American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-9, Issue-1, pp-307-329
www.ajer.org
Research Paper
Open Access

Solar Stills Performance and Productivity Enhancement Methods – A detailed Review

Eslam Ahmed[1*], Khaled Ramzy[2*], Tamer M. Mansour[2], Tamer M. Ismail[2*] and Mohamed M. Khairat Dawood[2]

[1] *Department of Mechanical Engineering, Sinai University, Egypt*
[2] *Department of Mechanical Engineering, Suez Canal University, Ismailia, Egypt*

Abstract: *Energy and water are the most essential elements for human's life. There is an acute shortage of both energy and water, especially in the third world countries. Most of energy demands in the world are met by fossil and nuclear power plants. A small part of energy demands is met by renewable energy technologies such as, solar, wind, biomass and geothermal energy. Many desalination systems have been established to overcome the fresh water lack problem, but most of these techniques need intensive energy source. Therefore, utilization of renewable energy for desalination is considered as the most significant and economical method for producing fresh water with small cost. Solar stills are a valuable devices that can be used for purifying of salty and brackish water for different purposes. In this study, a review of different factors that affecting the solar still productivity such as design parameters, climatic conditions and the operations methods has been studied. In addition the different enhancement techniques like stepped solar still, wicks, internal and external reflectors, internal and external condensers, using phase change materials and using nanoparticles has been presented. From this review it can be concluded that using stepped absorber increases the productivity and using hybrid solar still systems leads to increase the solar still performance and productivity.*

Keywords*: Solar energy; desalination; solar still; performance;productivity*

I. INTRODUCTION

The requirement of drinking water is asignificantcase in numerouszonesin the world. The enduringlack of drinkable water is the furthermostessential issue in the third world countries where usage of water for survival from pollutedresources causesriskyharmon health. Oceans are about 97.5% of the total amount of earth water the other 2.5% amount of water is available in the environment, iced places, and grounded water. Kalogirou, [1] reported that a creation of 1000 m^3 for each day of potable water needs 10^7kg of petroleum oil for each year. That amount of oil is very critical as it includes repetitive vitality cost which insufficient of the water lackworld zones could manage. Commonbusiness desalination factories utilize digging fuel in various countries which are rich with oil to supply the conventional resources of water source.Humans in numerous other regionsin the world have no money and no oil sources to let them to progress onmatchingmethod. Problems related to utilize of digging fuels, partly could be fixed by bearing in mindprobableusage of renewable energy bases like solar, biomass, geothermal, or wind energy. It occurs that the regions where water is wanted are enriched with sources of renewable energy. Most third world countries with hugeregions but owning no right to use to grid ofelectricityseem to be well familiar in renewable energies. Recently, most care has been given toutilize of renewable energylike solar energy as a basis for desalination, particularly in farzones.Desalination is a water actionprocedure that splits salts and impure particles from saline water to createwater at low total dissolved solids (TDS) to human usage. Solar energy couldbe made use in desalinationdirectly and indirectly way. Systems that integrate solar energy gathering systems with traditional desalination ones are named indirect ones. At these systems, solar energy is utilized to produce the heat essentialtodistillation or to create electricity that is utilized to feedessential electrical power for traditional distillationsystems for example multi effect (ME), multi stage flash (MSF) and reverse osmosis (RO). Systems that utilizedirectly solar power to createdrinking water are named direct systems [2]. Solar stills are regarded as one of the directtypes that utilize directly the solar energy to drive the desalination process. Solar stills utilize the same procedures that happen in nature to produces rain falls, specifically evaporation process and condensation process. The solar still consists frominclined apparent cover shields a blacked basin, water is heated up by the basin to maximize the solar irradiation absorption producing evaporation and condensation of water on the internal surface of the cover, and then it is collected in the collecting channel to use it. There are two kinds of solar stillsnamelypassiveand activesolar stills. In the passive one the main and only power source is solar energy while for active one an additional external thermal power is promoted into passive solar still for quicker evaporation. Excess thermal energy from any wasted power source can be used. There are many advantages of using solar stills as a distillation system such as:

- Made easilyfrom obtainableresidentresources.
- Verylow-cost maintenance.
- There is no requirement of skills for construction or operation of the still.
- Its operation is pollution free.
- Can reduce the dependence on rainfall.
- The slow motion distillation procedureletsdrinkable water only to evaporate and gather on the inclined cover, quitting all impurities behind.
- Can be operating on saline water or brackish one.

While the disadvantages of the solar stills are:

- Low productivity.
- Little efficiency.

II. PARAMETERS INFLUENCINGSOLAR STILL YIELD

There are many parameters thatinfluencing the solar still output. There are three main parameters have the straight effect on the solar still performance. The first areclimate parameters while the second aredesign parameters. The operating parameters are the third which contain all the ways which directly lead to enhance the performance of solar still; Table 1 shows these parameters in brief.

Table1: *Parameters affecting the solar still performance.*

Climate parameters	Design Parameters	Operating Parameters
Solar intensity	Type of solar still	Water depth
Ambient temperature	Orientation and Inclination of still	Water-glass temperature
Wind velocity	Insulation and cover inclination and material	Salinity of water
Sky conditions	Phase change material	Colouring of water
	Absorption area andsun tracking systems	Input water flow rate

2.1 Climate parameters

The first parameter isclimate parameter which contains: solar intensity, atmospheric temperature, windvelocity and sky conditions.

2.1.1 Solar intensity

Feilizadeh et al. [3] improvedmathematicalequations to expect the behaviour of a solar conventional still. Influence of sides of the still on the quantity of falling solar intensity on the basin water and all sides had been taken into attention. Time differences of the falling beam radiation on dissimilarportions of solar still were studied established on the current model. The theoretical model is compared with experimental records in the literature. The theoretical models showed a good agree with theexperimental outcomes. The results cleared that the maximum and minimum quantity of beam radiation on the rear and the side walls occur at middle day respectively. Theincident solar intensity increases during the morning and decreasesduring afternoon. Water received beam solar radiation ratiowas greater in summer than in winter. The resultsof summer, winter and whole year were 0.68, 0.38 and 0.55 respectively.A numerical simulation of solar in single basin desalination system in Iran was investigated by Afrand et al. [4]. The area of still was 1 m^2 with a glass cover inclination angle 25° to get additional solar energy. The glass cover, water interface, humid air and bottom temperatures were calculated by using numerical method. The results of July and December were compared. The results demonstrated that, the productivity in July is greater than December also the solar still efficiency was supreme at noon and the change in efficiency and the still output valueswasrelated with the solar radiation.

2.1.2 Wind velocity

El-Sebaii [5] calculated numerically the impact of wind on the yield of dissimilarsolar stills designs by developing computer program on usual summer days and winter days. Numerical calculations have been performed to correlate productivity with wind speed atchanged masses of water and various thicknesses of streaming water for the different designs. The results concluded that wind speed is not dependenton the shape of the still.With increasing wind speed the water and glass temperatures dropsbecause of heat losses in the still cover. The solar still outputwas proportional with wind speed and the brine heat capacity with 10m/s in summer and 8 m/s in winter.A regenerative solar still was mathematically modelled by Zurigat et al. [6]. The unit contains two effects with facility for water cooling the glass coverto stream in and from of the other effect causing an improving in the difference in temperatures betweenwater and cover. The theoretical model of the systemwas compared with another conventional one under identicalwind speed. The results presented that the yield had been increased by 50% more than conventional still when the wind velocity had been amplified from 0 to 10 m/s.

2.1.3 Ambient temperature

The influence of ambient temperature changes on solar still productivitywascomputedby utilizing the theoretical model of Malik by Nafey et al. [7]. An equation was demonstrated to calculate the yield of conventional solar still. The mathematical equation communicates the independent and dependent variables which calculate theoutput. The mathematical results presented that a good agree with the experimentoutcomes. The mathematical calculations investigated that ambient temperature has a slight enhancement in productivity of 3% when the ambient temperature increased by 5^{o}C.Al-Hinai et al. [8] used mathematical model under manydesign, climatic and operational parameters to discuss the impact of ambient on the still production. The theoretical results demonstrated that growing the ambient temperature lead to improve the output of the solar still slightly.Increasing the value of the ambient temperature from 23^{o}C to 33^{o}C increases the still productivity by 8.2%. Also the cost analysis showed that cost of potable water with simple solar stills was16.3 \$/m^3.

2.1.4 Sky condition

Hegazy [9] determined experimentally the influence of dust gathering influence through glass cover with various inclination angles. Global correlationamongfactor of dust, inclination angle and number of experiment days with spread of ± 6% derived from data relating to decrease in glass transmittance was introduced. The results concluded that dust accumulation reduce the glass transmittance and horizontal glass cover has the most contaminated dust rather than vertical glass cover with a combination of fine and coarse dust elements.The effect of seasonaldust depositionon the output of a solar distillation system was studied theoretically by El-Nashar [10]. The modelpresented calculations for the system performance. The results concluded that dust formation caused a drop in the transmittance of theglass by 10 to 18% in a monthcaused a huge fall in productivity.

2.2 Design parameters

The second parameter arethe design parameters which contains many factors such as: the type of solar still, absorption area, phase change materials, insulation thickness, orientation of still, cover inclination angle,cover material and sun tracking systems.

2.2.1 Type of solar still

Dwivedi and Tiwari [11] tried to compute thecoefficients ofheat transfer insidepassive single slope single effect and double slope single effectsolar stills in winter season and summer season.They used water depths of 0.01m, 0.02m and 0.03m byutilizingsomemathematical models like Dunkle's, Kumar and Tiwari, Adhikari et al., Chen et al., Clark's and Zheng et al. models as shown in Fig. 1. The results showedthat the Dunkle's model is the best model between the different models. Dunkle's model achieves the best agreeamong theoretical and experiments results.

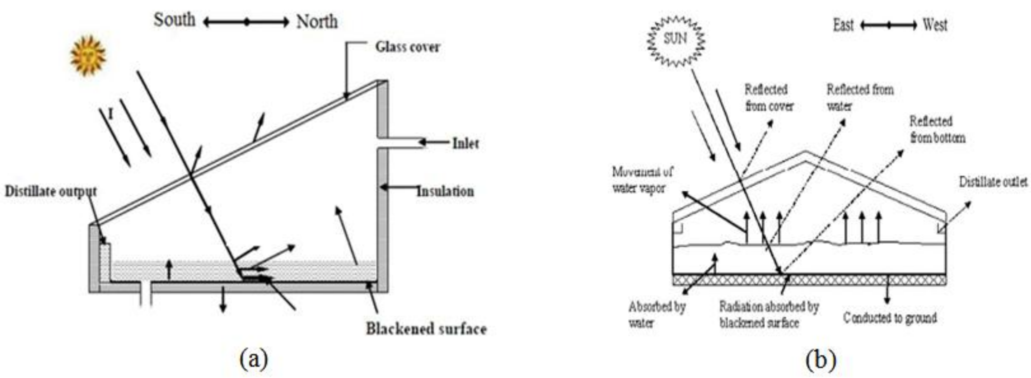

***Fig. 1:** (a)-Single slope solar still (b)-Double slope passive solar still [11].*

Mord et al. [12] examinedexperimentations in active solar still (double slope still attached with a flat collector). The effective area of the double slope solar still and flat plate collector were1.20 m^2 and 1.35 m^2 respectively. The results presented that active solar still enhanced the drinking water output of 10.10 l/m^2 per day and enhanced the thermal efficiency by 80.60%. While the yield of conventional still was 7.80 l/m^2 per day with thermal efficiency of 57.10%operating under identical operating conditions.A mathematical model in transient mode was calculated for a three layered basin solar still by E1Sebaii [13]. The energy equation for the still wascomputed analytically utilizing the elimination technique. The system performance was investigated by computer program on identical summerand winter days for various water masses in everybasin layer. The results concluded that theoutputdrops with increasing in water mass in everylayer. The daily output reaches supreme value for the leastwater amountin cooperationoflesser and mid basins.

2.2.2 Absorptionarea and heat storage

The energy stored by the heat storage materials can be utilizedduringdarkness and through the cloudy days which ensure continuous production of distilled water in the absence of sun rays. Some of solar radiationdropping on the still is absorbed by the storage materials as a heat which led to decreasing the water temperature of still through the day daylight. Heat is released through the night keeping the still to produce drinkable water through the night. These heat storage materials lead to an improvement of sensible heat storage capacity and water surface area. These materials such as jute clothes, sponges, fins, flat perforated plate, and cottons. Also increasing the absorption area between water and basin layer leads to an enhancement in the output of solar still.Experimentations in conventional still with jute cloth were done by Sakthivel et al. [14] as shown in Fig. 2. The lowestside of the jute cloth is immersed into the water. Thebasin area was0.5 m^2 with glass covertilted at angle of 25^o with the horizontal. The behaviour of the modified still was associated with a still with no modificationat equivalent time with variousamounts of water. The results showed that with 30 kg of water, the jute cloth stillproduction was 20% extra than the passive still. The supreme of modified still efficiency was 8% higher than the efficiency of the conventional still.

Kabeel [15] experimentally examined pyramid shaped still and the cost analysis of this shape. The still basin wasshaped in concave form with a square shaped area of 0.24 m^2 as shown in Fig. 3. The thickness of wick material sited on the concave surface was 5 cm. Cost analysis of the pyramid shaped still wasalso calculated. The results cleared that the yield of the still in 24 h was 4 l/m^2 and the efficiency was 45% while the one distillate litre cost was 0.065 $.Omara et al. [16] enhanced the solar still behaviourby enlarging the still absorber area. Three stills were designed and manufactured todiscuss the still production enhancement. The first stillwas a conventional, the second was a finned type still, whilethe third still was a corrugated solar still. The behaviour of three stills was verified for equal water depth. For the finned still,the yield improved40% and 21% for the corrugated still related with the conventional solar still. The efficiencies for the conventional, finned and corrugated stills were 35%, 41% and 47.5% respectively.

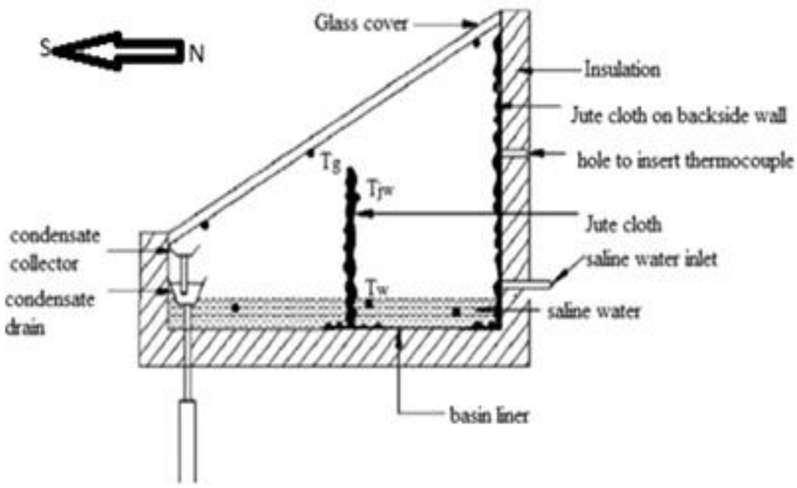

Fig.2: *Schematic diagram of jute cloth solar still [14].*

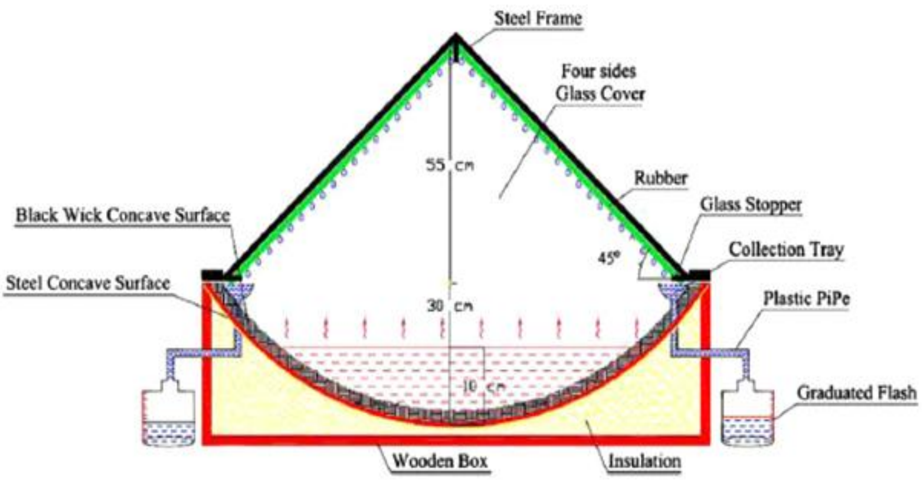

Fig.3: *Concave wick pyramid still [15].*

2.2.3 Phase change materials (PCM)

A solar still is placed above a concentrator by Arunkumar et al. [17]. Copper balls with diameter of 1.2 mm are positioned in saline water. Every ball had a minor hole on the top to permit filling wax with paraffin which wasconsidered as PCM as shown in Fig. 4. Once filling, the hole was closed with rubber cork. The yield of the modified solar still without and with PCM was 3.5 l/m^2.day and4.5 l/m^2.day respectively.

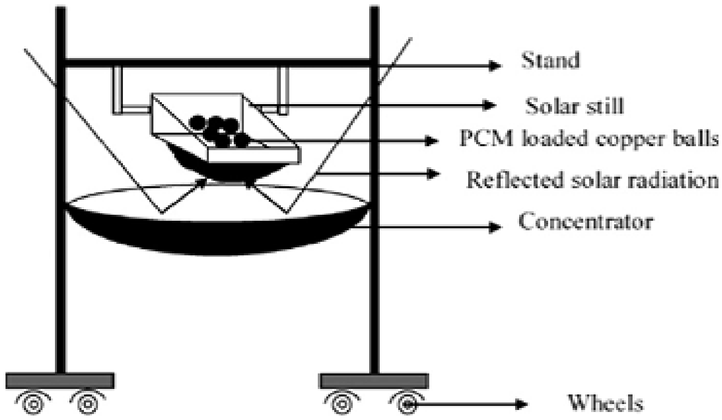

Fig.4: *Schematic of a still coupled with PCM and concentrator [17].*

Ansari et al. [18] remarked the influences ofstorage ofheat on the distillationby utilizing conventional solar still coupled with a PCM below theabsorber. The heat created throughout the day time was kept in the PCM for far ahead utilize incloudy days andnight. The results concluded that the select of the PCM be subject to the highest temperature reached by the basin water.Kabeel et al. [19] studied theoretically a comparative study amongvarious PCMs on thebehaviour of the conventional still. Inorganic and organic PCMs with their all thermo physical features also the melting temperature wasdiscussed. Besides, economical discussions for all chosen PCMs had been discussed. The results concluded that the inorganic and organic PCM had the maximumoutput and minimum cost. While organic PCMwas recommended because of its lower negative influence on the environment. Besides that, the PCM thicknesshad no significantinfluence on the output. It was also recommended because it gives the least cost.Kabeel and Mohamed [20] improved the solar still performance by addition of PCM as a heat storing medium to a conventional still. They used two identical solar stills, the first solar stillwas a conventional as base for comparison while the second was a conventional still with PCM. The two solar stills had beenexperimentally fabricated, testedand cost analysis had been also calculated. The results concluded that theoutput for solar still coupledwith PCM wassupreme by 67%–68.8%more thanthe conventional still. The estimated cost of 1 L of fresh water was about 0.24 LE for solar still with PCM and 0.252 LE for the conventional still.

2.2.4 Insulation and cover materials of solar still

Single and double basin equal area solar stills were built and tested by Al-Karaghouli and Alnaser [21]. One of the stills sides was insulated while the other was not. The results presented thatin June, double basin still whichthe sides were insulated, theyield was 1.76 l/day while for the case sides were not insulated;the productivity was 1.41 l/day. For the single basin still, the June daily yield was 1.28 l/day in the still with sides insulated and 1.11 l/day for the still with sides not insulated. In February, March, April and May, the meanyields were 1.05, 1.34, 1.42 and 1.63 l/day respectively for theinsulated sides' stills and 0.84, 0.94, 1.05 and 1.18 l/day without insulated sidesfor the double basin still respectively. For single basin still, the productivity was 0.72, 0.77, 0.89 and 1.01 l/ day with insulated sides, respectively and 0.66, 0.75, 0.81 and 0.95 l/daywithout insulated sides respectively.Mohamad et al. [22] made experiments and economic studies on three irregular solar stills with dissimilar insulation at sameconditions. The results presented that the yield of the irregular solar still with constant thermal insulation improvedby 35% as the average air temperature raised from 17 to 30°C at constant solar radiation. For greatest thermal insulation, polyurethane rigid foam material insulation introduces the best waterproduction from the irregular stills. While the financialopinion, the sawdust insulating material introduces the least cost for potable water output.

Ghoneyem and Arifllerі [23] fabricated and examined four single effect solar stills. Three stills had a glass cover of various thicknesses (3, 5 and 6 mm); the fourth still cover was plastic. Results showed that the variation of total transmittance of the cover and film ofcondensate was insignificant forincidence angle up to 60° and for regions with latitudes of 0° and 45°. The still subjected to the smallest glass cover thickness had the best rate of production up by 15.5%. Mean daily hourly output of still with 3 mm glass cover thickness was about 0.03 kg/m^2 greater than that still with 5mm glass cover thickness and 0.04kg/m^2 greater than that still with 6 mm glass cover although the productivity gained from still with the plastic cover was the smallest value. The obviously reduction in production even with the high transmission of the plastic in dry conditions is because of fogging and dripping from the cover back to the water basin. So, plastic should not be used as a cover.Akash et al. [24] discussed experimentation resultsfrom the conventional type solar stills. The solar stills with the same basin area, glazing material, thickness of insulation and glass cover area and thickness. The experiments were conducted by utilizing solar still with different cover inclination angles of 15, 25, 35, 45 and 55^o. The results showed that the optimalinclination anglewas 35^{o}which achieves the normal solar radiation on the cover all the months of year.A conventional solar still had been theoretically modelled using fourth order Runge–Kutta technique by Aybar and Assefi [25] to discuss the impact of water deepness and the tilt angle of cover on the solar still outputatlocal atmospheric condition. The results demonstrated that the best depth of water gives the maximum production rate was the minimum one. Furthermore, the best glass cover anglewasequivalent to the latitude of place of setup.Thesystem total yield was gained 5.3 kg/m^2.day. The theoretical results are valid with an experimental result in the literature. The relative error of 3.37% is remarked.Theoretical studies on heat transfer byradiation inside stepped solar still had been developed by El-Samadony et al. [26]. Factor ofradiation shape amongglass cover and water had been calculated. The influence of glass cover inclinationand solar intensityin view of the factor ofradiation shape were demonstrated. The results demonstrated that the effect of factor of radiation shape on the solar still thermal behaviour is remarkable on the output of step stillespecially at little solar intensity with great glass cover tilt angle desired to be equivalent to the location latitude.

2.2.5 Orientation andinclination of the still

Abderachid and Abdenacer [27] theoretically investigated the orientation influence on the behaviour of a symmetric double basin solar still. A program had been modelled to calculate and compare the influence of the four orientations on the behaviour of a symmetric double slope and asymmetric double effect solar stills to catchthe best design parameters for both of them under local. The data essential for the theoretical computer program were used from measured meteorological data. The deduced results concluded that orientation isnoticeable parameter in enhancing the solar still performance. The stability of solar radiation had been noticed in the south–north orientation because Algeria locates in north hemisphere leads to greater reception of solar radiation by both two stills, on the other handit'smaximum for the asymmetric solar still. Kudret [28] studied the performance parameters at steady state situation of multi effect solar still. The system fabricatedfrom flat collector combined with multisurfaces of evaporating and condensingas shown in Fig. 5. The system had beenverifiedand compared in condition of natural solar radiation and simulated electrical heating with conventional still. The results cleared that the output of two effects solar still was 4.20 kg/day.m^2 for fan cooled component and 3.37 kg/m^2.day for natural convection mode.The output of conventional solar stillwas 2.88 kg /day.m^2.Experimental studies on inclined solar still utilizing black cloth wick and black fleece wick stationary on the basin were studied by Aybar et al. [29]. The still had beenestablished and verified atlocal atmospheric condition. The still had inclination angle of 30°. Black cloth wick and black fleece wick makes water hot. The feed water went in the basin ran down creating a layer of water on the basin. The results cleared that utilizing of black cloth wick and black fleeces wick improved the output of the still three times over inclined basin solar still without black cloth wick and black fleece .Sodha et al. [30] tested a multi wick solar still. The jute cloth pieces had beenlocated in growing length divided by tinny black polythene sheets, resting on foam insulation sustained by nylon ribbon. The results showed that the output were 2.50 l/m^2 day and34% efficiency. The cost less than half forconventional type still at the same area, more output even in cloudy day and no shading influencebecause ofminorelevation of the wall sides.

2.2.6 Sun tracking systems

Abdallah and Badran [31] developed a sun tracking solar still to enhance the performance of a conventional solar still. Two identical stills were built; one of them was fixed as a reference for comparison and the other was integrated with a sun tracking apparatus. Utilizing the sun tracker leads to water temperature and evaporation rate and yield increase. The results concluded sun tracking stillenhanced the efficiency and productivityby 2% and 22% respectively. Also the cost value for fabricating the system was 282$.Three different experimental studies under local climatic condition by utilizing a tubular solar still (TSS) were done by Mohamed [32]. The first experiment consisted of a rectangular trough full with saturated water black clothTSS. The second experiment was about using TSS with a half cylindrical shape trough with no clothing. The third experiment was about the second experiment in addition to a parabolic concentrator solar tracking system (PCST-TSS). The experimental results concluded that third experiment gives the best productivity and cost among the three experiments. The PCST-TSS output was improved by 676% with 45.50 % cost reduction per litre (CPL) compared with the first experiment. The gained productions were 4.20 l/m^2.day for the first experiment, 3.60 l/m^2.day for second experiment and for third experiment 3.53 l/m^2.day with efficiencies equivalent to 36.65%, 30.22% and 28.54% respectively.

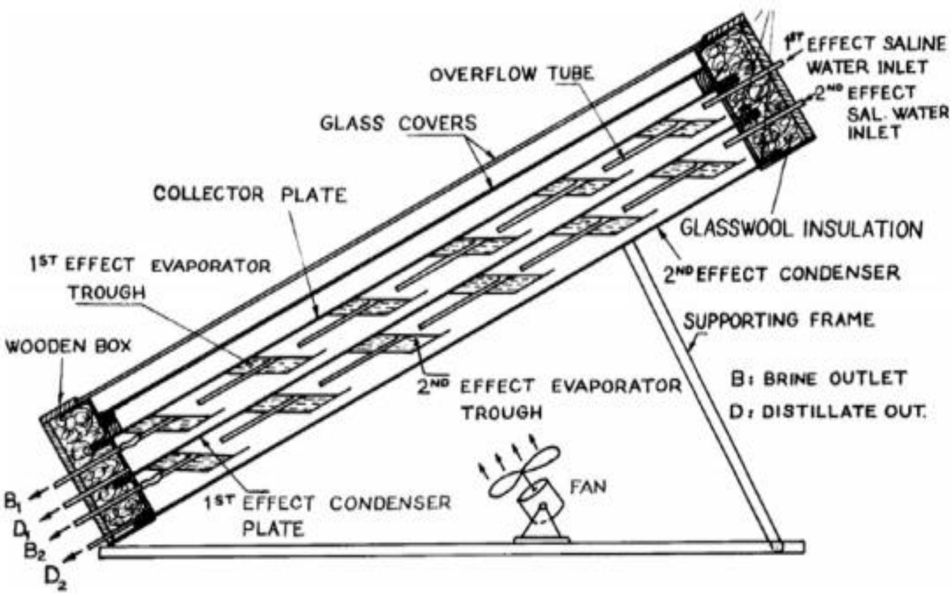

***Fig.5:** Schematic of tilted multi-effect solar still [28].*

2.3 Operating parameters

The third parameters are the operating parameters including water depth, difference in temperatures among water and glass cover, salinity and colouring of water.

2.3.1Water depth

Experimental studiesinpassive and active solar stills atseveral deepness of water (0.05 m, 0.1 m and 0.15 m) are researched by Tripathi and Tiwari [33]. The results concluded that the coefficient ofconvective heat transfer among the basin and inner glass cover be influenced by the water amountat the basin. For greater depths of water, the output was great after the sunshinebecause of heat storing impact.Experiments in double and single slope solar stills were done at the same time by Rajamanickam and Ragupathy [34]. The two stills had two identical areas.Tests were studied at various depths of water. The results demonstrated that the increase inamount of water was inversely proportional with the solar still output. The highest output was 3.10 l/m^2.day and 2.30 l/m^2.day for the double slope and single slope still respectively achieved at the lowest water depth.Abdul Jabbar and Ahmad [35] tested a conventional solar still at five various water depths; 1 cm, 4 cm, 6 cm, 8 cm and 10 cm. A relationship ($y = 3.17d^{0.19}$) was established to associate the yield (y) with water depth (d). The resultsdiscovered that the yield of still had beenaffected by the water depth up to 48% for depths fluctuating from 1 to 10 cm.Anil and Tiwari [36] stated investigation on the annual and the seasonal performance atseveral water depths in conventional solar still with inclined cover 30^o. The results concluded that the highest daily yield in every month for minordepth ofwater throughout the year. The daily productivity for theleast water depth had been found to be the maximum, 32.57% in summer and 32.39% in winter. The annual productivity becomes constant atdepths of water more than 0.10 m.

2.3.2 Water- glass temperature

Kumar et al. [37] tested experimentally a hemisphericalsolar still with and withoutwater cooling system. The basin was insulated with sawdustwith while the sides were insulated by glass woolas shown in Fig. 6. Separate systems were made for flowing and gathering the flowing water at the upper surface of cover. The results demonstrated that the conventional solar still efficiency was 34%; while the still with coolingmethod efficiency was 42% atwater rate offlow 0.01 l/min.Abdulla [38] experimentally compared a conventional still with a stepped still. Various modifications like flowing warm air below the steps by utilizing a combination of blower and solar air heater as shown in Fig. 7, also using of aluminium filling below the absorber plate had been studied. Influence of water passing over the cover is also studied. The conventional and the stepped still had the same area and water depth. The results presented that the step solar still without any modificationsefficiencywas 48% and 34% for conventional still. The efficiency was 52%, 55%, and 59% for air preheated, aluminium filling and glass cover cooling respectively.Badran et al. [39] coupled conventional solar still with flat plate collector utilizingsaline and tap water to study the influence of adding the collector to the conventional stills at local atmospheric conditions as shown in Fig.8. Different operation conditions such as: still coupled with the collector all the day period, still attached with the collector in sunlight only and still without the collector all the day had been discussed. The results concluded that still coupled with collector leads to increasing in the water temperatures which enlarge the difference in temperatures among the water and glass cover. The still coupled with the collector for 24 h, theoutput was increased by 231% and efficiency was reduced by about 2.5% relatedto the alone still. The productivity increased only by 2% in the case of coupling the collector with the still during sunlight period compared to the alone still.A solar still with two glass cover effects had been researched experimentally by Yousef and Mousa [40] as shown in Fig.9. Cooling water was flowed in and out from second effect. The water and glass cover temperature varianceenlargedat first effect. The results showed that the productivity of the modified still was 20% greater compared with the non-modified still. Ragh et al. [41] analysed thermal theoretical model consisting of conventional solar still joined with natural circulation evacuated tube collector (ETC). The general behaviour of the solar still had been calculated theoretically throughout summer day. The theoretical results concluded that integrated natural (ETC) with conventional still raised the watertemperatureto 80°C with rate of circulation up to 44 kg/h in single tube which leads to getting daily productivity about 4.0 kg/m^{2}at 0.03 water deepness. The energy and exergy efficiencies were 33% and 2.5% respectively. The output was greater with 10 evacuated tubes at depth of water 0.03 m.

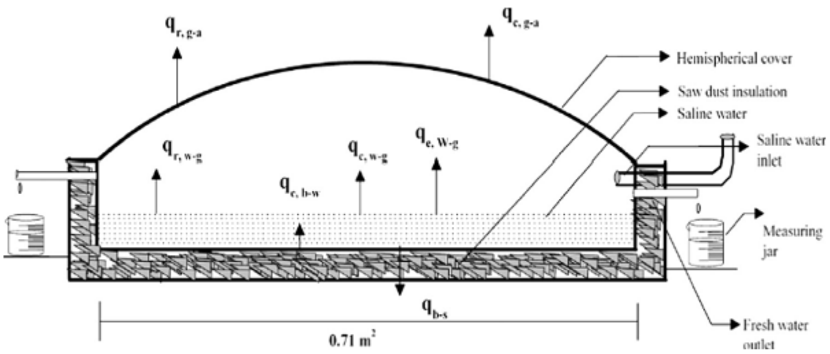

Fig.6: *Hemispherical solar still [37].*

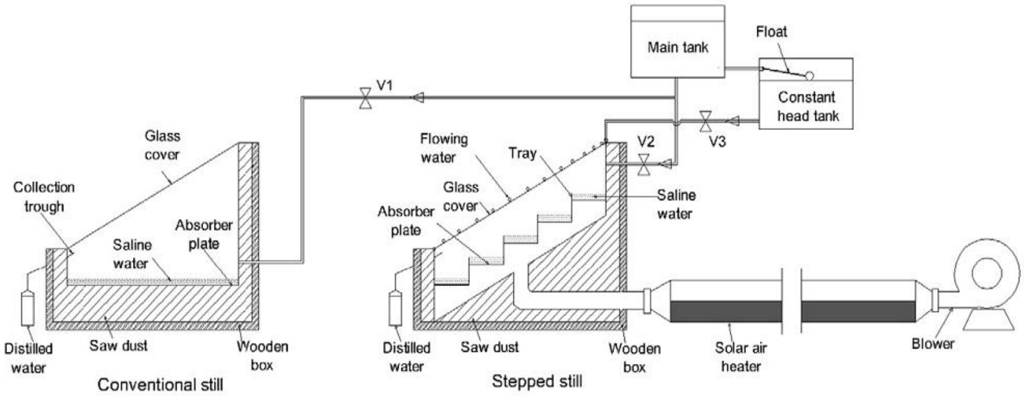

Fig.7: *Schematic of test rig [38].*

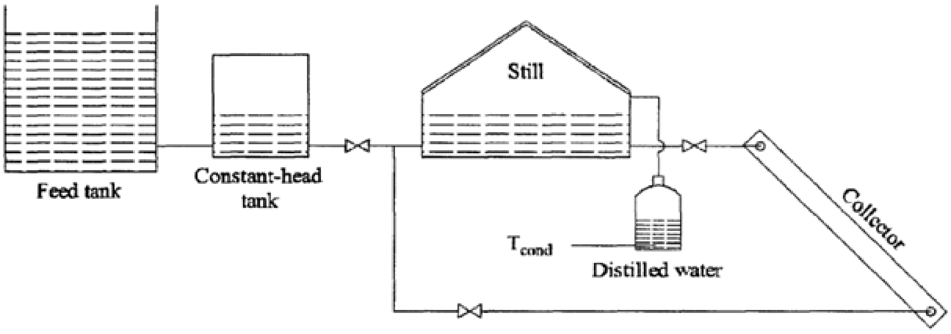

Figure 8: *Schematic of test rig [39].*

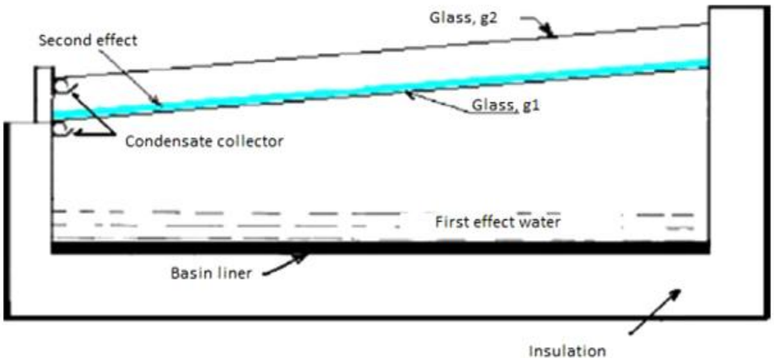

Fig.9: *Regenerative solar still [40].*

2.3.3 Salinity of water

Nafey et al. [42] explained solarscheme for desalination consists from solar collector with flash part. The system was examined at constant rate input power as a sun simulator. The influence of surfactant like sodium lauryl sulfate in somewhat minor amounts of concentration with a minor mass of solar distillation procedurewas studied. The results cleared that a slight quantity of surfactant additive creates the max brine temperature (MBT) significantly greater. The increase percentage in the outputwas 0.7%, 2.5%, 4.7% and 7% at additive concentration the same to 50, 100, 200 and 300 ppm respectively. An increase in the surfactant concentration higher than 300 ppm had no effect on the system output and MBT. Concentration ofsurfactant higher than 400 ppmdropped the output by 6%.Indoor and outdoor experimentationswere investigated to discuss the influence of feed flow ofwater and salt concentration on the production of still by Mahdi et al. [43]. A tilted wick-type solar still was coupled with charcoal cloth and evaporated material for saline water transport. The results demonstrated that increased the flow rate of water input decreased the efficiency of the wick-type solar still. In indoor testing, the efficiency decreased from 38% to 20%whenconcentration of NaCl saltaugmented from 0% to 10% by weight.

2.3.4 Colouring of water

Akash et al. [44] designed and manufactured single effect solar still made from stainless steel to discuss the influence of using dissimilar inks and dyes on the behavior of the still. Three different type materials were used with the same amount of water in each run. The first one was black absorbing rubber mat, while the second one was black ink in water solution.The third run was black dye in water. All runs were referenced to therun was conductedwith no absorbing material in the water. The results cleared that the water productionhad been improved by 60% when black dye was utilized and about 45% when black ink was used. For black rubber mat, the enhancement was 38%.Anil [45] studied numerically and experimentally the result of addition dyes to a solar desalination unit. Finite difference method is utilized to solve the model. For the experimental study, two equal solar stills was fabricated and tested. The used dyes in the experiments were black methylamine, red carmoisine and dark green at different concentrations. The theoretical outcomescleared an agreement with experimental results. Usage of dye solution increased the output by 29% with 172 ppm concentration.

2.3.5 Input water flow rate

Tabrizi et al. [46] built weir cascade solar still consisted from fifteen steps as absorber plate with several flow rates to develop the daily yield of it as shown in Fig. 10. The result showed a fall in daily output equal to 7.4 kg/m^2.day when the flow rate was augmented. Due to the steps, the waterresidence time at the still augmented.Two cascade type solar stills with and with noheat storingunit were used by Tabrizi et al. [47] to test the result of water flow rateabove the absorber on the productivity. The usage of weir on every step cause an increasing in the residence time of water and fall in water flow rate which thin water layer covers the evaporation surface. The results showed that lowering rates of flow causes unfitting water spreading, preventing sustain a constant water film above the surface of evaporation. The highest productivity at least possible rate of flow of 0.06 kg/min for stills with and with no heat storage system was 4.9 and 5.2 kg/m^2.day respectively.El-zahaby et al. [48] introduced new experimental shape of solar still with flashing chamber. The influence of usage the spray system was studied at different three water rates 3.64, 4.0 and 9.33 l/h on the still behaviour. The results demonstrated that thermal efficiency was 25, 26 and 40% for water flow rates 9.33, 4.0 and 3.64 l/h respectively.

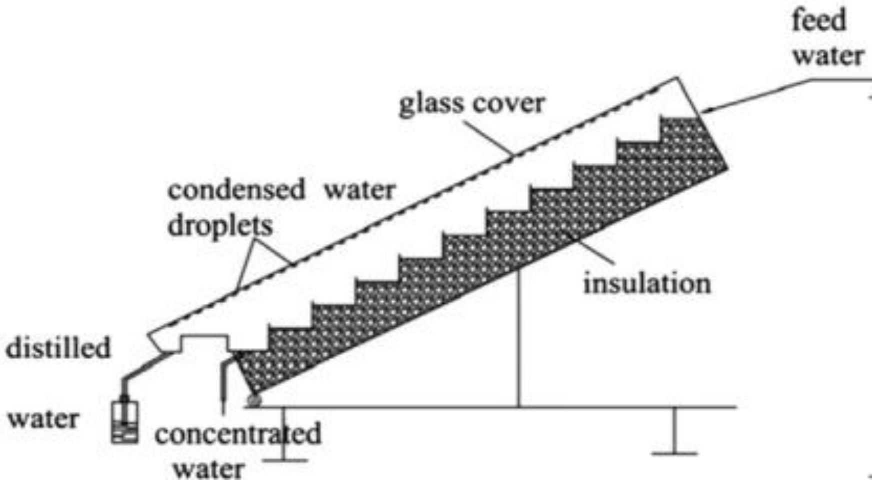

Fig.10: *Weir cascade solar still [46].*

III. OTHER DESIGNS OF SOLAR STILL

Ibrahim et al. [49] investigated solar still working under sub atmospheric pressure to minimize the required energy necessary to the desalination process. The system composed of solar still coupled to an outside condenser which was cooled byairwith a vacuum pump to present the vacuum condition in the solar still as shown in Fig. 11. The experimental results and cost analysis from modified still were related with the results of a conventional one. The results presented that maximum efficiency of 40%. There was an improvement of 16% and 30% in a comparison with the conventional still output and efficiency respectively. The output cost per litrefor conventional still was 17% lesserthan the modified solar still.Nassar et al. [50] tested experimentally a solar vacuum distillationunit. Concave mirror had been utilized to focus the solar radiation. The still worked at pressure of 25 kPa absolute. A condenser was used to condense the exit vapour and collected it. Results demonstrated that the production was 20 l/m^2.day of the vacuum still whilefor conventional still was 5 l/m^2.day. The yield of the vacuum still enhanced by 303% relatedto the conventional one.Hansen and Murugavel [51] increased water surface area presented for evaporation of water by integrating inclined solar still with conventional solar still andwarm water storing tank as shown in Fig. 12. The results determined that the daily output of the combined still with finnedabsorber was 74.3% higher than the inclined still and 34% higher than the inclined still combined with flat absorber. Thecombined still with warm water storing tankefficiency was 15% more than the still with nowarm water storing tank.

Rahbar et al. [52] fabricated and tested triangular and tubular solar stills on typical winter days with same effective area form both of them. The results concluded that in the experiment second day, supreme efficiency of 41% for tubular solar still and 35% for triangular solar stills. The mean water output in one week was 1.6 l/m^2 for tubular and 1.34l/m^2 for triangular solar stills.Sathyamurth et al. [53] examined the factors which have the significant effect on a triangular pyramid solar still performance with cover inclination angleequal to 13°. The studied parameters are convective, evaporative heat transfer coefficients, difference in temperaturesbetween the surfaces of evaporative and condensing, condensing area. The results presented that the importance of coefficients ofevaporation and convection heat transfer in designing any solar desalination setup. The influence of difference in temperatures among the surfaces ofwater and glass coveris also significant in optimization the range of working temperatures. New hybrid distillation methodology including evacuated solar water heater to calculate the distillate continuous production, jut geotextile and solar still were presented by Omara et al. [54]. The unit consisted of two typical solar wick stills and one conventional solar still. One of the wick stills was double layer and the other was single layer as shown in Fig. 13. Results concluded that two solar wick stills had faster response to the solar energy. It also had more operating temperatures and efficiency than the conventional one. The double layers square wick had the highest productivity at 20° base tilt when compared to the conventional and plane wick stills angle compared to 30°.Madhlopa and Johnstone [55] modelled and calculateda conventional solar still with disjoined condenserperformance. The system contained three basins, one of them (basin1) was located in the evaporation chamber and the others (basin2, 3) were in the condenser. The glass cover over basin 3 was an opaque cover. The upper portion of the cover had been protected from sunrays to preserve it away from the solar radiation as shown in Fig. 14. The performance of system had been related with the performance of a conventional still at identical conditions. Results concluded that the production output of the modelled still was 62% more than the conventional type.

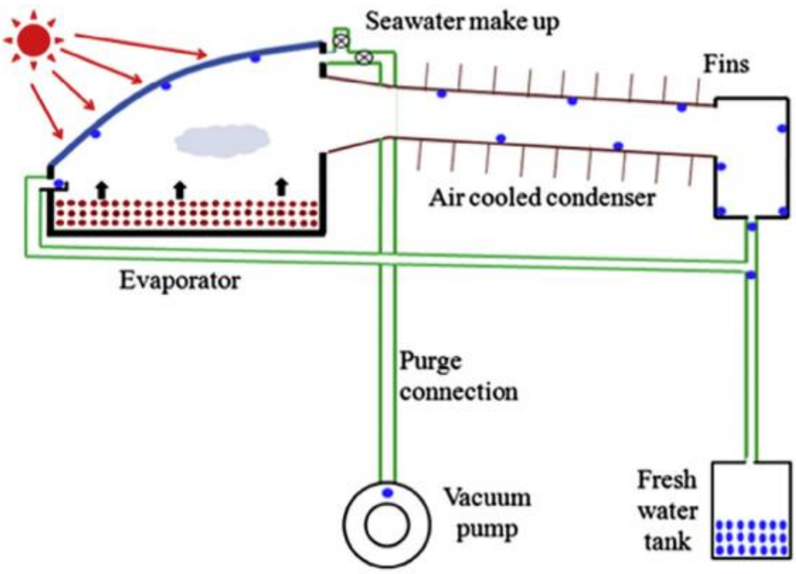

Fig.11: *Vacuum solar still [49].*

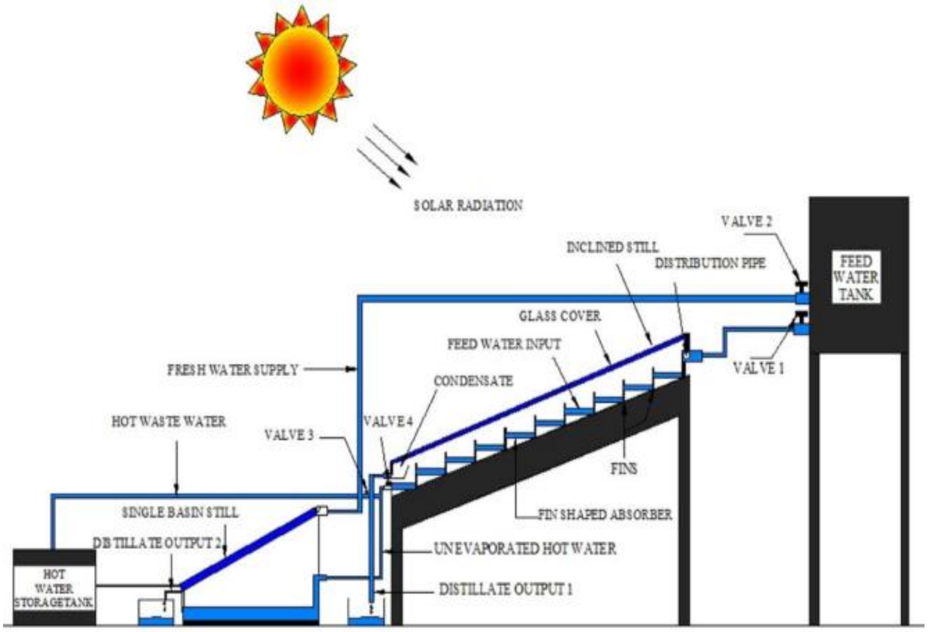

Fig.12: *Schematic of integrated desalination system [51].*

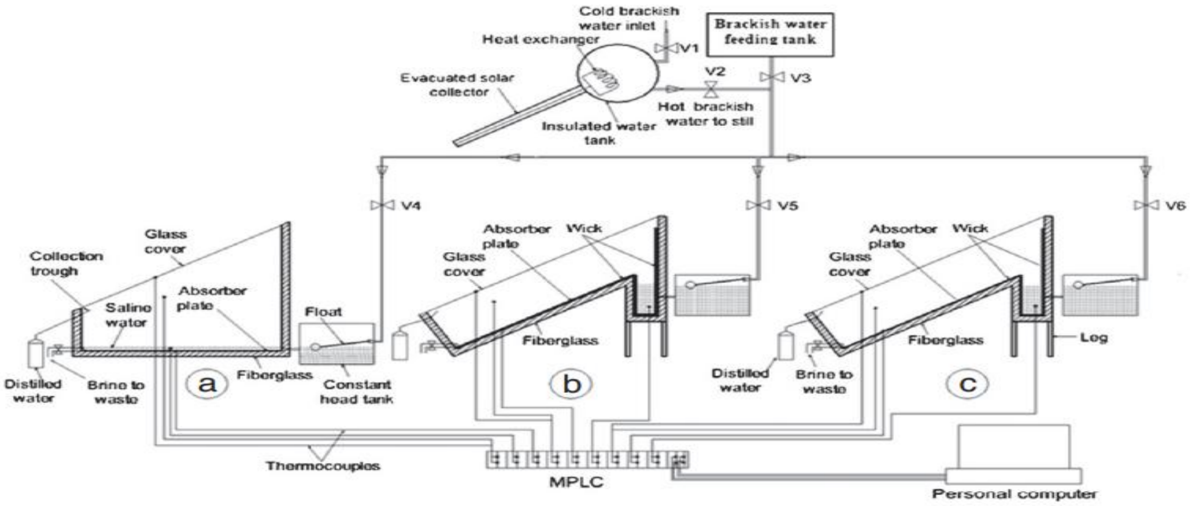

Fig. 13: *Schematic of (a) Conventional still. (b) Double layer wick still. (c) Single wick solar still [54].*

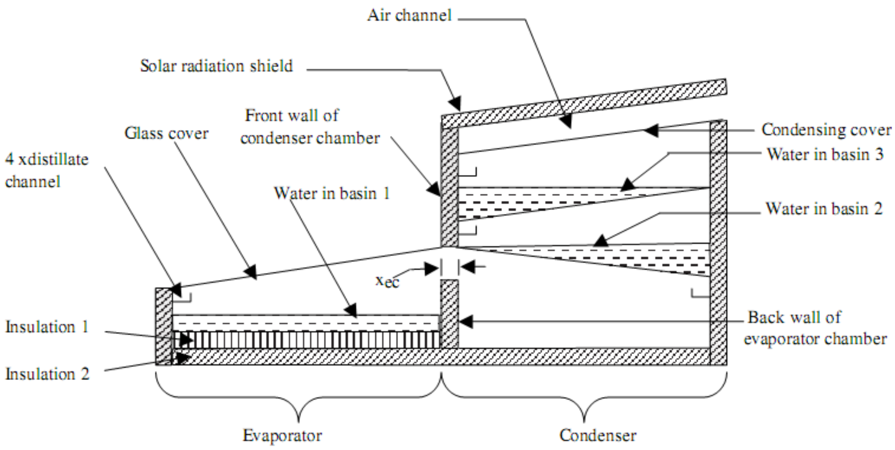

Fig.14: *Schematic of separate condenser with passive solar still [55].*

Movable thermo electrical solar still coupled with an outside reflector andcondenser had beensuggested by Monowe et al. [56]. The system had been constructed in order to reduce the latent energy of condensation losses. The latent energyhad beengathered in condenser and reused in saline water preheating process or in operating the still throughout dark. The results demonstrated that the efficiency reaches 77% when the preheated saline water had beenutilized in home purposes. The efficiency reached to 85% when the preheated saline water wasutilized at night operation.Eltawil and Omara [57] coupled conventional still with spraying unit, a flat solar collector, outside condenser, solar air heater and perforated tubes to improve the output of the conventional stills as shown in Fig. 15. The developed solar still (DSS) was matched with another conventional solar still (CSS). The results concluded that the yield of DSS was ranged from 51–148% more than the CSS. Using outside condenser coupled enhanced the yield by 51%. Usage of circulated high temperature water in passive and active sprays with no condenser caused an enhancement in the DSS productivity by 56% for passive sprays and 82% for active sprays. Steppedsolar stillcombined with vacuum tube solar collectorhad beendiscussed experimentally as well as theoretically in order to enhance the solar still behaviour by Kabeel et al. [58]. The results from the stepped still were compared with conventional solar still. The feed water temperatureto the modified still had been fluctuated utilizing a vacuum tube solar collector as shown in Fig. 16. Theoretical results indicated a decent understanding with experimental results. The results concluded that the highest output of modified still was 57% more than the conventional still. The efficiency and cost of 1 l of yield was 53% and 0.04 $ respectively and for the conventional solar still was 34% and 0.05 $ respectively.Khairat et al. [59] coupled conventional still and four PV cells with two typical solar parabolic dishes as shown in Fig. 17. The setup was constructed and experimentally tested at local climatic conditions. The setup was modified to rise the water temperature throughout the sunshine period. Water was recycled to the cone tanks and splashed in the still to improve the evaporation. The results proved that, the daily production for one solar dish was 9 and 6 kg/day at 10 and 20 mm water deepness respectively. Using two solar dishes equipped with the still improved the yield about 13.6 kg/day at water deepness of 10 mm and 7.7 kg/day at water deepness of 20 mm.

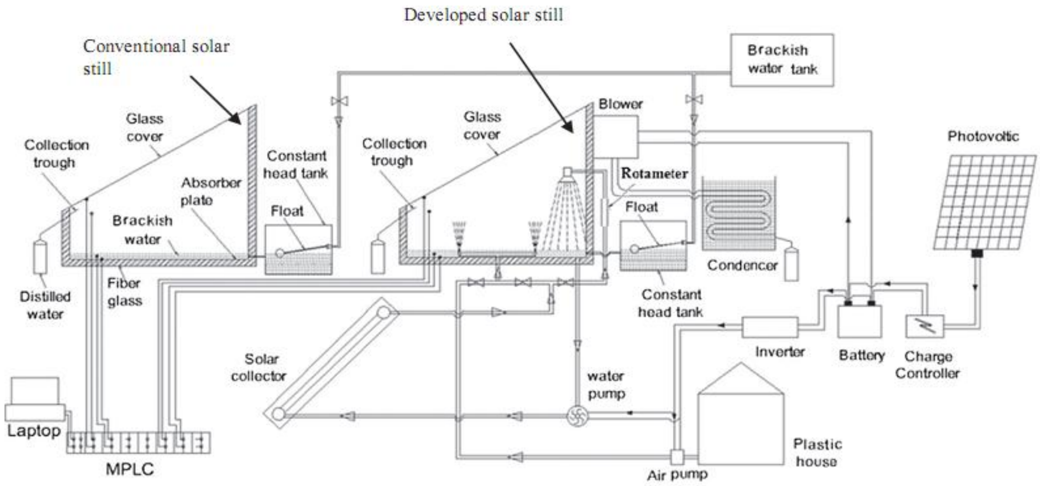

Fig.15: *Schematic of the experimental set up [57].*

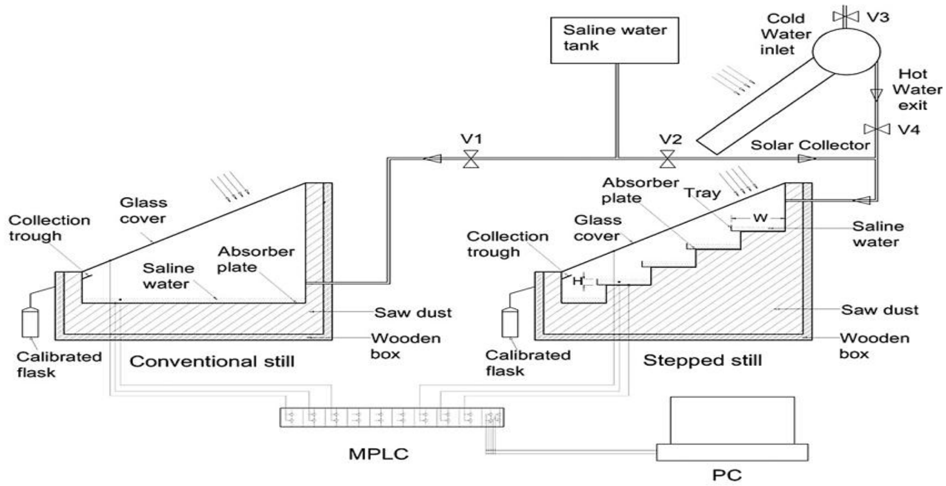

Fig.16: *Schematic of the experimental set up [58].*

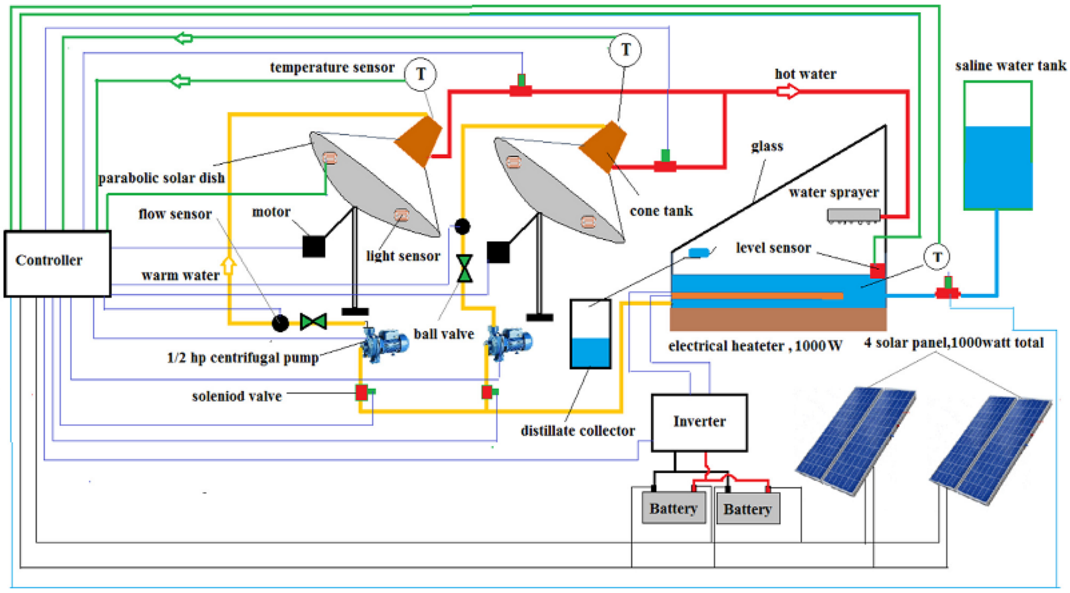

Fig. 17: *Schematic of the experimental set up [59].*

A double passage solar air collector had beenintegrated with enhancedPCM single slope solar still and tested experimentally by Kabeel et al. [60].Air was warmed by the double pass solar air collector before entering the modified still through injectors in to the water causing bubbles in the water to rise the rate of evaporation inside the still as shown in Fig. 18. The results obtained from the modified system were associated with the conventional still which had the same area as the modified still at same climate conditions. The water yield of the modified system was 108% more than the conventional one.Pandey [61] studied the impact of forced dried air bubbling on the performance of conventional solar still. Air was bellowedinside the conventional still by mean of air blower. A polythene tube was placed in the raw water through the water inletas shown in Fig. 19. Temperature of glass cover was cooled by flowing raw water aboveit. A conventional still was built as a base for comparison. The results showed that the production for air bubbled still was 2.61l/m^{2}and 1.80l/m^2 for the conventional still in 24 hr.

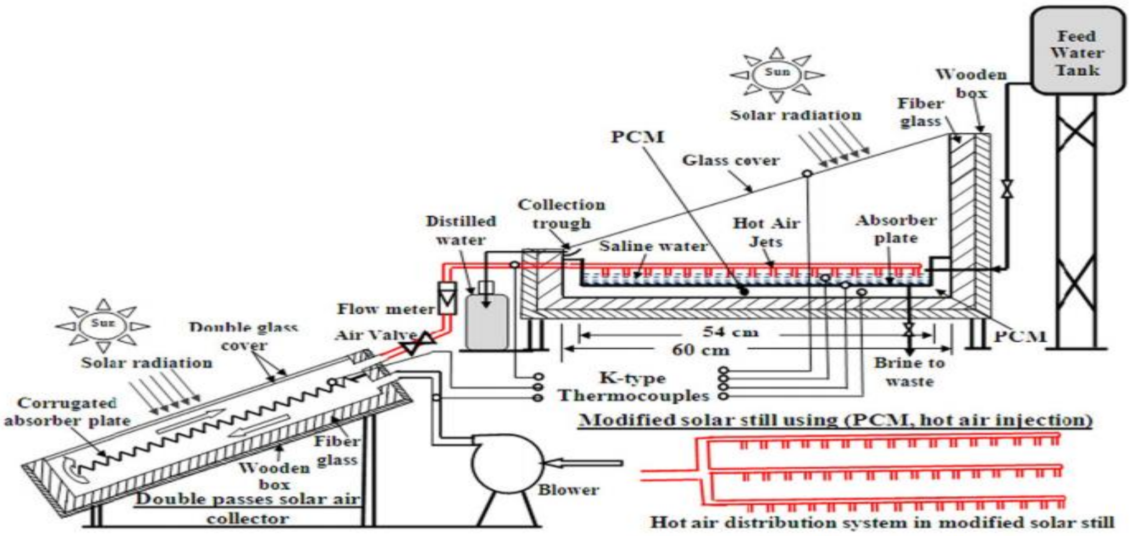

Fig. 18*: Schematic of the modified system [60].*

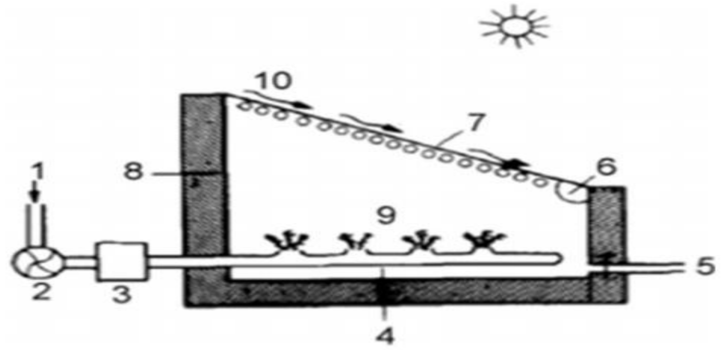

Fig. 19: *Schematic of the air bubbled solar still [61].*

Small solar pond, stepped solar still and conventional solar still had beenseries linkedand tested twice by Velmurugan et al. [62]. In the first experiment pebbles, baffle plates, fins and sponges are augmented in both of solar stills. In the second experiment the single slope solar still was exchanged by a wick type solar still but the same other still and solar pond were utilized. The results found that the productivity in the first experiment was supreme of 80%. In the second experiment the productivity was maximum of 78%.Somwanshi and Tiwari [63] integrated a conventional solar still with an air cooler water tank as shown in Fig. 20. The function of the air cooler tank was to provide a cooled water to flow over the still cover. The system was tested experimentally at four different local climatic conditions. The results showed that annual productivity improved between 41.3% and 56.5%. While the improvement in annual efficiency was in the range from 7.4% to 9.9%. Enhancement in the productivity was the highest for hot and dry climate and the lowest for warm and humid climate. The distillate production slightly improved with increase of rate of mass flow to 0.08 kg/s.A conventional solar still productivityhad been increased by expanding the condensation surface area by Bhardwaj et al. [64]. The extended area above the still body consisted of four top hollow square channels. The total area for each channel wasabout 0.13 m^2 as shown in Fig. 21. The results determined that the output of fresh water improved 50% by with extra condensation area which was 7.5 times more than a reference conventional still.Sahota and Tiwari [65] carried out proposed hybrid solar still systems loaded with water based Nanofluids with and with nohelically coiled heat exchanger as shown in Fig. 22.In order to get the optimal meditation of nanoparticle at base fluid for the number of nanofluids for the each of hybrid stills with and without the heat exchanger. The exergo- economic and enviro-economic results showed that for the still without heat exchanger, the optimum range obtained for using $TiO_2$was 0.04–0.11% while it was to be found 0.06–0.13% for Al_2O_3. The results showed also that the range of using CuO was 0.08–0.16%. When the heat exchanger was integrated with the hybrid still, the range was 0.04–0.09%, 0.04–0.10%, 0.06–0.13% for CuO, TiO_2 and Al_2O_3respectively.

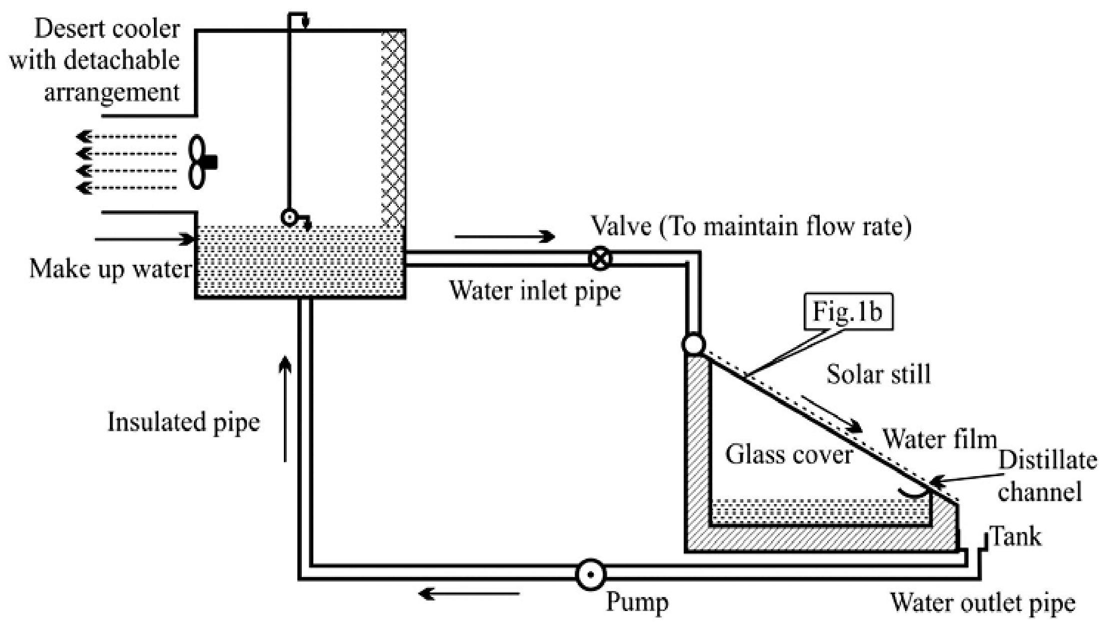

Fig. 20: *Schematic of the system [63].*

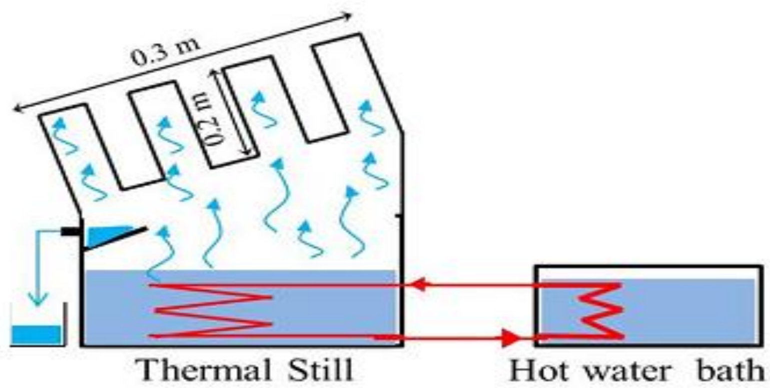

Fig. 21: *Schematic of modified still [64].*

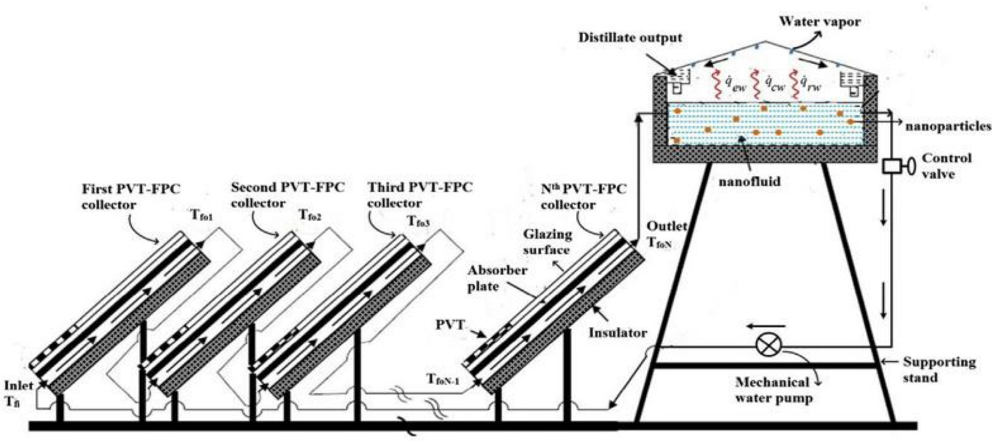

Fig. 22: *Active solar still with no and with internal heat exchanger [65].*

Sharshir et al. [66] experimentally tested three solar stills and compared the performances of each of them. The first one was a conventional solar still (CSS). The second and the third were conventional pyramid solar still (CPSS) and modified pyramid solar still (MPSS) respectively. The MPSS was combined with evacuated tubes and nanofluids which were copper oxide (CuO) and carbon black (CB) Nano materials with 1.5% wt as shown in Fig. 23. The results demonstrated that with CuO the total output of freshwater was enhanced by 28 and 55% in case of MPSS more thanCPSS and CSS. With CB thepercentage of improvement in total production of freshwater was 34 and 57% in case of MPSS higher than CPSS and CSS respectively.Nazari et al. [67] made experiments and theoretical studies about conventional solar still integrated with an outside thermoelectric condensing passage and copper oxide (Cu_2O) Nano fluid. Four thermoelectric cooling modules (TEC) werefittedall over the walls of the outsidepassage to create cooled condition in the flow of vapour and in the Cu_2O water Nano fluid with varioussize concentrations as shown in Fig. 24. Cost analysis of purified water for various cases had been conducted. The results concluded that the productivity, energy and exergy efficiencies of the modified solar still increasedabout 39%, 39% and 31%, respectively compared to a conventional solar still. The distillate water cost per litrewas 0.02 $/l/m^2 for the improved still.

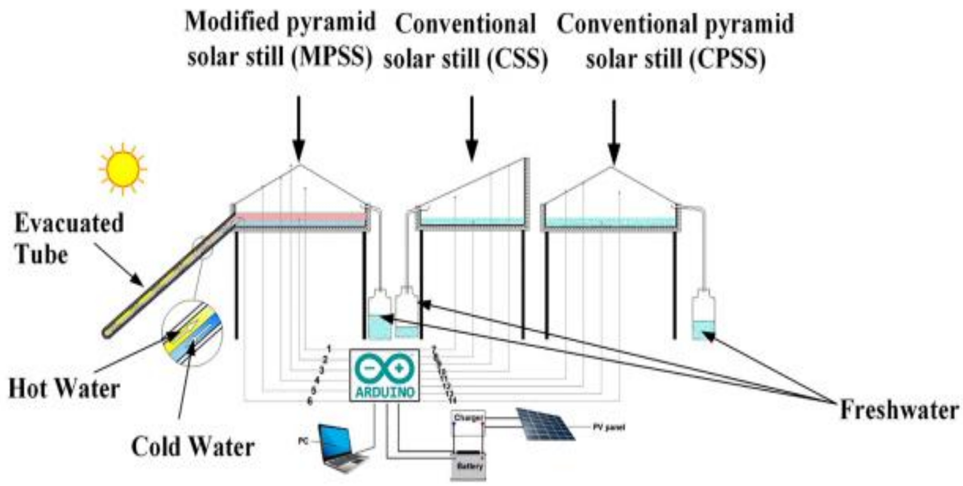

Fig.23: *Schematic of the experimental setup [66].*

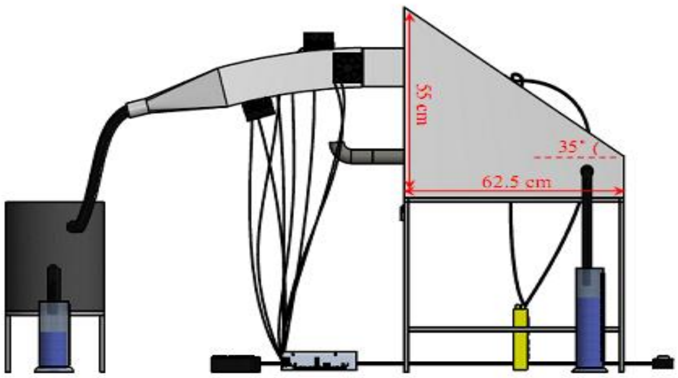

Fig.24: *Schematic of the modified solar still [67].*

Rashidi et al. [68] simulated the flow of Nano fluid and the generation of entropy in conventional solar still by volume of fluid CFD model. The used Nano fluid in the model was Al_2O_3. Analysis ofentropy generation was introduced in order to estimate the simulated model from the second law of thermodynamics point of view. The theoretical results wereassociated with the experimental ones obtainablefrom literature. The results presented that the productivityenhanced by 25% when the solid volume fraction increasedfrom 0% to 5%.An improvement of18%in the mean Nusselt number was obtained when the volume fraction of solid improvedfrom of 0% to 5%. The thermal entropy and viscous generations increased by 25% and95%respectively when thevolume fraction of solid improvedfrom of 0% to5%.A cascade solar still withhad been introduced numerically by Rashidi et al. [69] to focusing on the analysis of the solar still sensitivity production. The results concluded that the particles of Al_2O_3 with great concentration attained an increase in the output of still about 22%.Shanmugan et al. [70] made experimental and numerical studies in conventional solar still equipped with thermalstoring system by utilizing mix ofPCMwith $C_{18}H_{36}O_2$, Al_2O_3 nanoparticles and black paint to improve the still performance. The results presented that the efficiency enhanced by about 60%.Simple heat and mass transfer model had been calculated to evaluate acoupled solar still with an underground heat exchanger (GHEX) by Salman [71]. The still had an inlet area of 0.5 m^2 with0.2 m diameter and 70 m length heat exchangeras shown in Fig. 25. The system model was analysed under transient mode under climate area during the year. The results concluded that the fresh water was powerfully subjected to the solar radiation, for the maximum and minimum values of solar intensity; the output was 5 kg/m.day and 0.3 kg/m.day respectively. For unit length the maximum output was 9 kg of fresh water at pipe diameter 0.55 m.Mahmoud et al. [72] discussed the impact of solar heat power storing and solar concentration ratios (CR) on the transient behaviour and the yield of solar still with two humidification-dehumidification effectsdesalination unit (SS-HDH) as shown in Fig. 26.Transient theoretical model had been developed with mass and energyrelations for the various operational and environmental conditions contain water depth and PCM with and without nano particles. The results indicated that linear increase of CR increased water temperature which in turns increased the yield. The best parameters for maximum water yield with avoiding scale creation in the still basin without PCM were 11.60 l/m^2 per day at water depth of 0.2 m and CR of 2.Angle bars to increase the water residence time, cooling system on the glass cover, top and bottom flat plate outside reflectors had been integrated with an inclined solar still by Ketabchi et al. [73]. The still was inclined at adjustable tilt angle to attain the maximum quantity of solar radiation throughout the year. The results showed that only streamingwater on the glass cover had the highest influence on yield improvement in spring while using top reflector at the optimaltilt angle achieved the greatest output in winter. When the feed water and cooling water streamed at 0.09 and 0.72 l/min respectively over the solar still with basin inclination angle, upper and lower reflectors tilted at 25°, 10° and 45° respectively, the maximum output of 4.2 kg/m^2 was gained.

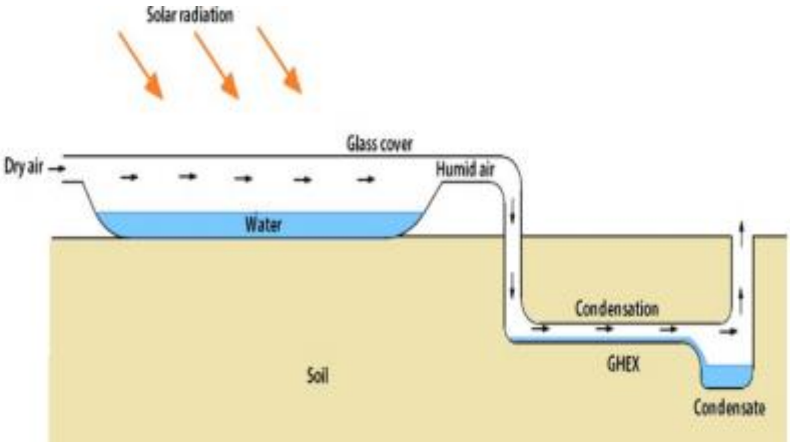

Fig.25: *The proposed model solar still [71].*

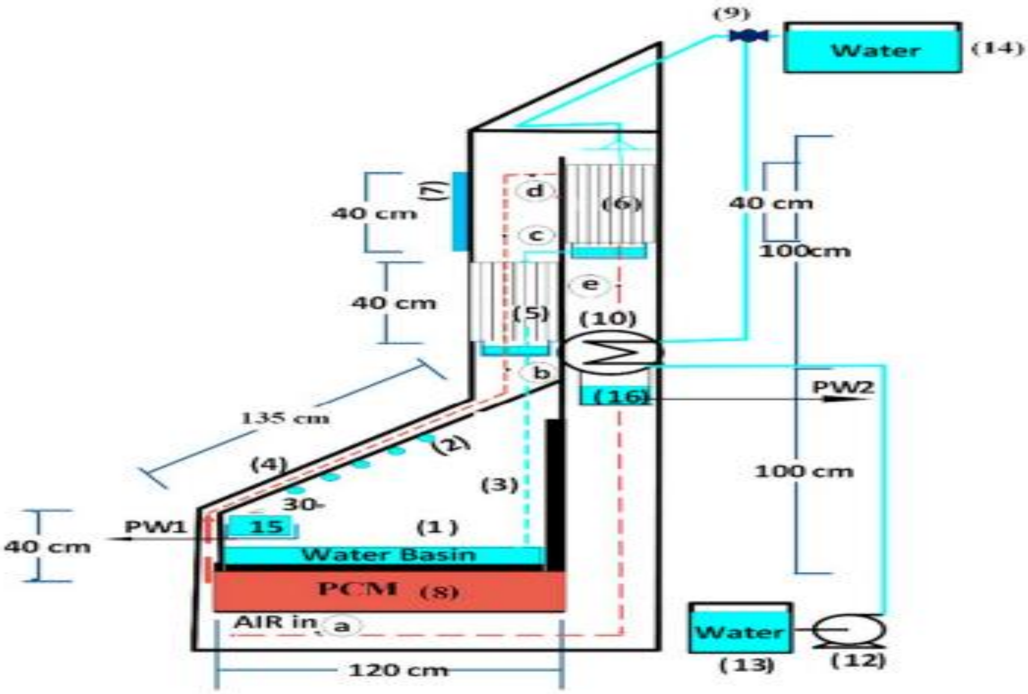

Fig.26: *The mathematical model of the system [72].*

Saini et al.[74] investigated theoretical model of conventional solar still combined with solar photovoltaic panel module and passive condenser. The influence of packing factor (β_c) of the solar cell of dissimilar PV technologies had been examined. The calculated results showed that the maximum overall thermal efficiency of the system was about 58%, 55%, 53%, 53%, and 41% for values of β_c0.85, 0.65, 0.45, 0.25 and 0 respectively whenC-Si SPV module had been used. The fresh water production of the integrated system was about2 kg, 3 kg, 4 kg, 4.5 kg and 5 kg per day for β_c of 0.85, 0.65, 0.45, 0.25 and 0 respectively when C-Si PV module had been used.The value of cost per litre was 0.05 $/L, 0.07 $/L, 0.08$/L at interest rate equal to 4%, 8%, and 10% respectively for 30 years life system duration.Theoretical studies including yield, exergo-economic and enviro-economic parameters of double slope solar still (DS) equipped with number of evacuated tubular collectors (N-ETC-DS) had been analysed by Singh [75]. The studies had been done on four cases; case

(1): Comparison of proposed N-ETC-DS had been completed on the base of products with products of previous literature systems called photovoltaic thermal (PVT). Case (2): Flat plate collectors (FPCs) incorporated with DS. Case (3):PVT compound parabolic concentrator collectors (CPCs) combined with DS case (4): PVT compound parabolic concentrator collectors (CPCs) combined with conventional DS. The results determined that the cost of produced drinking water was lowered by 74.5%, 136.2% and 83.0%.The yield was greater by about 51%, 53% and 38% for case 1 than case 2, case 3 and case 4 respectively.Yousef et al. [76] integrated hollow cylindrical shaped pin fins fixed in PCM with conventional stillto improve the characteristics of PCM storing unit heat transferused at the still. The experiments were done in three cases; the first case was justconventional still. The second case was solar still with PCM. While the third case was solar still with cylindrical shaped hollow pin fins heat sink fixed in the PCM. The three cases performanceswere experimentally tested and compared to each other atidentical climatic conditions. The results showed that the existence of PCM adverselyinfluencesthe drinkable water yieldin the day with an obvious increase in the overallstill output. The total daily output of water inthe third casewasgreater than those of first and second case by 17% and 7%, respectively.Mu et al. [77] fixed the Fresnel lens (FRL) above conventional solar still to focus the incident sun rays to the focal point which fixed at the absorber bottom in order to increase the input energy to the still used for distillation process and to raise the phase change heat transfer coefficient of water. The results showed that water output and efficiency increased by 67% and 85% respectively compared with a conventional still without FRL. Performance of a combined photovoltaic (PV) panel with conventional solar still had been presented by Ayman and Hassan [78]. The integration of the PV was over the still cover where the power of PV was transformed to heat throughout an electric resistance fixed in the basin and directly conductedto the water basin. The PV was placed by which the reflected solar energy from PV was diffused to the basin water. The behaviour of the integrated unit wasexamined for black steel wool fibres (BSWF) attached in the basin as shown in Fig. 27. The results concluded that the still output the PV with the conventional solar still (CSS) and with the CSS with the BSWF fixed in the still basin enhanced by9%, and 23%, respectively. Usage of PV as a reflector increased the output of the still by 3.2%.Kabeel and Abdelgaied [79] enhanced a pyramid-shaped solar still by utilizing absorber plate (graphite) which had high thermal conductivity properties withglass cover cooling. Two identical pyramid shaped solar stills were built and tested at the same conditions, one of them was conventional pyramid shaped solar still without any enhancement as a reference and the other the modifications. The graphite acts as good sensible store material. The experimental results concluded that the increase in the daily output andefficiency of the modified pyramid shaped still ranged from 105.9 to 107.7% and 97.2 to 98.9% respectively, as associatedwiththe traditional pyramid shaped still.The exergy of double slope solar still coupled with phase change material (PCM) and combined photovoltaic with solar collector (PV/T) collector was theoretically investigated by Mehdiabadi et al. [80]. PV/T collector is heat exchanger which collects solar radiation and changes it to thermal and electrical powers to improve the production of distillate water throughout the sunshine period by heating up the brackish water as shown in Fig. 28. Besides that,the usage of PCM makes to createdistillate water during night period. Results presented that the productivity of water improved by 11%. The exergy efficiency enhanced by 27% and 2% on July and December respectively, when the stream of water mass enlarged from 0.001 to 0.01 kg/s. Increase non-distillate watermass rate from 20 to 30 kg caused to a reduction of the fresh water output by 4.8% during sunshine, but the productivity was increased by 7.5% through the night.

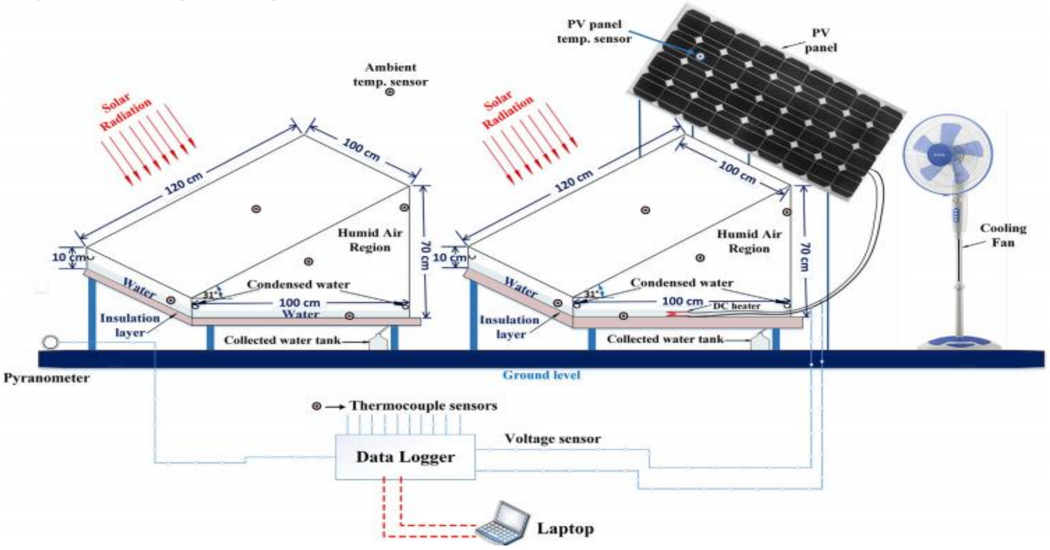

Fig.27: *Layout of the experimental setup [78].*

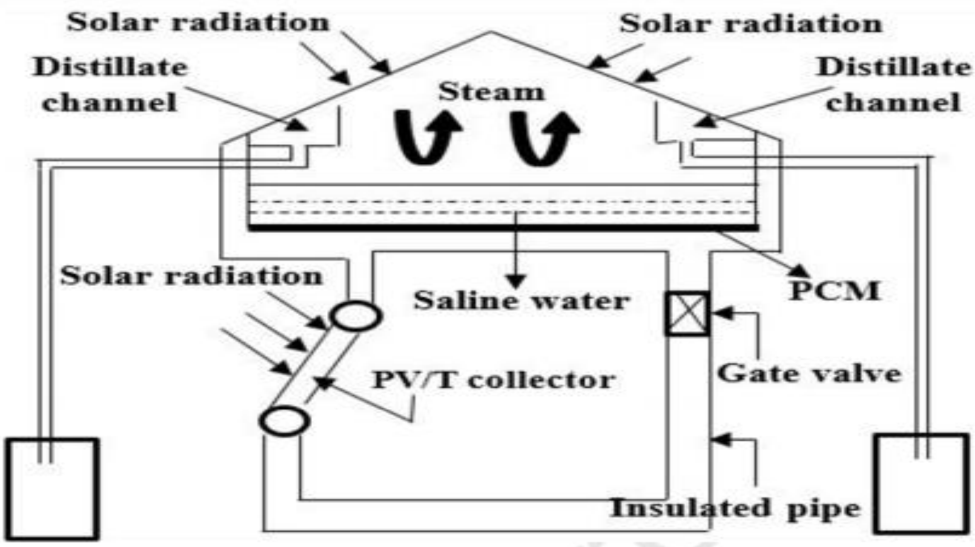

Fig.28: *Schematic of the proposed model [80].*

IV. CONCLUSION

A comprehensive study of several parameters that affecting the performance of all types of solar stills. The investigationput three key points which summarize the all solar still parameters. Thisstudy includes also some solar stills proposals which in turn improve performance of the conventional stills. The followingfundamentals of this study are:

- There are three main parameters which have the great result on the general solar still performance including climate, design and operation parameters.
- For climate parameters; solar radiation, wind speed and dust formation had the importantinfluence on the still output while the ambient temperature has the slight influence.
- For design temperature; single slope single basin solar still is better than double slope single basin solar still because the single slope can obtain the incident solar intensitythrough the year at different latitude areas.
- The best orientation of any solar still when it faces the south parallel to earth equator if it located at northern hemisphere and faces the north if it located at the southern hemisphere. The best cover tilt angle or still angle for inclined stills is the angle equivalent to the latitude of still area; it can collect the incident solar radiationnear to normal during the year.
- Using glass cover with available smallest thickness is the best for fresh water production and the best insulation material from economy point of view is sawdust. For greatest thermal insulation, polyurethane rigid foam material insulation gives the best water production from the irregular solar stills.
- Increasing the absorption and evaporation area leads to increasing the productivity. This achieved by using heat storage materials such as jute clothes, sponges cubes, fins, flat perforated plate, and cottons and different shaped ferrous materials. Also using of PCM materials guaranteed continuous production during the night from the solar still.
- Integration of sun tracking devices with any type of solar still offer the best performance of them.
- For operational parameters;water depth is the most effective operation parameters among the operational parameters, for more amount of water at the basin the productivity is high after the sunshine due to the heat storing effect. The increase of amount of water is inversely proportional with the performance of the solar still. The annual productivity comes to be constant at water deepness more than 0.08-0.10 m.
- Increasing the water temperature with lowering the glass temperature by means of water or air cooling systems leads to an increase in the performance of any type of solar still.
- Water colouring was found able to enhance thesolar still output regardless the health risks. Also using of high salinity water in distillation process could reduce the solar still performance.
- Using stepped basin solar still increases the heat transfer area among the absorber and the water on condition of water stream rate on the stepped absorber decrease. This leads to form thin film of water over the absorber and the water residence timein the still decrease, soenhancesignificantly the output of the still.
- Forced convection between the water surfaceandthe glass cover instead of natural convection enhances the convective and evaporative heat transfer coefficients inside solar still.
- Using hybrid solar still systems double the performance of solar still but it require much components which lead to increase the total cost per litre of distillate water.

REFERENCES

[1]. Kalogirou, S.(2005).Seawater Desalination Using Renewable Energy Sources,*Prog. Energy Combust. Sci*., vol. 31, pp. 242–281.
[2]. Rodriguez, L. and Camacho, C.,(2001).Perspectives of solar-assisted seawater distillation. *Desalination*, vol. 136, pp. 213–218.
[3]. Feilizadeh, M., Soltanieh, M., Jafarpur, K.,and Karimi, M. R.(2010).A new radiation model for a single-slope solar still,*Desalination*, vol. 262, pp.166–173.
[4]. Afrand, M., Behzadmehr, A.,and Karimipour, A.(2010). A numerical simulation of solar distillation for installation in Chabahar-Iran,*World Academy of Science, Engineering and Technology*, vol. 71, pp. 515–520.
[5]. El-Sebaii, A.(2000). Effect of wind speed on some designs of solar stills,*Energy Convers Manag*, vol. 41, pp. 38–523.
[6]. Zurigat, H.,and Abu-Arabi, K.,(2004). Modeling and performance analysis of a regenerative solar desalination unit,*Appl Therm Eng*, vol. 24, pp.1061–72.
[7]. Nafey, A. S., Abdelkader, M., Abdelmotalip, A., and Mabrouk, A.(2000). Parameters affecting solar still productivity,*Energy Convers Manag*, vol. 41, pp. 809–1797.
[8]. Al-Hinai, H., Al-Nassri, M. S., and Jubran, B. A.(2002). Effect of climatic, design and operational parameters on the yield of a simple solar still,*Energy Convers Manag*, vol. 43, pp.50–1639.
[9]. Hegazy, A.(2001). Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors,*Renew Energy*, vol. 22, pp. 40–525.
[10]. EL-Nashar, A. M.(2009). Seasonal effect of dust deposition on a field of evacuated tube collectors on the performance of a solar desalination plant,*Desalination*,vol. 239, pp. 66–81.
[11]. Tiwari, G. N., Singh, H. N., and Tripathi, R.(2003). Present status of solar distillation,*Sol Energy*, vol. 75, pp. 73–367.
[12]. Morad, M., Hend, A., El-Maghawry, and Wasfy, K.(2015). Improving the double slope solar still performance by using flat-plate solar collector and cooling glass cover,*Desalination*, vol. 373, pp. 1–9.
[13]. E1-Sebaii, A.(2005). Thermal performance of a triple-basin solar still,*Desalination*,vol. 174, pp. 23-37.
[14]. Sakthivel, M., Shanmugasundaram, S., and Alwarsamy, T.(2010). An experimental study on a regenerative solar still with energy storage medium – jute cloth,*Desalination*,vol. 264, pp. 24–31.
[15]. Kabeel, A.(2009). Performance of solar still with a concave wick evaporation surface,*Energy*, vol. 34, pp. 9–1504.
[16]. Omara, Z., Mofreh, H.,and Kabeel, A.(2011). Performance of finned and corrugated absorbers solar stills under Egyptian conditions,*Desalination*, vol. 277, pp. 7–281.
[17]. Kumar, A., Denkenberger, D., Ahsan, A., and Jayaprakash, R.(2013). The augmentation of distillate yield by using concentrator coupled solar still with phase change material,*Desalination*, vol. 314, pp. 92–189.
[18]. Ansari, O., Asbik, M., Abdallah, B., Arbaoui, A., and Ahmed, K.(2013). Desalination of the brackish water using a passive solar still with a heat energy storage system,*Desalination*,vol. 324, pp.10–20.
[19]. Kabeel, A., El-Samadonya, Y., and Wael, M.(2018). Comparative study on the solar still performance utilizing different PCM,*Desalination*, vol. 432, pp. 89–96.
[20]. Kabeel, A., and Mohamed, A.,(2016). Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions,*Desalination*,vol. 383, pp. 22–28.
[21]. Al-Karaghouli, A. and Alnaser, W. E.,(2005). Performances of single and double basin solar stills,*Applied Energy*,vol.78, pp. 54–347.
[22]. Mohamad, M., Soliman, S., Abdel-Salam, M., and Hussein, H.(1995). Experimental and Financial Investigation of Asymmetrical Solar Stills with Different Insulation,*Applied Energy*, vol. 52, pp. 265–271.
[23]. Abdulrahman, G., and Arifleri, (1997). Software to analyze solar stills and an experimental study on the effects of the cover,*Desalination*, vol. 114, pp. 37–44.
[24]. Bilal, A., Mousa, M., and Waleed, N.(2000). Experimental study of the basin type solar still under local climate conditions,*Energy Conversion and Management*, vol. 41, pp. 833–890.
[25]. Hikmet, A., and Assefi, H.,(2009). Simulation of a solar still to investigate water depth and glass angle,*Desalination and Water Treatment*, vol. 7, pp. 4–35.
[26]. El-Samadony, Y., Wael, M., and Kabeel, A.(2016). Influence of glass cover inclination angle on radiation heat transfer rate within stepped solar still,*Desalination*,vol. 384, pp. 68–77.
[27]. Trad, A., and Abdenacer, (2013). Effect of orientation on the performance of a symmetric solar still with a double effect solar still (comparison study),*Desalination*,vol. 29, pp. 68–77.
[28]. Kudret, S. M.(1964). Design and performance evaluation of a multiple-effect, tilted solar distillation unit,*Sol Energy*, vol. 8, pp. 23–30.
[29]. Aybar, H.S., Egelioglu, F., and Atikol, U.(2005). An experimental study on an inclined solar water distillation system,*Desalination*, vol. 180, pp. 9–285.
[30]. Sodha, M.S., Kumar, A., Tiwari, G., and Tyagi, R.C.(1981). Simple multiple wick solar still: analysis and performance,*Sol Energy*, vol. 26, pp. 31–127.
[31]. Abdallah, S., and Badran, O., (2008). Sun tracking system for productivity enhancement of solar still,*Desalination*, vol. 220, pp.76–669.
[32]. Elashmawy, M.(2017). An experimental investigation of a parabolic concentrator solar tracking system integrated with a tubular solar still,*Desalination*, vol. 411, pp. 1–8.
[33]. Tripathi, R., and Tiwari, G., (2005). Effect of water depth on internal heat and mass transfer for active solar distillation,*Desalination*,vol. 173, pp. 187–200.
[34]. Rajamanickam, M. R., and Ragupathy, A., (2012). Influence of water depth on internal heat and mass transfer in a double slope solar still,*Energy Proc*, vol. 14, pp. 8–1701.
[35]. Jabbar, K., and Ahmad, H., (2009). On the verification of the effect of water depth on the performance of basin type solar stills,*Solar Energy*,vol. 83, pp. 21–1312.
[36]. Tiwari, A., and Tiwari, G., (2007). Thermal modeling based on solar fraction and experimental study of the annual and seasonal performance of a single slope passive solar still: The effect of water depths,*Desalination*, vol. 207, pp. 184–204.
[37]. Kumar,A., Jayaprakash, R.,Denkenberger, D., Ahsan, A., Okundamiya, M., andkumar, S.(2012). An experimental study on a hemispherical solar still,*Desalination*,vol. 286, pp. 8–342.
[38]. Abdulla, S.(2013). Improving the performance of stepped solar still,*Desalination*,vol. 319, pp. 5–60.
[39]. Ali, B., Ahmad, H., Imad, S., andMohammad, O.(2005). A solar still augmented with a flat-plate collector,*Desalination*,vol. 172, pp. 227-234.

[40]. Zurigat, and Abu-Arabi,(2004). Modeling and performance analysis of a regenerative solar desalination unit,*Appl Therm Eng*, vol. 24, pp.72–1061.
[41]. Singh, V., Kumar, S., Hasan,M., Khan, E., and Tiwari, G. (2013). Performance of a solar still integrated with Evacuated Tube Collector in natural mode,*Desalination*,vol. 318, pp. 25–33.
[42]. Nafey, A., Mohamad, M., and Sharaf, M.(2008). Enhancement of solar water distillation process by surfactant additives,*Desalination*, vol. 220, pp. 23–514.
[43]. Mahdi, J., Smith, B., and Sharif, A. O.(2011). An experimental wick-type solar still system: design and construction,*Desalination*, vol. 267, pp. 8–233.
[44]. Akash, B., Mohsen, M., Osta, O., and Elayan, Y. (1998). Experimental evaluation of a single- basin solar still using different absorbing materials,*Renew Energy*, vol. 14, pp. 10–307.
[45]. Rajvanshi, A.(1981). Effect of various dyes on solar distillation,*Sol Energy*, vol. 27, pp. 51–65.
[46]. Tabrizi, Mohammad, D., Hamid, M., and Razzaghi, K.(2010). Effect of water flow rate on internal heat and mass transfer and daily productivity of a weir-type cascade solar still,*Desalination*, vol. 260, pp. 47–239.
[47]. Tabrizi, Mohammad, D., and Hamid, M.(2010). Experimental investigation of a weir-type cascade solar still with built-in latent heat thermal energy storage system,*Desalination*, vol. 260, pp.53–248.
[48]. El-Zahaby, A., Kabeel, A., Bakry, A., El-agouz, S., and Hawam, O., (2010). Augmentation of solar still performance using flash evaporation,*Desalination*, vol. 257, pp. 58–65.
[49]. Ayman, I., Elsayed, A., and Salman, E.(2015). A modified basin type solar still: Experimental performance and economic study,*Energy*, vol. 93, pp. 335–342.
[50]. Nassar, F., Saib Y., and Salem, A.(2007). The second generation of the solar desalination systems,*Desalination*, vol. 209, pp. 81–177.
[51]. Hansen, R., and Murugavel, K., (2017). Enhancement of integrated solar still using different new absorber configurations: an experimental approach,*Desalination*,vol. 422, pp. 59–67.
[52]. Rahbar, N., Asadi A., and Fotouhi-Bafghi, E.(2018). Performance evaluation of two solar stills of different geometries: tubular versus triangular: experimental study, numerical simulation, and second law analysis,*Desalination*; 443:44–55.
[53]. Sathyamurthy, R., Kennady, H., Nagarajan, P., and Ahsan, A.(2014). Factors affecting the performance of triangular pyramid solar still,*Desalination*, vol. 344, pp. 383–390.
[54]. Omara, Z., Eltawil, A., and Elnashar E.(2013). A new hybrid desalination system using wicks /solar still and evacuated solar water heater,*Desalination*,vol. 325, pp. 56–64.
[55]. Madhlopa, andJohnstone, (2009). Numerical study of a passive solar still with separate condenser,*Renew. Energy*, vol. 34, pp. 1430–1439.
[56]. Monowe, P., Masale, M., Nijegorodov, N., and Vasilenko, V.(2011). A portable single-basin solar still with an external reflecting booster and an outside condenser,*Desalination*, vol. 280, pp. 332–338.
[57]. Eltawil, and Omara, Z., (2014). Enhancing the solar still performance using solar photovoltaic, flat plate collector and hot air,*Desalination*, vol. 349, pp. 1–9.
[58]. Kabeel, A., Khalil, A., Omara, Z., and Younes, M.(2012). Theoretical and experimental parametric study of modified stepped solar still,*Desalination*,vol. 289, pp. 12–20.
[59]. Mohamed Khairat, Kabeel, A., Khaled Ramzy, Tamer Nabil, Basem Elnaghi, and Ahmed elkassar, (2019). Enhancement of single solar still integrated with solar dishes: An experimental approach,*Energy Conversion and Management*, vol. 196, pp. 165–174.
[60]. Kabeel, A., Mohamed A., and Mahgoub, M.(2016). The performance of a modified solar still using hot air injection and PCM,*Desalination*,vol. 379, pp. 102–107.
[61]. Pandey, C.(1984). Effect of dried and forced air bubbling on the partial pressure of water vapour and performance of solar still,*Sol Energy*, vol. 33, pp. 8–13.
[62]. Velmurugan, V., Pandiarajan, S., Guruparan, P., Harihara, L., David, C., and Srithar, K.(2009). Integrated performance of stepped and single basin solar stills with mini solar pond,*Desalination*, vol. 249, pp. 902–909.
[63]. Aneesh, and Tiwari, (2014). Performance enhancement of a single basin solar still with flow of water from an air cooler on the cover,*Desalination*, vol. 352, pp. 92–102.
[64]. Bhardwaj, R., Kortenaar, M., and Mudde, R.(2015). Maximized production of water by increasing area of condensation surface for solar distillation,*Applied Energy*, vol. 154, pp. 480–490.
[65]. Sahota, L., and Tiwari, G.,(2017). Exergoeconomic and enviroeconomic analyses of hybrid double slope solar still loaded with nanofluids,*Energy Convers Manag*,vol. 148, pp. 30–413.
[66]. Sharshira, S., Kandealc, A., Ismail, M., Gamal, A., Kabeel, A., and Nuo, Y.(2019). Augmentation of a pyramid solar still performance using evacuated tubes and nanofluid: Experimental approach,*Applied Thermal Engineering*, vol. 160, pp. 113–997.
[67]. Nazari, S., Habibollah, S., and Mehdi, B.(2019). Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: An experimental study,*Journal of Cleaner Production*, vol. 208, pp. 1041–1052.
[68]. Rashidi, S., Shima, A., Masoud,B., and Rahmat, E.(2018). Volume of fluid model to simulate the nanofluid flow and entropy generation in a single slope solar still,*Renewable Energy*, vol. 115, pp. 400–410.
[69]. Rashidi, S., Masoud, B., Nader, R., and Javad E.(2018). Steps optimization and productivity enhancement in a nanofluid cascade solar still,*Renewable Energy*,vol. 118, pp. 536–545.
[70]. Shanmugan, S., Palani, S., and Janarthanan, B.(2018). Productivity enhancement of solar still by PCM and nanoparticles miscellaneous basin absorbing materials,*Desalination*, vol. 433, pp. 186–198.
[71]. Salman, H.(2019). Integrated solar still with an underground heat exchanger for clean water production, *Journal of King Saud University-Engineering Sciences*, vol. 68, pp. 33–40.
[72]. Amir, M., Hassan, F., Shinichi, O., andMahmoud, A.(2019). Influence of partial solar energy storage and solar concentration ratio on the productivity of integrated solar still/humidification-dehumidification desalination systems,*Desalination*, vol. 467, pp. 29–42.
[73]. Faezeh, K., Shiva, G., Saba, S., Zahra, S., Mahshid, G., and Hassan, R.(2019). Experimental performance evaluation of a modified solar still integrated with a cooling system and external flat-plate reflectors,*Solar Energy*, vol. 187, pp. 137–146.
[74]. Vineet, S., Lovedeep, S., Jain, V., and Tiwari, G.(2019). Performance and cost analysis of a modified built-in-passive condenser and semitransparent photovoltaic module integrated passive solar distillation system,*Journal of Energy Storage*, vol. 24, pp. 100–809.
[75]. Singh, D.(2019). Exergo-economic, enviro-economic and productivity analyses of N identical evacuated tubular collectors integrated double slope solar still,*Applied Thermal Engineering*, vol. 148, pp. 96–104.
[76]. Mohamed, Y., Hamdy, H., Kodama, S., and Sekiguchi, H.(2019). An experimental study on the performance of single slope solar still integrated with a PCM-based pin-finned heat sink,*Energy Procedia*, vol. 156, pp. 100–104.

[77]. Lei, M., Xuesong, X., Thomas, W., Claire, D., Rocio, G., Young, P., Huiyao, W., Krishna, K., Pei, X., and Sarada, K.(2019). Enhancing the performance of a single-basin single-slope solar still by using Fresnel lens: Experimental study,*Journal of Cleaner Production*, vol. 239, pp. 1–13.
[78]. Abd Elbar, A., and Hamdy, H., (2020). An experimental work on the performance of new integration of photovoltaic panel with solar still in semi-arid climate conditions,*Renewable Energy*,vol. 146, pp. 1429–1443.
[79]. Kabeel, A., and Mohamed, A., (2020). Enhancement of pyramid-shaped solar stills performance using a high thermal conductivity absorber plate and cooling the glass cover,*Renewable Energy*, vol. 146, pp. 769–775.
[80]. Erfan,M., Faramarz, S., and Fatemeh, S.(2020). Exergy performance evaluation of a basin-type double-slope solar still equipped with phase-change material and PV/T collector,*Renewable Energy*,vol. 145, pp. 2409–2425.

Eslam Ahmed,etal. “Solar Stills Performance and Productivity Enhancement Methods – A detailed Review”. *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp. 307-329.