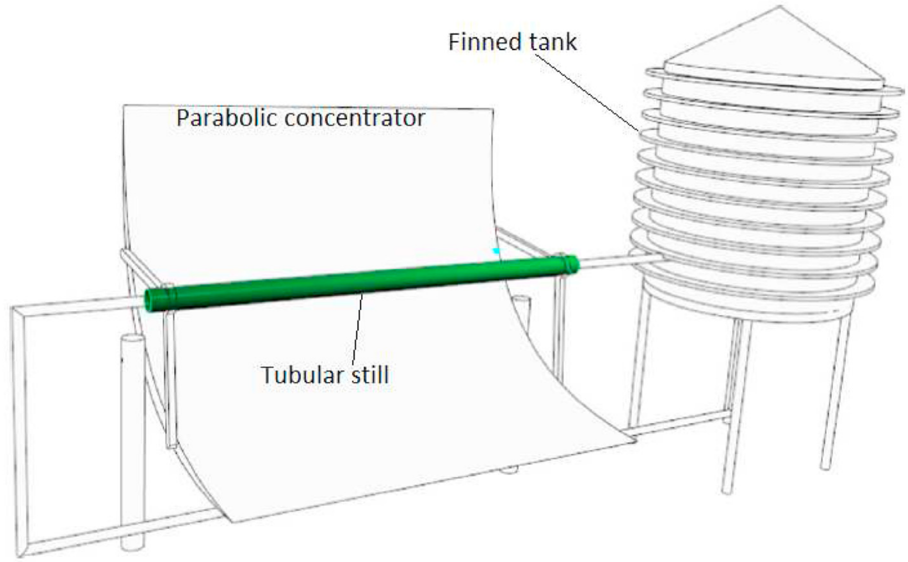

Figure 19. Advanced Novel tubular solar desalting system connected with parabolic concentrator and feed water supply connected with finned storage tank so that preheated water with concentrator improves performance [91].

supportive elements utilized, respective climatic conditions and the maximum solar radiation availability. For simplicity, distillate output for all the systems has been shown in terms of l/m^2/day. The distillate production output under the same basin area (converted into unit area wherever necessary) and on daily basis (mostly given by the researcher otherwise presumed 8 h a day and converted results accordingly).

3.1. Pyramid solar desalting system (PSDS)

For a solar desalting system having basin top cover which represents pyramidal shape called as pyramid solar desalting system. It carries larger evaporation area for the similar basin area still as compared to conventional type stills that makes the offered still more fruitful. PSDS may become more advantageous by adjusting pyramid still top cover height, orientation angle of top cover along with some other special measures.

Kabeel [73] experimented on PSDS concave jute wick still in Egypt as shown in Figure 2. It has increased surface area to absorb larger solar thermal energy and hence greater output reflects. The still basin contained 1.2×1.2 m^2 basin areas with 10 cm water depth in it and 45° top glass cover orientation angle. It was recorded better result with concave

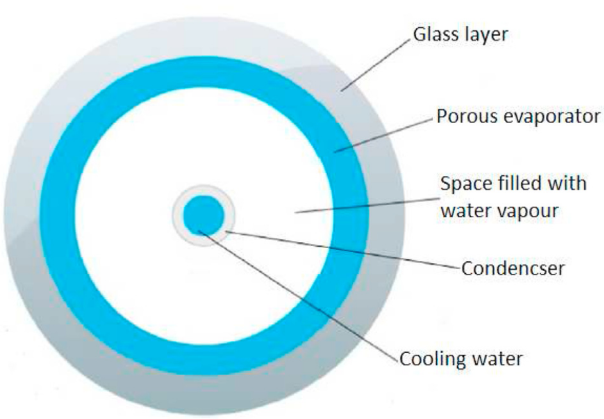

Figure 20. Internal constructional detail of advanced Novel tubular solar desalting system.

jute wick as compared to simple PSDS as jute wick provides thin layer of water for evaporation hence greater evaporation and condensation form better yield. Related for the referred system has been shown in Figure 3 as per the data used from [73].

Sathyamurthy et al. [74] presented an experimental study and revealed the factors that affects on the performance of triangular PSDS. these factors was heat transfer coefficient, temperature differences at different segments in still, cover areas, different water depth in basin and variation in wind speed for the most favorable manipulative design of solar still units. It was observed 15.5% improved result with 4.5 m/s wind speed with better yield up to 4.701 l/m^2/day. This experimental study was performed in Chennai climatic conditions with the inclination angle of 30° as shown in Figure 4. Also, effects of variation in water depth, wind velocities, on different types of solar still units were analyzed by Tiwari et al. [75] and El-Sebaii [76, 77, 78] correspondingly.

3.2. Hemispherical solar desalting system (HSDS)

This still does not require tracking of solar irradiation, so more suitable in design and establishing a set up with better approachability of solar radiant energy. This still have high water depth at the center in basin but have better and identical solar energy inclusion through its hemi spherical shaped top cove that's why called as hemispherical solar desalting system.

Arunkumar et al. [79] experimented on HSDS with or without top cover cooling by flowing water combinations as shown in Figure 5. It has 0.05 m water depth, 0.71 m^2 area of basin and 10 ml/min water mass flow rate. The result was found better with water cooled glass cover by 42% efficiency in comparison with HSDS with no water cooling at top glass surface having 34% efficiency only. As water cooled top cover increases rate of condensation and in due course yield improved.

3.3. Tubular solar desalting system (TSDS)

In this solar desalting system, distillation occurs in long tube which have a rectangular tray with water mass. This system does not want any additional solar tracking device and some supplementary elements like parabolic concentrator may improve the results further.

Arunkumar et al. [80] experimented on TSDS having concentrator and 2×0.03 m^2 basin area and found appreciable results for 3 conditions

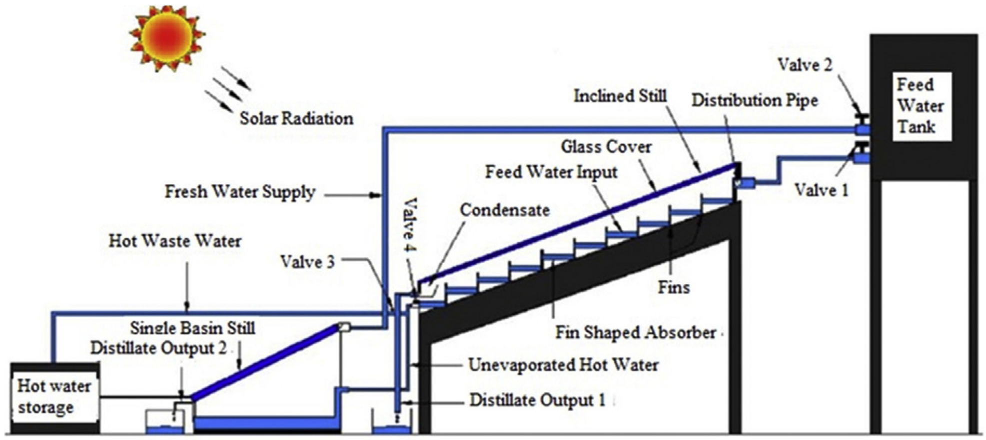

Figure 21. Schematic Novel setup diagram of combined solar desalting system with SSSDS and inclined solar desalting system along with fins in this way a cumulative distillate can be collected through both the systems [92].

i.e. (i) yield with no cooling, (ii) yield alongwith air cooling, (iii) yield with water cooling Coimbatore climatic condition as shown in Figure 6. The results observed for (i), (ii) and (iii) were as 2.05 l/m^2/day, 3.05 l/m^2/day and l/m^2/day respectively.

After that, Elashmawy [81] studied TSDS in the climatic conditions of Hail, Saudi Arabia with 3 combinations like first TSDS filled with salty water along with black cloth wick, second TSDS with no wick and third with CPC coupled with solar tracking device as shown in Figures 7 and 8. In it, the yields were 4.71 l/m^2/day, 3.60 l/m^2/day and 3.35 l/m^2/day with respective daily efficiencies by 36.5%, 30.5% and 28.5% for 0.59 m^2 basin surface areas. The first combination shows better performance as black wick absorbs further solar thermal energy which leads more evaporation and condensation so results more distillate.

3.4. Solar desalting system with ‘V’ type glass covering (VSDS)

In this type of solar stills, half portion of top cover is suitable with solar latitude angle with better performance and the next half is not as good as for solar latitude side. That side of still from where water basin can receive larger effective solar energy and also have higher glazing effect in the system. Kumar et al. [82] took a different type of solar desalting system having ‘V’ type top glass covering and the solar still assisted with four diverse combinations like still with no or with charcoal, with boosting mirror or charcoal or both. These combinations have different results for the respective combinations as 24.47%, 30.05%, 11.92% and 14.11% efficiency and 2.516 l/m^2/day, 3.226 l/m^2/day, 2.7 l/m^2/day and 3.526 l/m^2/day yield as shown in Figure 9. This system have 0.5 × 0.5 m^2 basin area with 0.4 m^2 boosting mirror area and 22° glass cover orientation as shown in Figure 10. In all the combinations presented above boosting mirror type VSDS with charcoal reported better yield because of receiving higher solar thermal energy.

Suneesh et al. [83] studied on VSDS with and with no use of air flow over top glass cover along with the application of thin cotton net over top cover. This set up was established Coimbatore climatic conditions located in Tamilnadu, India as shown in Figure 11. They observed the results for various conditions such as VSDS without thin cotton net, VSDS with thin cotton net and VSDS with thin cotton net and air flow over it and those were 3.3 l/m^2/day, 4.3 l/m^2/day and 4.6 l/m^2/day potable water correspondingly.

3.5. Wick solar desalting system (WSDS)

This system utilizes a wide range of materials is used having properties like porosity, non-reactive with dirty water, elevated temperature sustainability etc. and should be cost effective with long lasting suitability to the system. Wick provides very thin water film and supports efficient evaporation under direct or diffused solar radiation. Wick may be oriented in many directions or the combinations with each other.

Pal et al. [84] amends double slope solar desalting system by adding multi-wick (MW) into the basin along with transparent walls. The experiment was conducted Allahabad climatic condition, as shown in Figure 12a. This still comprise 2 m^2 basin area, 2 cm depth of water and 15° top cover orientation. The improved results were reported for modified design with black cotton wick and jute wick. The response for yield production and thermal efficiency for both the experiments were as 9.012 l/m^2/day, 7.040 l/m^2/day and 23.03 %, 20.94% correspondingly.

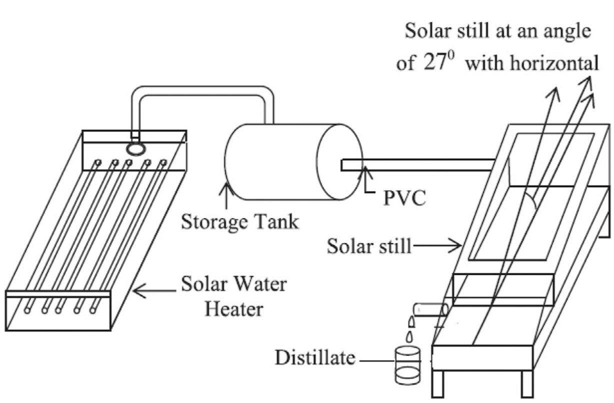

Figure 22. Schematic diagram of Novel single basin double step solar desalting system coupled with solar heater which utilizes additional heat from solar collector [93].

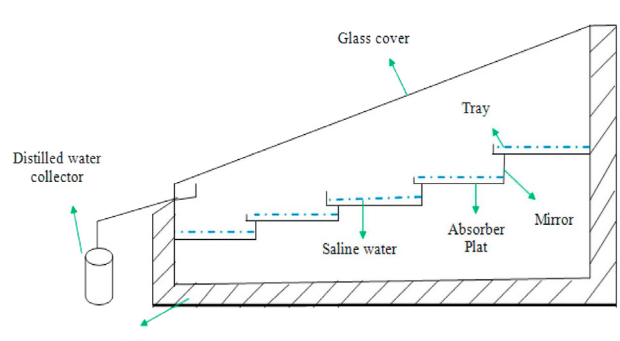

Figure 23. Schematic reference diagram of multistep single basin solar desalting system which is combination of multi absorbers, boosting mirrors and fins, all improves the performance in combined way [94].

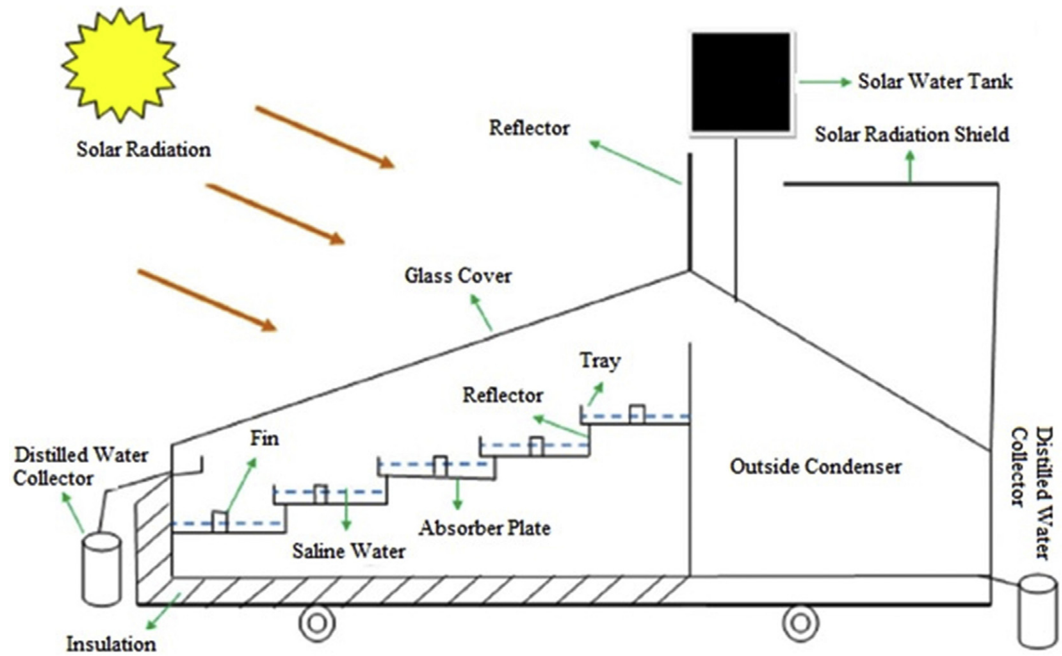

Figure 24. Schematic diagram of proposed Novel single basin multistep solar desalting system having multiple reflectors, fins, absorbers, solar radiation shield with additional condenser that improves condensation over a defined evaporation area [94].

Ni et al. [85] revealed a low cost solar distillation system and process in which a floating wick (fabric wick) having salt rejection capability due to its specialty in design, working principle and system mechanism as shown in Figure 12b. As sea water contains 3–3.5 wt% of total dissolved solid having NaCl, $CaCo_3$ etc. that can clog the pores of filtration medium which are minimized here by corrugating it and floated over foam. The system has evaporation area and condensation area are 21×20 cm^2 and 55×55 cm^2 respectively with 57% evaporation efficiency under one sun solar intensity conditions. The desalting process and corresponding results are also presented through CFD modeling.

3.6. Diffusion solar desalting system (DSDS)

DSDS as a novel technique is used to produce more distillate in effective and efficient way than the usual distillation methods. Diffuser plate orientation decides the type of DSDS like horizontal, vertical or inclined type multi effect diffusion solar desalting system. In it various plates are arranged in such a way having air gap between them and plates contain wick wetted by either capillary action or by any direct technique. This distillation system follows the working in such a way that first heat due to solar radiation comes into the air opening so water gets evaporated, diffused and condenses into the gap on its subsequently cold condensing plat and this intact practice is called diffusion decontamination [86]. This method utilizes larger surface areas for evaporation and condensation, hence higher production of potable water results.

Kaushal et al. [87] experimented on vertical floating wick DSDS. In this experiment, the heat from concentrated salty water from sink outlet was reused for reheating the inlet salty water efficiently as shown in Figure 13. Simple vertical multi-effect type DSDS and proposed DSDS with some modification (floating wick) was compared with 21% more essence due to better design and continuous heat recovery. Also they presented the economic investigation and correlation factor also, discovered the low payback period for the proposed model [88]. In the proposed system, thermo coal is used as floating medium for the cotton wick. The proposed system has area of basin by 1.5×0.77 m^2 with 1.52×0.68 m^2 areas of diffusion plates separated by 10 mm with 2 cm water height maintained in it. It was reported better yield in night also as 0.98 l/m^2/day for the base model and 1.34 l/m^2/day for the projected model due to better heat revival through heat exchanger incessantly as shown in Figure 14.

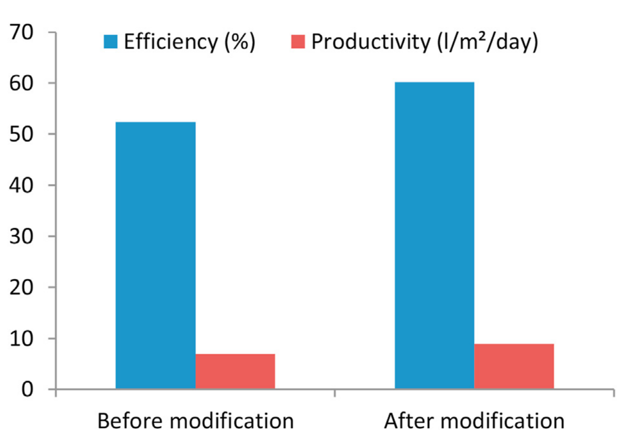

Figure 25. Comparison between reference (before modification) solar desalting system and modified solar desalting system [103].

3.7. Weir solar desalting system

It may be in step form or cascade form also having many additional arrangements for the improvement of its performances. In it a thin film of water layer flows and heat recovered from hot intense salty outlet water through additional arrangement.

Sarhaddi et al. [89] considered cascade type weir solar desalting system as shown in Figure 1 with PCM and compared the same model with no PCM, also analyzed various parameters in different atmospheric conditions. The results were validated with good agreement. It was concluded that cascade WSDS with PCM performs superior in semi hazy day as PCM gives added heat to basin water which is responsible for better yield production. Also, weir still system devoid of PCM in clear day performs better as well. The corresponding results were as 76.69% utmost efficiency as shown in Figure 15 and 7.05 l/m^2/day potable water.

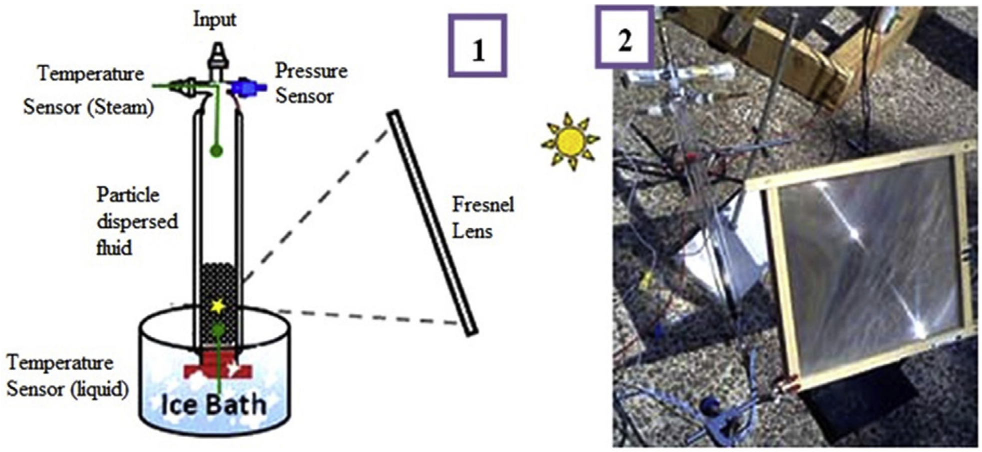

Figure 26. Solar vapor generation and distillation system. (1) Schematic diagram of the system with essential elements and process parameters. (2) Experimental set up photograph [95].

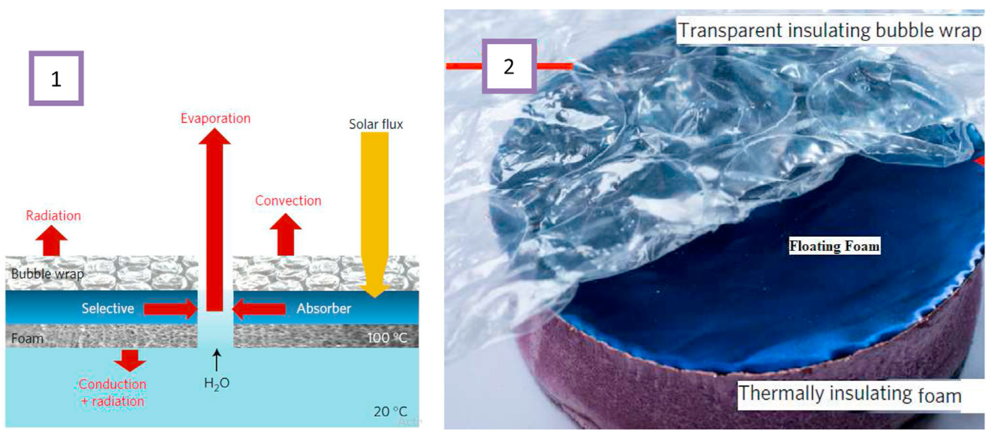

Figure 27. Steam generator and distillation unit with floating structure. (1) Figure shows the working principle with essential system integrations. (2) Actual photographic view of experimental set up [96].

4. New conceptual designs referred as novel solar desalting systems (NSDS)

Novel solar desalting systems are the new approaches and designs proposed by different researchers which need to be relooked into the designs, viability, self-sustainability, economy, output, etc. These designs may open the ways of acceptability to solar desalting systems as a prime medium of potable water producers for all individual houses along with commercial applications too.

The variations in results for all the novel solar desalting systems depends directly or indirectly on the still design specialty, additional supportive elements utilized, respective climatic conditions and the maximum solar radiation availability. For simplicity, distillate output for all the systems has been shown in terms of l/m^2/day. Different solar intensities applied/utilized in various experiments either in open atmosphere or in confined laboratory area, for that natural solar intensity

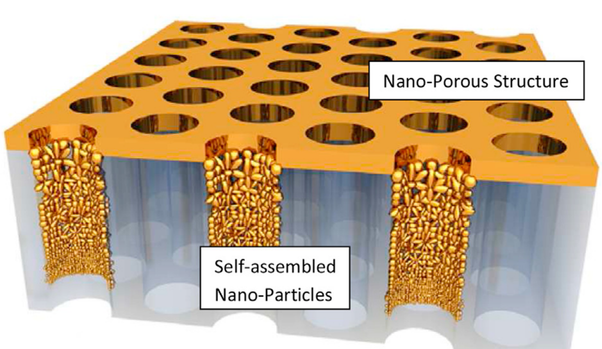

Figure 28. Basic schematic diagram for self assembled Plasmon enhanced solar distillation element in which top segment represents a template with Al_2O_3 lower segment filled with Au NPs [97] otherwise, the whole nano-porous medium treated as anodic aluminum oxide membrane filled with Al NPs [98].

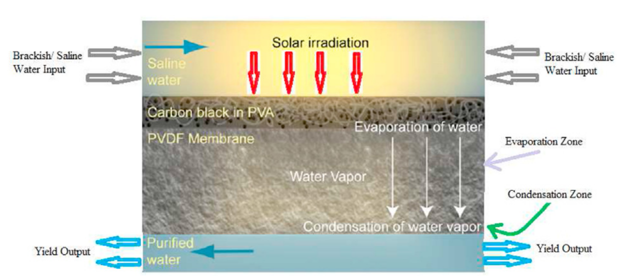

Figure 29. Figure shows the smart porous membrane (carbon NPs deposited PVA + PVDF) for distillation underneath the membrane with basic filtration working principle.

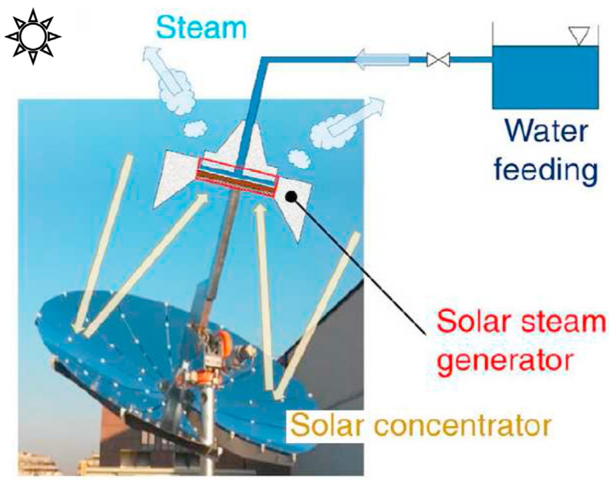

Figure 30. Schematic diagram of solar steam generator and distillation system with parabolic concentrator prepares a cheaper, efficient and self-sustainable distillation system rather than nano-material operated solar distillation systems [101].

available in open atmosphere is as usual but for laboratory conditions, solar intensities are simulated with the help of different simulators from one sun to 10 suns solar radiation intensity.

Wassouf et al. [90] offered a distinctive design of solar desalting system having portability feature with very low cost relative to conventional solar desalting systems and can be mainly used for domestic purposes. Still carries flexible inflated thin plastic prismatic and pyramid top cover type solar still strengthened by inflated vertical hold up tubes as shown in Figures 16 and 17. Both the prototypes followed similar working principle and constructional features as shown in Figure 18. Pyramid solar desalting system with 0.2 m^2 basin areas produces 0.5 l/m^2/day at a rate of $ 0.046 per liter having 49.9% efficiency. Triangular solar desalting system with 0.6 m^2 basin area produces 0.9 l/m^2/day potable water at a rate of at $ 0.063 per liter with 35.8% efficiency.

Al-Nimr and Dahdolan [91] offered an innovative still together with parabolicaly focused in which preheated water is supplied through finned reservoir. This system contains tubular still with porous inner surface and parabolicaly focused and finned tank that receives more solar energy. All the arrangement preheated brackish water for better distillation and produces added distillate as shown in Figures 19 and 20. A representation of mathematical model with the help of simulation has been shown. The result recorded as 33.8% maximum efficiency and 3.0 l/m^2/day distillate for 2 m/s air flow velocity.

Hansen and Murugavel [92] revealed an efficient solar desalting system with SSSDS and inclined solar desalting system with fins represented in Figure 21. It has dual distillate, one from SSSDS and next from inclined desalting system. SSSDS has 0.3 and one m^2 areas for basin and inclined still basin with 30° glass cover inclination in both stills. This system reported the results as 5.2 l/m^2/day yield with 46.9% efficiency.

Kalita et al. [93] exposed a new model represented in Figure 22. It works in four stages i.e. first stage resembles single basin with double stepped basin still, second stage resembles jute wick still, and third stage appeared as steps with charcoaled jute wick absorber and in fourth stage double glass cover for covering the absorber. The agreement of these stages makes this still is a multi combination solar desalting system and shows more potable water for different stages as for one to four are as 1.81 l/m^2/day, 3.14 l/m^2/day, 2.15 l/m^2/day and 3.94 l/m^2/day respectively. In this way, a cumulative distillate output obtained by adding the individual distillate received from respective stages.

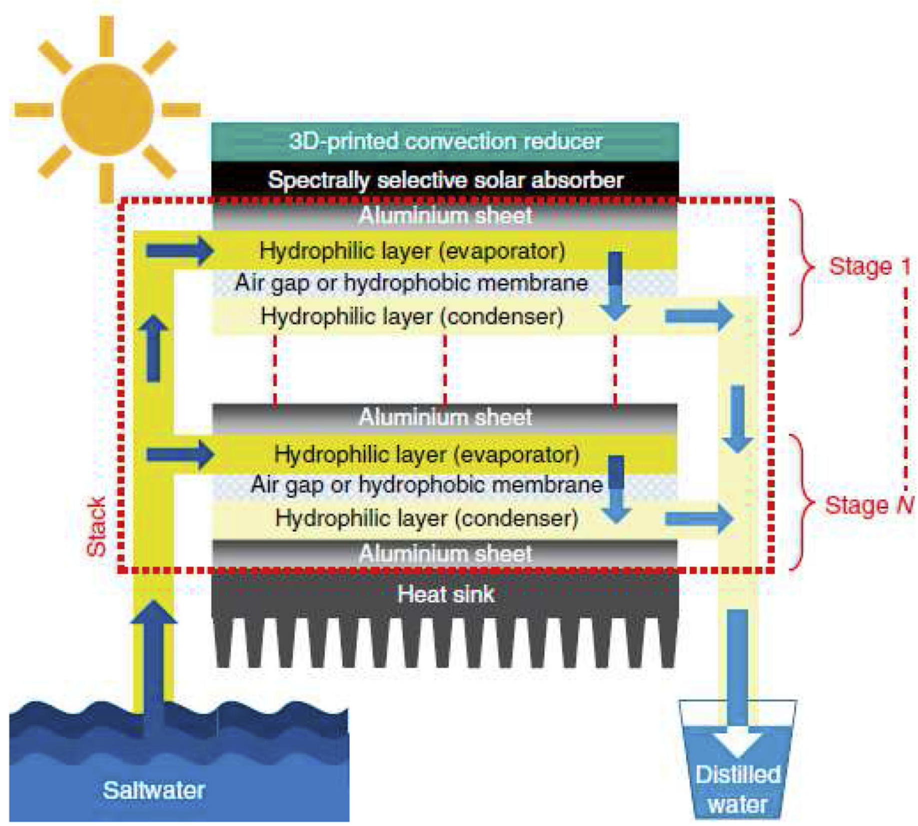

Figure 31. Detailed diagram of solar passive distiller with N number of distiller stages which works for desalting process for day time on the other hand system cleaning through rinsing process at night time [102].

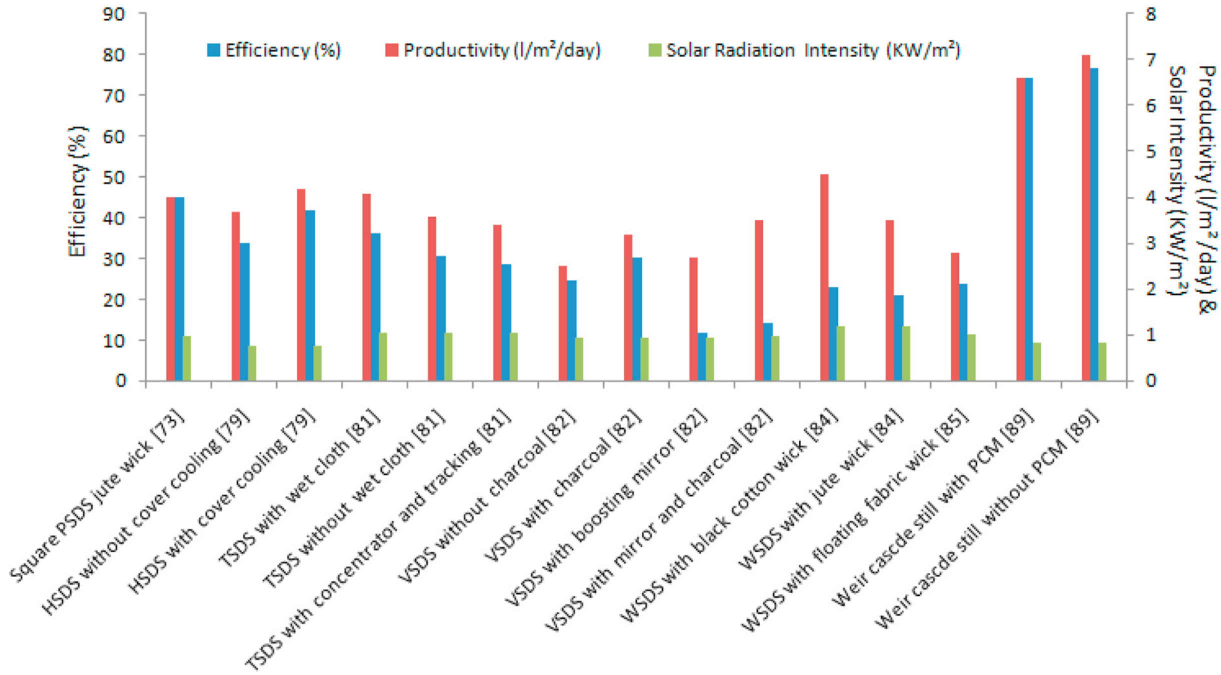

Figure 32. Variations in performance of various NCDSSs based on various physical parameters, designing concepts, material utilized and solar radiation intensities as per open atmospheric conditions or confined laboratory conditions.

Muftah et al. [94] tailored the existing single basin multi step solar desalting system as shown in Figure 23 (referred system) which was smartly customized by adding vertical fins and absorber plates in the steps of basin liner, provides extra absorber area enclosed with radiation resistant shield and also incorporated with reflecting mirror as shown in Figure 24 (proposed system). These combinations provide enhanced distillate which was statistically tested cautiously. Efficiencies before and after modifications, were recorded as 52.3% and 60.2% respectively. Offered model establishes improved production of potable water up to by 8.9 l/m^2/day in comparison with reference system as 6.9 l/m^2/day yield as represented in Figure 25.

Neumann et al. [95] experimented specially for steam generation which directly reflects the amount of distilled water generated. Two establishments has been shown in the experiment, one with carbon nano-particle (N115) in which negligible solution temperature increment (due to open system) and second with nano-shell (SiO_2/Au) in which reasonable temperature increment in solution happens, as vapor pressure also exerts a partial pressure on the solution, hence temperature increases. This is a microscopic model based on nano-sale heat flow as represented in Figure 26. Test was conducted for 25 ml and 35 ml and nano-shell responds better as it requires only 5 s to raise the solution temperature by 100 °C rather than 20 s as required by NPs. The maximum induced heating can be achieved as 9.93×10^{12} W/m^3. System working is as efficient as 80% absorbed sun light utilizes for evaporation and only 20% energy for surrounding heating.

Ni et al. [96] experimented on a simple set up which have a strong concept of thermal concentration that have been applied for patent also. In this system, an optical concentrator i.e. floating graphite based two layer absorber which utilizes its localized heat to evaporate water that cab escaped through a narrow opening in floating absorber and the total evaporation area is enclosed with a bubble wrap to minimize the convection and radiation losses as shown in Figure 27. System can generate 100 °C steam easily be reducing conductive, convective and irradiative losses and bubble wrap done excellent job to do this. System has 0.008 m^2 absorber area and having 85% of steam generating capacity.

Zhou et al. [97] represented a self assembled NPs and highly efficient broad band Plasmon enhanced absorbers for steam generation and distillation process as shown in Figure 28. In this system, a nano-porous gold template is placed over alumina nano-porous membrane (500nm) closely filled with gold NPs (ˇ90nm). The overall absorber having two gold-sputtered templates (Au/D-NPs) can absorb 99% of solar energy (first case) and absorber having gold NPs with gold template only can absorb 90% of solar energy (second case). The results appeared for the first case under four sun intensity as 41.3 l/m^2/day distillate (i.e. 10.3 l/m^2/day for one sun) whereas 2.4 l/m^2/day distillate for second case under one sun solar intensity only with 98°C steam temperature. Hence first case performs better due to two gold-sputtered templates which absorb maximum solar energy. Almost same set up has been implemented for the conduction of same set of experiment having nano-porous (300nm diameter, 450 nm length) anodic aluminum oxide membrane with closely filled aluminum NPs as shown in Figure 28, done by Zhou et al. [98]. This experimental set up has 45.6 l/m^2/day evaporation rate under four sun solar intensity (i.e. 11.4 l/m^2/day for one sun) which has slightly better than the previous experiment as in this case, two factors of plasmonic structure results positively i.e. hybridization of localized surface Plasmon and non-radiating Plasmon decay (helpful for broad band solar absorption up to 96% under 4 sun laboratory conditions). The overall concept of work follows hybridization than oxidation and finally comes out substrate (distillate).

Dongare et al. [99] enhanced the conventional membrane distillation system by incorporating carbon black NPs in hydrophilic polyvinyl alcohol (PVA) coating deposited at polyvinylidene fluoride (PVDF) membrane (0.2 μm) which forms a thin (25 μm) bi layer of optically porous structure as shown in Figure 29. System has 3.3 × 6.8 cm^2 absorber area and maintains the temperature of 20°C for feed water and distillate water respectively with 25°C maximum ambient temperature, also system can absorb solar intensity with 53.8% efficiency under the available average solar intensity by 700 W/m^2. The results have been validated through COMSOL 5.2 simulation with good agreement.

Kashyap et al. [100] developed a unique anti-clogging graphite film which is suitable desalting the high saline water for long period in an efficient, economic, self sustainable and large scale distillation process. This smart material is a porous polymer skeleton with embedded graphite flakes (Exfoliated graphite) and carbon fibers (carbonized rayon). The membrane performance was good due to anti clogging property achieved by specially designed pore dimensions and coating of

Table 1. New conceptual design solar desalting systems with their specialty, efficiency, yield results, distillate cost, maximum temperature conditions available with performing parameters and work regime. The concluding remarks have been given on the basis of maximum operating conditions only standard laboratory or atmospheric conditions. Productivity performance has been represented on the basis of l/m^2 for a particular day as per given by various researchers and if not, it has been presumed 8 h for a day and results represented accordingly.

Solar Desalting System	Work Regime, Specialty with Different Parameters	Maximum Solar Radiation and Maximum Temperature Conditions	Result			Concluding Remarks
			Efficiency (%)	Productivity ($l/m^2/day$)	Distillate cost ($/l)	
PSDS [73]	Egypt, Black painted wick utilizes capillary action, Square pyramid with jute wick	978.52 W/m^2 maximum solar radiations at 12.00 p.m. Wick surface temperature: 76.85 °C at 2 p.m. Basin water temperature: 61.27 °C at 2 p.m. Ambient temperature: 35.06 °C at 3 p.m	45	4.01	0.065	This experimental study utilizes capillary effect working principle and wick is utilized to improve the evaporation and pyramidal shape of top cover provides overall larger surface area for evaporation.
PSDS [74]	Chennai, India, top cover of triangular pyramid shape, variation in wind velocity and water mass depth used as 4.5 m/s optimum wind velocity, optimum water mass depth is 0.02m.	4.5 m/s optimum wind velocity, optimum water mass depth is 0.02 m at which 74 °C maximum water surface temperature, 63 °C maximum top glass temperature and 984.73 W/m^2 maximum solar radiations at 12.00 p.m.	Better than conventional still	4.701	Economic	An experimental work revealed the effect of water depth, wind speed etc. and suggested that convective and evaporative heat transfer coefficients plays important role for designing the still.
HSDS [79]	Tamilnadu, India, Hemispherical top glass cover without cooling, glass wool insulation for side walls, saw dust insulation for basin liner.	732 W/m^2 and 745 W/m^2 are average solar radiation and maximum solar radiation respectively. 62.42 °C and 42 °C are water temperature and top glass cover temperature respectively.	34	3.66	0.019	A new conceptual design explored through experiment and variations of water temperature cover temperature, ambient temperatures etc. have been noticed and revealed that larger temperature difference gives more yield
HSDS [79]	Tamilnadu, India, hemispherical top glass cover with cooling with same test setup in all respect	732 W/m^2 and 745 W/m^2 are average solar radiation and maximum solar radiation respectively. 63.11 °C and 40 °C are water temperature and top glass cover temperature respectively.	42	4.2	0.017	Further extension of previous work utilizes additional working parameter and according to that reveals that top glass cover with cooling water creates larger temperature difference so produces greater yield as compared to earlier experiment
TSDS [80]	Coimbatore, Tamilnadu, Tubular glass covering without cooling	Solar radiation range in clear sky is 652–1159 W/m^2	Better than conventional still	2.05	0.018	The yield depends on ambient temperature, solar intensity and wind velocity independently and has reasonable productivity.
TSDS [80]	Coimbatore, Tamilnadu, Tubular glass covering with air cooling	Solar radiation range in clear sky is 652–1159 W/m^2, 4.5 m/s optimum wind velocity and corresponding water temperature was 84 °C.	Better than conventional still	3.05	0.016	The experimental study was further explored with the addition of air cooling (additional working parameter) which improves condensation.
TSDS [80]	Coimbatore, Tamilnadu, Tubular glass covering with water cooling	solar radiation range in clear sky is 652–1159 W/m^2, 10 ml/min optimum water flow	Better than conventional still	5.0	0.015	The previous experimental work utilizes additional working parameter i.e. water

(continued on next page)

Table 1 (*continued*)

Solar Desalting System	Work Regime, Specialty with Different Parameters	Maximum Solar Radiation and Maximum Temperature Conditions	Result			Concluding Remarks
			Efficiency (%)	Productivity (l/m^2/day)	Distillate cost ($/l)	
		velocity and corresponding water temperature was 89 °C				cooling which improves the results up to optimum level
TSDS [81]	Saudi Arabia, Tubular glass with wet cloth	1030 W/m^2 maximum solar intensity, 69 °C, 67 °C and 42 °C are trough temperature, tube temperature and ambient temperature respectively at 475g water mass.	36.5	4.71	0.033	This was the second experimental test set and found better response with wet cloth than without cloth study.
TSDS [81]	Saudi Arabia, Tubular glass without cloth	1030 W/m^2 maximum solar intensity, 71 °C, 68 °C and 44 °C are trough temperature, tube temperature and ambient temperature respectively at 330g water mass.	30.5	3.6	0.044	This was the first experimental test set out of the sequential study of this study done by the same researcher and found good response without wet cloth
TSDS [81]	Saudi Arabia, Tubular still with concentrator and solar tracking device	1030 W/m^2 maximum solar intensity, 111 °C, 123.5 °C, 109.5 °C and 53 °C are trough temperature, parabolic faced tube temperature (diffused beam), sun faced tube temperature (direct beam) and ambient temperature respectively at 330g water mass.	28.5	3.35	0.024	This experimental test set found better response with wet cloth and tracking device but tracking device does not increases a remarkable output.
VSDS [82]	Coimbatore, Tamilnadu, India, 'V' type top glass cover still without charcoal	917.85W/m^2 maximum solar intensity.	24.47	2.516	Economic	This experimental work has the benefit of wall height equality to all sides as not in single slope solar still system, so performs better than conventional single slope solar stills.
VSDS [82]	Coimbatore, Tamilnadu, India, 'V' type top glass cover still with charcoal	917.85W/m^2 maximum solar intensity	30.05	3.226	Economic	Performs better due to phase change material and in addition with larger solar radiation gain despite less hindrance by side walls of still.
VSDS [82]	Coimbatore, Tamilnadu, India, 'V' type top glass cover still with boosting mirror	942W/m^2 maximum solar intensity	11.92	2.7	Less Economic	Boosting mirror enhances diffused solar radiation gain which improves the performance.
VSDS [82]	Coimbatore, Tamilnadu, India, 'V' type top glass cover still with boosting mirror and charcoal	966.16W/m^2 maximum solar intensity	14.11	3.526	Less Economic	Phase change material incorporation with boosting mirror simultaneously works better to improve the performance.
VSDS [83]	Coimbatore, Tamilnadu, India, 'V' type top glass cover without thin cotton maze	1110W/m^2 maximum solar intensity, 35 °C, 53 °C and 62 °C maximum ambient temperature, inner glass	Better than conventional still	3.3	0.014	This experimental setup is the simplest VSS and used for comparison with other series of setup ahead.

(*continued on next page*)

Table 1 (*continued*)

Solar Desalting System	Work Regime, Specialty with Different Parameters	Maximum Solar Radiation and Maximum Temperature Conditions	Result			Concluding Remarks
			Efficiency (%)	Productivity (l/m^2/day)	Distillate cost ($/l)	
		temperature and glass temperature respectively.				
VSDS [83]	Coimbatore, Tamilnadu, India 'V' type top glass cover with thin cotton maze	1110W/m^2 maximum solar intensity, 35 °C, 48 °C and 59 °C maximum ambient temperature, inner glass temperature and glass temperature respectively.	Better than conventional still	4.3	0.012	Thin wet cotton maze adds one additional parameter of cooling effect in natural mode which improves the performance of still.
VSDS [83]	Coimbatore, Tamilnadu, India 'V' type top glass cover with thin cotton maze in air blow condition over the glass surface	1110W/m^2 maximum solar intensity, 35 °C, 47 °C and 59 °C maximum ambient temperature, inner glass temperature and glass temperature respectively.	Better than conventional still	4.6	0.028	The experimental setup has thin wet cotton maze at the top cover of still basically adds cooling effect parameter in addition with air blow i.e. force mode which improves the overall performance in the form of yield.
WSDS [84]	Allahabad, Uttar Pradesh, India, still with black cotton wick, less decay rate and better life to multiple wick of black cotton	1198 W/m^2 maximum solar intensity, 67 °C and 47 °C are the maximum basin water temperature and maximum ambient temperature respectively.	23.03	4.5	0.037	This experimental setup has vertical wicks of black cotton which absorbs more radiation due to additional parameter of black color and the side walls are also provides the extra condensation surface area which leads performance of the solar distillation system.
WSDS [84]	Allahabad, Uttar Pradesh, India, still with jute wick, more decay rate and lesser life to multiple wick of jute	1198 W/m^2 maximum solar intensity, 47 °C is the maximum ambient temperature respectively.	20.94	3.52	0.039	This setup has jute wicks such as traditional wick which absorbs usual radiation and the side walls are also provides the extra condensation surface area which shows a considerable performance of solar still.
WSDS [85]	Cambridge, Massachusetts, USA, Floating fabric wick on foam	1000 W/m^2 (one sun) maximum solar intensity taken for the experiment, 42 °C vapor temperature	24	2.8	Economic	A special concept of salt rejection (due to its arrangement and design) for long term distillation process with the help of floating fabric wick.
Weir solar desalting system [89]	Zahedan, Iran, Weir cascade type with phase change material	817 W/m^2 maximum solar intensity, 56.5 °C maximum water temperature	74.35	6.63	Economic	The further study of the experimental setup was extended by the thin layer of water mass i.e. cascade weir still along with PCM reflects much better performance than the earlier study.
Weir solar desalting system [89]	Zahedan, Iran, Weir cascade type without phase change material	817 W/m^2 maximum solar intensity, 58.5 °C maximum water temperature	76.69	7.05	Economic	The experimental study was extended by comparative analysis and as this system maintains thin layer of water mass which utilizes solar radiations better reflects better performance.

Table 2. Novel and proposed solar desalting systems or prototypes with their specialty, efficiency, yield results, maximum temperature conditions available with performing parameters and work regime. The concluding remarks have been given on the basis of maximum operating conditions only standard laboratory or atmospheric conditions. Productivity performance has been represented on the basis of l/m^2 for a particular day as per given by various researchers and if not, it has been presumed 8 h for a day and results represented accordingly. Maximum solar intensities may vary according to atmospheric conditions or simulators in laboratory (vary from one sun to ten sun).

Novel Solar Still	Work Regime, Specialty with Different Parameters	Maximum Solar Radiation and Maximum Temperature Conditions	Result		Concluding Remarks
			Efficiency (%)	Productivity (l/m^2/day)	
Triangular prism solar desalting system [90]	Bundoora, Victoria, Australia, Long prism supported with multi-inflated vertical tubes	1256 W/m^2 maximum solar radiation, 27 °C and 47 °C are the ambient temperature and still internal temperature respectively	35.8	1.5	A prototype for domestic applications with self sustainability and economy performs well under the given considerations.
Pyramid solar desalting system [90]	Bundoora, Victoria, Australia, Triangular pyramid with one inflated vertical tube only	1256 W/m^2 maximum solar radiation, 27 °C and 39 °C are the ambient temperature and still internal temperature respectively	49.9	2.5	Under the same constructional features except the still shape of prototype for domestic applications performs better against the previous setup under the same parameters.
Advanced tubular solar desalting system [91]	Irbid, Jordan, Parabolic concentrator and finned storage tank	1000 W/m^2 maximum solar intensity, 25 °C and 314.5 °C are the ambient temperature and porous evaporative temperature	33.8	3.0	This system utilizes maximum solar radiation due to finned tank, parabolic concentrator and tubular still.
SSSDS coupled with inclined solar desalting system [92]	Tirunelveli, Tamil Nadu, India, Inclined solar still with fins and fin shed absorbers	1039 W/m^2 maximum solar intensity, 37 °C, 68 °C, 56 °C, 57 °C and 50 °C are the ambient temperature, fin absorber temperature (inclined still and basin still), glass temperature (inclined still and basin still) respectively	46.9	5.21	This is a combination of stills along with fins and additional heat absorbers and the proper utilization of hot water spring maintains the effective productivity.
Single basin multi step solar desalting system [94]	Selangor, Malaysia, Still with multiple absorber and additional separate evaporator area	1100 W/m^2 solar radiation, 37 °C, 56.5 °C and 68 °C are the ambient temperature, glass and water temperatures after modifications respectively.	60.2	8.9	The above system for the same basin area was modified by adding vertical fins and multi step basin with individual evaporation area gives better performance than previous setup.
Nano-particle solar vapor generation and distillation system [95]	Texas, USA, Focused illumination of nano-particle (N115 carbon) with the help of Fresnel lens	With the help of Fresnel lens natural solar intensity of 1000 W/m^2 can be increased up to 9.93×10^{12}, steam temperature approximately 150 °C after 10min.	80	3.4	Nano-particle responds slightly less than nano-shell in the formation of vapor. In 20 s 0 °C water can reach 100 °C.
Nano-shell solar vapor generation and distillation system [95]	Texas, USA, Focused illumination of nano-shell (SiO_2/Au) with the help of Fresnel lens	With the help of Fresnel lens natural solar intensity of 1000 W/m^2 can be increased up to 9.93×10^{12}. The maximum steam temperature can be achieved by approximately 150 °C after 10min.	80	3.9	Nano-shell responds better in the formation of vapor as it utilizes solar irradiation as well as vapor pressure. In 5 s 0 °C water can reach 100 °C
Selective absorber floating structure solar steam generator and desalination system [96]	Massachusetts, USA, Spectrally suitable absorber (floating graphite based two layer) with localized heating	Maximum solar intensity utilized in the experiment are 1000 W/m^2 and 800 W/m^2, steam temperature achieved	85	2.9	This novel technique has floating solar irradiation absorber and the setup is well capable to minimize conduction, convection

(continued on next page)

Table 2 (*continued*)

Novel Solar Still	Work Regime, Specialty with Different Parameters	Maximum Solar Radiation and Maximum Temperature Conditions	Result		Concluding Remarks
			Efficiency (%)	Productivity ($l/m^2/day$)	
		100 °C (open atmosphere test conditions)			and radiation losses due small aperture opening for evaporation only.
Self assembly plasmatic absorber solar distillation system [97]	Nanjing, China, Confined pores filled with NPs (Au/D-NPs) makes an ideal solar absorber (two gold sputtered template)	Maximum solar radiation 1000 W/m^2 (under laboratory conditions), 98 °C steam temperature	90	10.3	The porous template filled with Au/D-NPs can absorbs 99% of solar irradiation energy and performs better observations with full-wave electromagnetic simulation.
Self assembly plasmatic absorber solar distillation system [97]	Nanjing, China, Confined pores filled with NPs (Au/NPs) makes an ideal solar absorber	Maximum solar radiation 1000 W/m^2 (under laboratory conditions), 98 °C steam temperature	90	7.7	The porous template filled with Au/NPs can absorbs 99% of solar irradiation energy with one sun intensity in lab experiment.
Nano-porous aluminum oxide membrane with Al NPs solar distillation system [98]	Nanjing, China, Aluminum based nano-porous plasmatic membrane confined with Al NPs suitable for high generation	Maximum solar radiation 1000 W/m^2 (under laboratory conditions)	88.4	11.4	Aluminum based plasmatic porous structure filled with Al NPs has 90% solar energy transfer efficiency and can better utilized for distillation process.
Optically porous carbon black NP membrane type solar distillation system [99]	Rice University, Houston, Texas, USA, Carbon black NPs suspended on floating membrane and porous structure makes convenient for better solar absorption	700 W/m^2 average solar intensity, peak ambient temperature and feed water or distilled water temperatures are 35 °C and 20 °C respectively.	53.8	4	Nano-particles increase the solar radiation absorptivity and porous medium increases the opportunity to condensate more vapor.
Flexible and floating anti-clogging graphite film solar distillation method [100]	University of Houston, USA, Porous polymer embedded with graphite flake and carbon fiber makes it anti-clogging, suitable for long period distillation	Maximum solar intensity utilized in laboratory is one sun (1000 W/m^2) and 43 °C smart material surface temperature.	62.7	3.8	Flexibility and anti-clogging tendency of the absorber material is the smartness in this system which results good distillation for long period of time.
Inexpensive narrow gap solar evaporator and distillation system [101]	Torino, Italy, A smart solar absorber (combination of copper coated with TiNOX, cotton, glass, polystyrene) with solar concentrator and narrow gap make this system efficient steam generator	Maximum solar intensity of 1 sun (1000 W/m^2) is utilized with 24 °C maximum ambient temperature.	90	10.4	Ten sun intensity achieved in the laboratory with the help of concentrator (integral part of solar distillation system) and narrow gap enhances the steam generation as efficiently as NPs.
N-stage hydrophilic micro-porous membrane type solar distillation system [102]	Torino, Italy, Micro-porous hydrophilic membranes separated by hydrophobic layers and suitable structure makes it convenient to absorb more solar radiation with multistep distillation process	Maximum solar intensity of 1sun (1000 W/m^2) is utilized under laboratory conditions with 55 °C and 45 °C maximum evaporator and condenser temperatures.	Efficient	24	Set up utilizes N-stages of micro-porous hydrophilic membranes for distillation process (in day time) and rinsing process (in dark time at night) for cleaning up the evaporative surfaces to cope up the distillation efficiency.

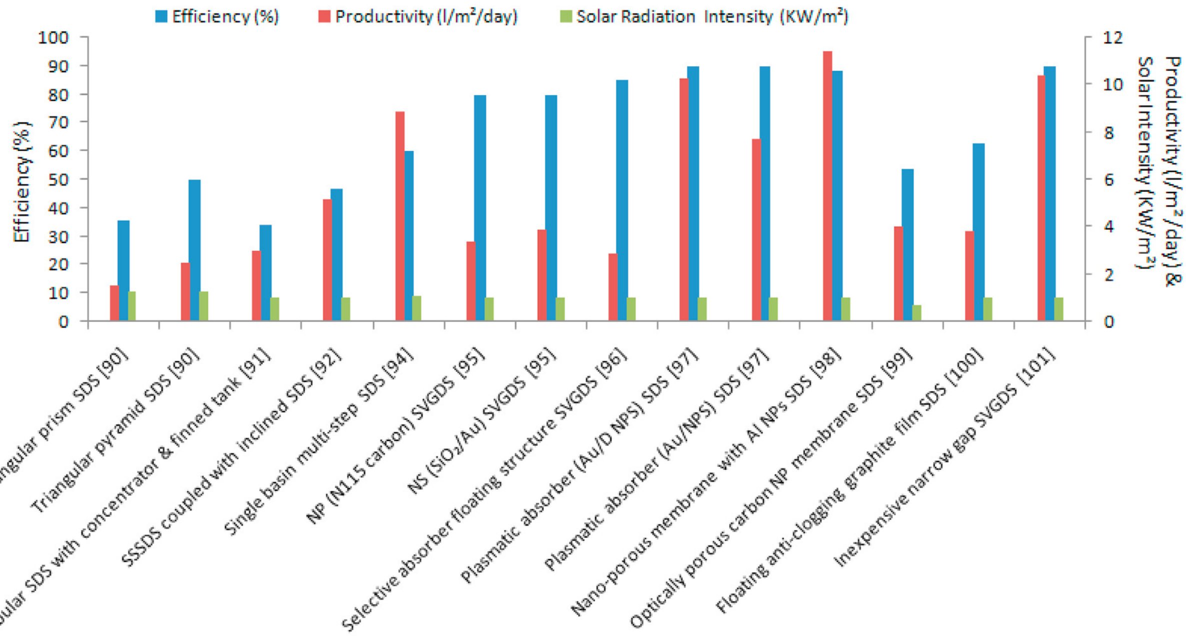

Figure 33. Variations in performance of various NSDSs based on its novelty, working principle, various physical parameters, designing concepts, material utilized (nano-particles, smart materials etc.) and solar radiation intensities as per open atmospheric conditions or confined laboratory conditions.

poly ethylene dioxythiophene and ploy styrenesulfonate on the surface. Experiment was under one sun intensity that can achieve 43°C material surface temperature with 62.7% distillation efficiency and distillation yield varies 4.8 l/m^2/day for pure water distillation and 3.8 l/m^2/day for saturated brine distillation.

Morciano et al. [101] developed a new equivalent efficient and high performance solar steam generator and distillation system as nano-strurctured system can do. It is a novel technique that achieves 85% of solar energy as well like nano-strurctured systems. This prototype contains systematic arrangement of copper coated with solar absorption material (TiNOx), cotton, and glass, polystyrene which produces greater stem due to localized heating of evaporative area, water distribution in a narrow gap and better thermal insulation around the system as shown in Figure 30. The experiment was conducted in laboratory conditions under 10 suns solar radiation intensity and showed 90% evaporation efficiency and 104 l/m^2/day distillate output (i.e. 10.4 l/m^2/day for one sun) with 24°C maximum ambient temperatures. This ultimate distillate yield corresponds due to high solar intensity (10,000 W/m^2) along with the better combination of absorbers integrated with narrow passage for applying concentrated heat.

Chiavazzo et al. [102] presented a unique low cost technique having N stages of distillation in day light time and on the other hand for cleaning the whole evaporative surfaces by rinsing at dark time (night time). The system has N stages of hydrophilic layers (solar absorber i.e. aluminum sheet coated with TiNOx) separated by hydrophobic micro-porous membrane that utilizes maximum solar radiations combined with different stages having absorber area 144 cm^2 as shown in Figure 31. The experiment and model has good agreement with its results i.e. 24 l/m^2/day distillate output and maintained the evaporator and condenser temperatures as 55°C and 45°C respectively.

5. Performance of new conceptual design solar systems (NCDSS)

Solar desalting and steam generating systems having specific design, working principle and technique to achieve its maximum output are studied by various researchers. Table 1 represents comparative information about specially designed passive solar desalting systems with single basin and Table 2 represents comparative information about novel solar desalting systems. Table 1 and Table 2 have been formed in such a way that all the considered solar distillation systems or steam generators can be presented and evaluated on the similar platform of yield output and efficiency basis under the considerations based on per unit area per day for maximum solar intensity for all the systems.

Some other similar studies have been presented by researchers [103, 104, 105] however; the considered systems have its individual identical design parameters, manufacturing concepts, components utilized and the working concept or technology. Further, economic, enviro-economic studies, energy matrix analysis, and performance observations for different systems along with special designs have been observed [106, 107, 108, 109, 110, 111]. But, yet a systematic approach has been reflected on having focused observations in which yield output, efficiency, design parameters and working principle considered for maximum solar irradiative intensity available for a particular clear day in respective climatic conditions or lab conditions have been included. Figure 32 shows the variations in performance of various NCDSSs and Figure 33 show the variations in performance of various NSDSs including efficiency, productivity and solar intensity.

6. Discussion

Various types of NCDSSs have been discussed along with NSDS and the overall performances of NCDSS are represented in Table 1 and Table 2 represents the performance of NSDSs. According to the variations in between efficiency and productivity reflects the effective performance of solar desalting system as shown in Figures 32 and 33 so that it's easy to recognize the worth full solar desalting system among all under the respective parametric conditions.

The overall observations show, cascade type weir solar desalting system with PCM or with no PCM, multi-step still with several absorbers are better but weir solar still with no PCM performs much better with 3.05% yield and 5.96% efficiency due to better utilization of localized solar heat to evaporate salty water quickly and instantly. Partitioned chamber SSSDS still performs well with 24% higher productivity for unit area basin in a day but mostly at mid time and represented in Figure 32. PSDS performs better because it does not require any solar tracking device for solar heat because of its design. It has average daily efficiency as 45% with distillate as 4.01 l/m^2/day at $ 0.065 per liter rate.

New conceptual designs with improved techniques with innovative novelty showed better performance, as nano-porous aluminum oxide membrane with Al nano-particles solar distillation system gives better productivity by 11.4 $l/m^2/day$ for one sun intensity due broad band absorption of solar radiation produces ultimate heat to evaporate and consecutively greater distillation. In the same way, self assembled plasmatic absorber (confined porous filled Au/NPs) solar distillation system and inexpensive narrow gap solar evaporation and distillation system performs better with higher efficiency by 90% because of its confined specialty i.e. for first system have closely packed NPs in membrane which prepares a porous structure suitable for absorbing all spectral solar intensities and for second case, system was focused through parabolic concentrator and this concentrated solar heat is received by smart material which is further utilized to evaporate water through a narrow gap under the influence of localized heat that helps in better performing the system as shown in Figure 33.

7. Conclusions

This work reviews NCDSSs and NSDSs and the following conclusions have been made as given below:

- Cascade type weir solar desalting system with and with no PCM performs better than other considered solar desalting systems based on productivity and efficiency. However, weir solar desalting system (cascade type) with no PCM performs optimum with 3% increased yield and 6% better efficiency.
- The overall performance of nano-porous aluminum oxide membrane with Al nano-particles solar distillation system gives better productivity with significantly better efficiency. As well as, self assembled plasmatic absorber (confined porous filled Au/NPs) solar distillation system and inexpensive narrow gap solar evaporation and distillation system performs better with higher efficiency.
- A specially designed solar desalting system with nano-particles combined with different assemblies prepares a plasmonic boundary which influences distillation performance at a greater extent.

8. Suggestions for future scope

In this review, NCDSSs and novel solar desalting systems (NSDSs) of passive type have been focused for solar desalting processes and steam generation performances, which should be more and more economic, feasible, self-sustainable and long lasting. All of the above, the following suggestions can improve the performance of solar desalting units.

- Develop more new designs to reveal economic, feasible, productive and self-sustainable system.
- Establish more temperature deviation between inner to outer surfaces.
- Utilize condensing and evaporative surface areas better.
- Solar tracking should be avoided for economy point of view.
- Develop a solar desalting system without the use of NPs but working with the same potential as with NPs can do.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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