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Techniques for Extracting Pure Water from Atmospheric Air by a Solar Collector and Absorbent Materials: Recent Advances and Development

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ABSTRACT

Because air is a clean, renewable source of water that is available everywhere, air extraction is regarded as one of the key means of supplying fresh water. Many researchers have looked into this issue. These investigations may be divided into two major categories. While the second group researches the direct absorption-regeneration of moisture from air, the first group works with the of air. This paper presents and explores previous theoretical and experimental works and study on the topic of extracting pure water from air and using different absorbent substances to absorb water vapor from the atmosphere. The fundamentals and improvements to the topic of pure water extraction and its great benefit were the use of different elements and materials when designing a prototype in the main components of the extraction systems. Drinking water is generated from the air by solar panels using solar energy and heat during the day. It has been discovered that some desiccant materials with good water absorbers, such as calcium chloride and silica gel, may be successfully utilized in the processes of extracting drinking water from ambient air by creating suitable designs. It has been demonstrated that using solar energy may change the high ambient air temperature, a primary cause of water scarcity, into a benefit.

1. INTRODUCTION

Solar energy is one of the most important renewable energy sources, as it is both sustainable and environmentally friendly., which can be exploited in many fields. Where the sun provides us with heat and light. Light is used to generate electrical energy, as for the heat generated by solar radiation, it is used for many different purposes. One of the problems facing the world in recent times is the problem of fresh water shortage, especially in arid and remote areas and areas that lack a continuous water source such as rivers and lakes because of their geographical location. Freshwater availability is always changing, and recent trends show that it is falling significantly, both qualitatively and quantitatively, over the world. As a result, the scarcity of freshwater will be the most serious challenge to humanity, and there is a great need to strengthen and develop sustainable solutions to solve the problem. Water creation in the atmosphere applications, which generates water from the atmosphere air, have mostly gone unused, but they may be a promising new option for addressing this problem. These systems have been energy-intensive, limiting their general use in the field [1-7]. Water shortages have surfaced as a possible worldwide interest in recent years [8]. Although the fact that water covers 70% of our planet, only 2.5 percent of it is available as pure water [9, 10]. According to World Health Organization (WHO) research, almost one-third of the world's population does not have access to potable water, and additional than 3 billion people do not have access to potable water for keeping cleanliness at their homes [11]. People have recently recognized the vital relevance of pure water obtainability in the context of the ongoing coronavirus epidemic. Furthermore, at least once a year, almost 4 billion people are affected by water scarcity, with 50 percent of them living in India and China [12]. Throughout Northern Africa, the Middle East, and Southern and Central Asia, water scarcity is persistent, severe, and widespread.

1.1 Solar collector

Solar collectors of different types are used to capture sun radiation and transform them into heat, which may then be utilized for a variety of purposes, for example supply of electrical energy, water heating, treatment of salt water, building heating [13]. There are various forms and kinds of sun collectors, as seen in the Figure 1.

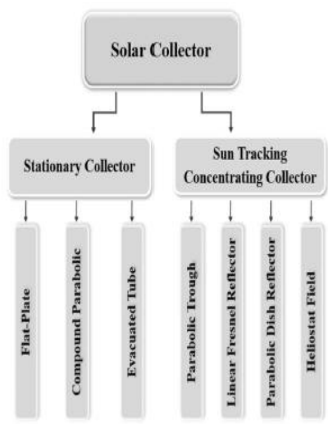


Figure 1. Classification of solar collectors [13]

1.2 Concentrating collectors

To obtain the most sun radiation, it is important to keep tracking of the solar position, and there are various kinds of these complexes, for example: parabolic trough collectors, Fresnel reflectors that are linear, reflectors with a parabolic dish, and central tower receivers.

1.3 Fixed collectors

These solar collectors stay stable and face the sun at a certain tilt angle, with several varieties for example compound parabolic collectors, flat plate collectors, and vacuum tube collectors, as seen in Figure 2.

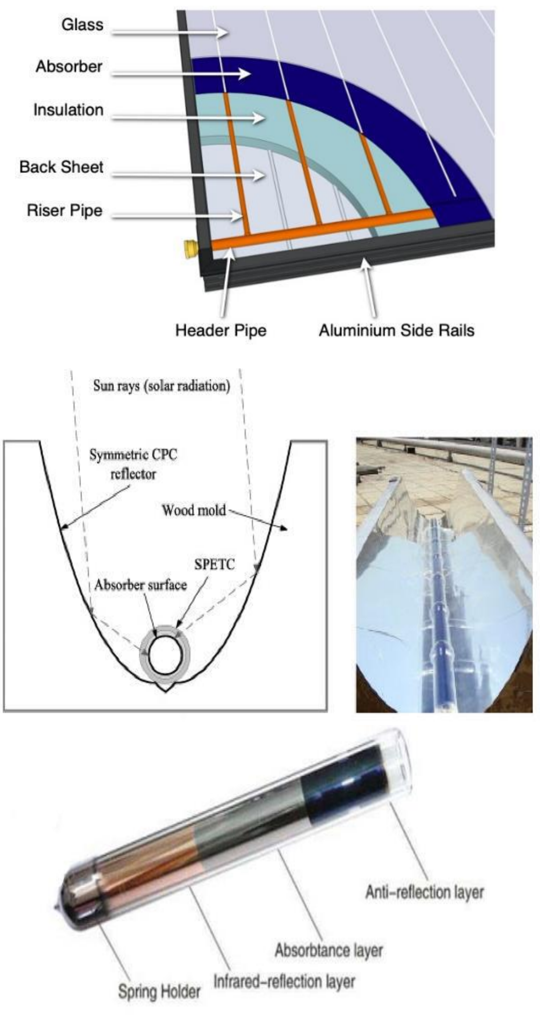


Figure 2. Fixed collectors (Flat plate, Compound parabolic, and Evacuated tube collectors) [13]

The following ideas can assist in addressing the problem of distributing fresh water to arid areas [14]:

1. Transportation by water from other locations.
2. Salty water purification
3. Water extraction by atmospheric air

Water transportation in these locations is typically prohibitively expensive, and purity is dependent on the existence of salt water supplies, which are typically scarce in dry locations. The atmosphere is a vast and renewable reserve of water. This limitless supply of water is obtainable everywhere on the planet's surface. When compared to other approaches, extracting freshwater via atmospheric air has various advantages. Air is a clean and renewable supply of water, and the quantity of water in the air is estimated to be 14000 km^3, whereas the quantity of earth's water is only approximately 1200 km^3 [15]. To urgently address water scarcity. This research presents a review of the techniques for generating water from moist air.

2. REVIEWING THE PREVIOUS WORKS

2.1 Experimental works

Aristov et al. [16] Introduced novel selective sorbents matured at the Boreskov Institute of catalysis (Russia, Novosibirsk) and discussion of its use for the output of pure water from Atmosphere gave a general structure of water outcome and proposed a solar powered unit Which can be a good option for deserts with a warm and dry climate. Lab test conclusion It showed the feasibility of producing fresh water by producing 3-5 tons of water for every 10 tons of absorbent substances per day.

Gad et al. [17] developed a new experimental setup that comprises mostly of three components: a corrugated bed, a flat plate collector with a moveable lid made of glass and a condenser that is cooled by air, as shown in Figure 3. The findings revealed that the solar Fresh water may be supplied at a rate of 1.5 L/m^2.day if the system is properly maintained. for the Egyptian city of El-Mansoura They also provided a theoretical analysis.

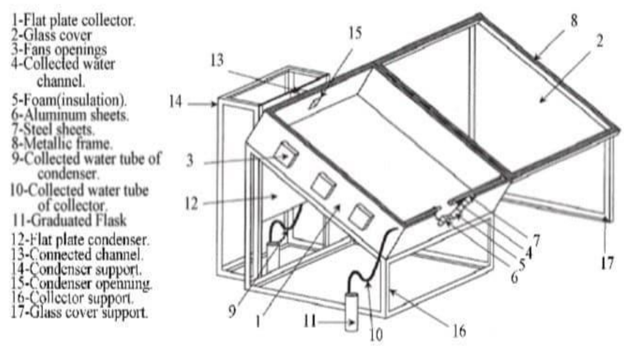
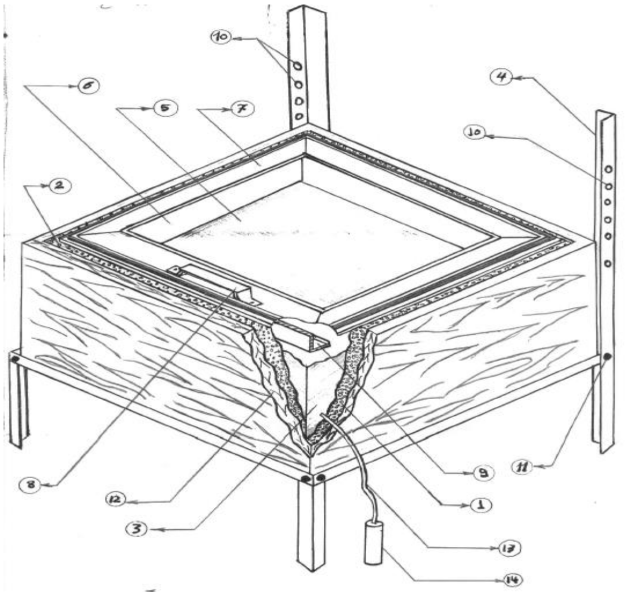


Figure 3. Schematic diagram of the experimental apparatus [17]

Kabeel [18] investigated the effects of gathering water from the air using a sand-based solar collector device, as shown in Figure 4. The sand bed is used to represent the Arabs in their desert country. Three distinct tilts of the system are investigated experimentally. 15 degrees, 20 degrees, and 25 degrees are the angles. The theoretical model was developed to investigate the impact. From a variety of variables, such as the solution's concentration and the intensity of solar light. The According to the findings, the method may save 1.2 L/m^2.day of fresh water of glass cover the agreement between theoretical and practical outcomes The results of the experiments were determined to be accurate. The findings also demonstrate that there is a trend During the testing phase a 25-degree angle produces better yields.

Kabeel [19] studied the impact of pyramid form on absorption and regeneration processes was investigated using two pyramids, as shown in Figure 5. The primary pyramid's bed was manufactured of saw wood, whereas the other pyramid's bed is built of cloth and has the same measurements. According to preliminary findings, the bedclothes absorb moisture extra solution (9 kg) than the bed with saw wood (8 kg). Following this strategy yields 2.5 L/m^2.day which could result in a more efficient system.



1- Foam (Isolation).
2- Steel sheets.
3- Collector Support.
4- Sandy Layer.
5- Glass Cover.
6- Metallic Frame.
7- Handle.
8- Collection basin.
9- Holes of Fixation.
10- Linking Bolt.
11- Wood sheets.
12- Collected Water Tube of Collector.
13- Graduated Flask.

Figure 4. Schematic diagram of the experimental apparatus [18]

Figure 5. Photograph of the system used [19]

Hamed et al. [20] presented a study experimental unit was developed and fitted specifically for this use in the Taif region climatic conditions, as shown in Figure 6, Kingdom of Saudi Arabia. The 0.5 m^2 unit includes a desiccant collection unit containing a sand bed mixed with calcium chloride. About 1 L/m^2.day of clean water can be regeneration from the drying bed. In addition, the study attempted to see how different parameters affect system yield during regeneration. These variables comprise system design factors as well as weather conditions.

Figure 6. View of the experimental unite [20]

Kabeel [21] used a wick-type solar device that was treated with a calcium chloride desiccant solution and produced 1.4 L/m^2.day of water production.

William et al. [22] designed a four-sided trapezoidal prism solar collector with glass fibers, as shown in Figure 7. This complex has a multi-shelved bed to make the most of the bed surface range within the complex. Experimental work shows the result of climatic conditions on the operation of the system day and night. The methods of absorption and evaporation are discussed for each practical case. Furthermore, the different host materials (sand and cloth) were sieved with calcium chloride solution. The comparison between the different types of beds is illustrated. The results revealed that the water completely evaporated to the canvas layer and sandy layer could reach 2.32 and 1.23 L/m^2 per day at the initial saturation concentration (30%) of $CaCl_2$.

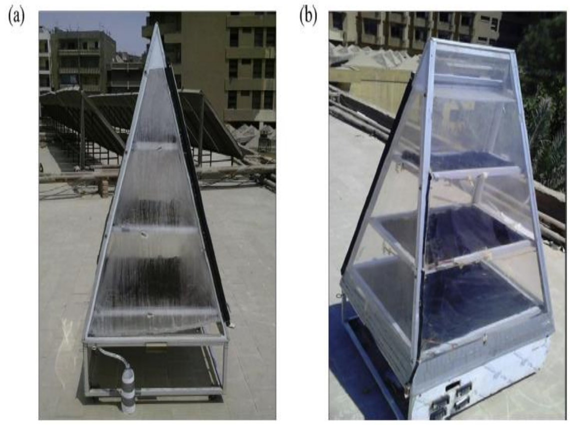


Figure 7. (a) Daytime operation of an experimental test rig. (b) the end of the day [22]

Kumar and Yadav [23] studied a novel substance composed of various materials for storing and producing water from atmospheric air, as shown in Figure 8. Experiments were conducted in climatic conditions of India in October. Three solar collectors are used in a dry-glass container system with a capture area of 0.36 m^2 to produce water, the distance between the glass and absorber materiel is 0.22 m and the inclination is 30 degrees, the thickness of the glass (3 mm) and the number of glass are single. It was found that the rate of water production depends on the concentration of $CaCl_2$ in saw wood. The maximum water yield was 180 ml / kg / day for a compound of a substance containing a concentration of 60%.

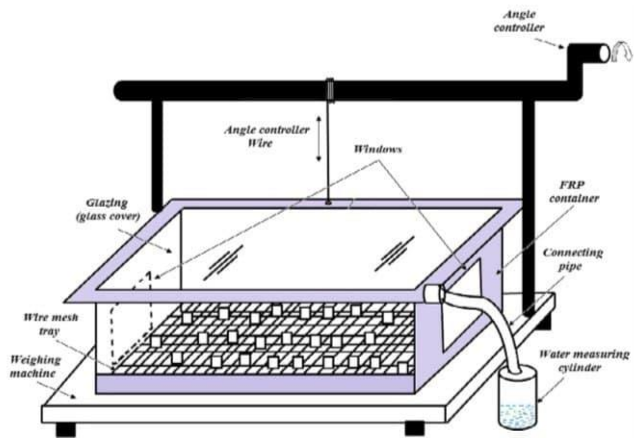


Figure 8. Schematic diagram for solar glass desiccant based system [23]

William et al. [24] presented for theoretical study A model of the regeneration process. When compared to other published models, the latest design shows a 15% increase in theoretical outcomes. The objectives of this work are to assess the impact of various operating circumstances (host materials initial dryer concentration, and initial mass of solution) on the performance of the system (water productivity, system efficiencies and evaporation rate). Also, the simulation model checks the performance of the system for various Egyptian climate conditions (summer and spring). Total water outcome, which can be It was achieved in spring about 3.02 L/m^2.day in Alexandria.

Wang et al. [25] devised a technique to collect roughly 14.7 kg of water while pouring 40.8 kg of sorbents into a sorbent bed with a size of 0.40.6 m. This technique ensures the great adsorbing ability at 23℃ and 90 percent RH, and reaches a big quantity of desorption (0.65g/g) between 70-80℃ with 8.8 Pa resistance to flow. In sorption process, pure water is collect under the condition of 85, 75 percent, and sixty-five percent RH; while in desorption process, 14.5kg, 13.6 kg and 0 kg water is collect under the conditions of 90℃, 77℃. and 60℃, respectively.

Wang et al. [26] designed and manufactured two solar powered devices to extract pure water from air on absorption technology: the first is of the open type, and the second is improved of the semi-open kind, as shown in Figure 9. Both technologies can be powered by a solar collector at a temperature of 70-80℃. 0.32 kg of accumulated water in the concept Folding machine with 2.25 kg of ACF-$CaCl_2$ sorbent. 9 kg of accumulated water using a 4 m^2. solar collector Zone with semi-open kind optimized device, corrugated and flat sorbents are made for packing 40.8 kg of sorbent ACF-LiCl.

Among those who have contributed to this work are Srivastava et al. [27]. In this research, as shown in Figure 10, three composite materials (LiCl/sand (CM-1), $CaCl_2$/sand (CM-2), and LiBr/sand (CM-3)) were used as salts with a concentration of about 37 percent, with sand as the host material. 115 ml/day and 73 ml/day are the highest amounts of water created by CM-1, CM-2, and CM-3, respectively.

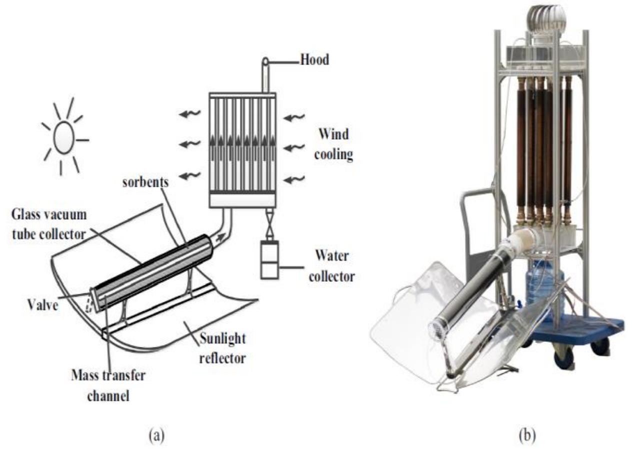


Figure 9. (a) Working diagram (b) Physical device [26]

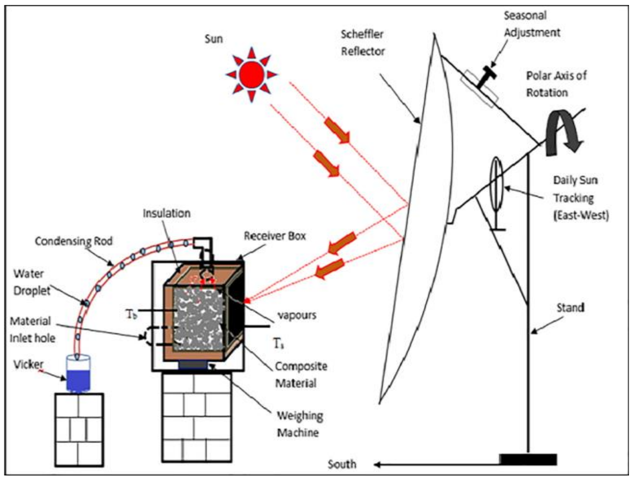


Figure 10. Schematic diagram of experimental setup [27]

Talaat et al. [28] discussed a new design for a conical fin water extraction unit. Water is collected from the atmosphere by heating it using solar energy, as shown in Figure 11. At night, the conical absorbent consisting of a tissue layer coated with black paint and the use of calcium chloride absorbent solution is exposed to moisture from the surrounding air. During the day when the temperature of the absorber rises due to solar radiation, the absorbed vapor separates from the mixture and condenses on the surface. The yield of the system was 0.63 l/m^2 day.

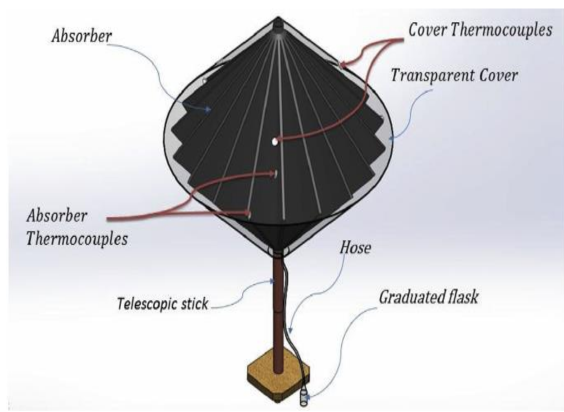


Figure 11. The major components and temperature sensor distribution upon this absorber and cover are shown in this schematic diagram of the experimental unit [28]

Mohamed Elashmawy [29] under extremely low humid air conditions, water extraction from ambient air was tried in an experimental setting (12 percent). The desiccant is placed in a rectangular basin with a bed made of black cotton, as shown in Figure 12. During the night, a small air blower is placed in the device to circulate the air surrounding the tube (absorption process). The absorption procedure was investigated at five various air speeds (natural, 0.5, 1, 3, and 4 m/s). The results revealed the largest water yield of 467 ml/m^2/day at an air speed of 4 m/s and a relative humidity of 25%.

Figure 12. Schematic diagram of the test-rig [29]

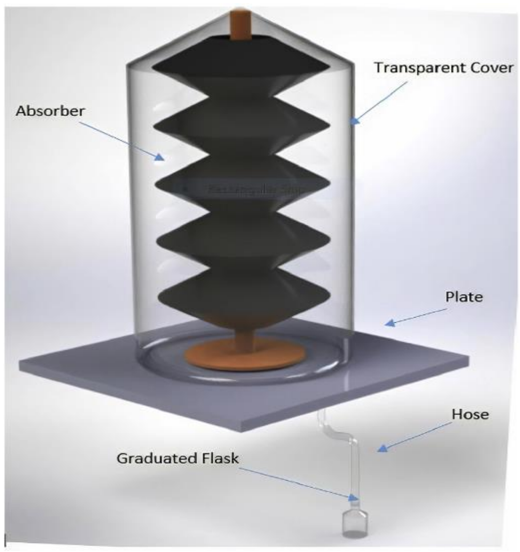


Figure 13. Schematic diagram of the apparatus [30]

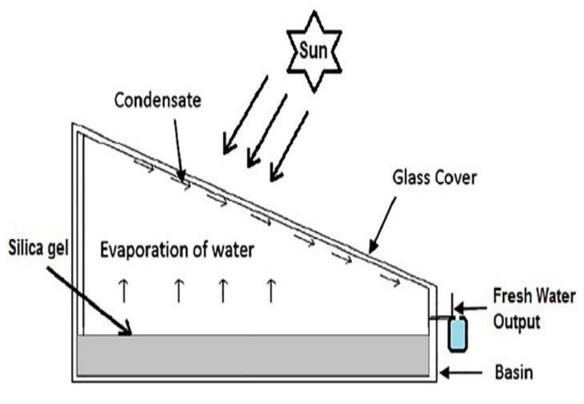


Figure 14. Schematic of solar recuperation system [31]

Fathy et al. [30] provided a theoretical and practical analysis of solar-powered foldable equipment for extracting water from the air in arid areas, as shown in Figure 13. Water is collected at a rate of 750 g/day.

Manoj Kumar et al. [31] employed orange silica gel as absorbent material, which absorbed humidity from air through the night, as shown in Figure 14. Through the day, water from the loaded silica gel was recovered utilizing a solar recuperation device. The trials were carried out in Coimbatore, India, on three identical Sundays in April 2020, and the average results are provided. According to the results, the system created 0.98 L/m^2 of drinkable water per day.

2.2 Theoretical works

Hall [32] suggested a cycle for extracting water from ambient air and use ethylene glycol as a desiccant liquid, then recovering it in a solar distiller. The effect of temperature and humidity on collected water were calculated, and the findings were given as a composition–psychometric chart.

Hamed [33] tested two techniques for extracting water from air by solar energy. The first technique relied on reducing the temperature of humid air below the condensation point by utilizing a LiBr-H_2O cooling through radiation absorption. The other method is based on absorbing humidity from air through the night by utilization a ($CaCl_2$) solution as absorbent material. The second technique was recommended as the most appropriate use of solar energy to recover water from the air.

Gandhidasan and Abualhamyel [34] developed an analytical investigation to extract air moisture using desiccant liquid. As an absorbent material, the suggested system uses one flat, inclined surface that is exposed to the atmosphere. This study presents an investigative approach for calculating the mass of water absorbed by the drier from the surrounding in the solar collector as a function of time. The drying agent's beginning circumstances and meteorological quantities are shown.

Hamed [35] investigated the theoretical cycle of absorbing steam from the air and described and analyzed it. In a simplified version, the properties of the desiccant ($CaCl_2$) are described, which can be employed in the computational study of the cycle performance. According to theoretical research, the cycle efficiency value is heavily influenced by the weak and strong solution concentration restrictions. The regeneration temperature limit and the mass of the strong solution per kilogram of steam produced are discovered to be highly dependent on the chemical's operating concentration.

Ahmed Sultan [36] presented a method that uses a packed tower for forced load absorption and renewal. The maximum effectiveness increases within the final desiccant concentration and reductions with the growth in the velocity of the regenerative air stream and the absorption temperature. To estimate system performance under various operating situations, a numerical model derived from empirical findings has been constructed.

Researchers [5, 37-44, 46, 47] presented different nanocomposite materials can be used for thermal energy storage and release which may be applied in solar water desalination unit. Also, designed modern solar still for production of pure water in the remote regions.

Table 1 contains a selection of publications that can be used to better follow up on the various ways for extracting water from the air.

Table 1. Publishing different methods for extracting water from the air

References	additive Material	absorbent material	Amount of absorbent	product water	Relative Humidity	Device type
Aristov et al. [16]	Alumina, silica gel, and porous carbon	SiO_2+CaCl_2	10 kg	3-5 L/m^{2}day	50-80%	special design solar-driven unit
Gad et al. [17]	inner layer of zigzag cloth	$CaCl_2$	2.25 kg	1.5 L/m^{2}day	20-80%	A surface solar collector with an inner zigzag layer of cloth with $CaCl_2$ solution
Kabeel [18]	Sand	$CaCl_2$	-	1.2 L/m^{2}day	-	single basin solar collector
Kabeel [19]	Cloth	$CaCl_2$	2.7 kg	2.5 L/m^{2}day	60%	Hierarchical solar collector with 4 shelves
Hamed et al. [20]	Sand	$CaCl_2$	1 kg	1 L/m^{2}day	40%	Solar collector in the form of a basin
Kabeel [21]	Cloth	$CaCl_2$	2.79 kg	1.5 L/m^{2}day	83%	Hierarchical solar collector with 3 shelves
William et al. [22]	Priming	$CaCl_2$	3.75 kg	1.4 L/m^{2}day	50%	Solar collector in the form of a basin
Kumar and Yadav [23]	saw wood and vermiculite	$CaCl_2$	1 kg	0.195 L/m^{2}day	-	Solar collector in the form of a basin
William et al. [24]	cloth and sand	$CaCl_2$	6-12kg	3.02 L/m^{2}day	83%	Fiberglass Four Sides Trapezoid Prism Solar Collector multi shelves
Wang et al. [25]	felt made of carbon	LiCl -ACF	40.8 kg	14.7 kg	85%	system that is semi-open
Wang et al. [26]	felt made of carbon	ACF-LiCl+ ACF $CaCl_2$	40.8 kg	14.7 kg	85%	system that is semi-open + system that is open
Srivastava et al. [27]	Cloth	$CaCl_2$	-	0.63 L/m^{2}day	-	solar collector with conical fins
Talaat et al. [28]	Sand	$CaCl_2$	-	0.08 L/m^{2}day	-	solar collector with Scheffler reflector
Elashmawy [29]	-	$CaCl_2$	1 kg	0.27 L/m^{2}day	60%	solar collector with two layers
Fathy et al. [30]	cotton cloth black	$CaCl_2$	175 g	Max 467 mL/m2 per day with a max air velocity of 4 m/s, minimum 230 mL/m^2 per day for a normal air velocity	12%	Tubular solar device with a small fan to circulate air at different speeds
Kumar et al. [31]	-	[Zr6O4(OH)4(fumarate)6 (MOF)-801	1 kg	0.25 L/m^{2}day	40%	Solar collector with air-cooled absorbent materials
Hall [32]	-	Gel that absorbs a lot of moisture.	1 kg	3.90 L/m^{2}day	85%	Tubular solar collector
Hamed [33]	layer of black cotton cloth	$CaCl_2$	-	750 g/day.	-	Solar powered foldable device
Gandhidasan and Abualhamyel [34]	orange silica gel	-	10 kg	0.98 L/m^{2}day	60-75%	single basin solar still

3. CONCLUSION

The creation of fresh water is currently one of the world's most pressing issues. Desalination is a time-consuming and energy-intensive process for producing climate-independent drinking water. Atmospheric air is a vast and abundant reservoir of water. This endless source of water can be found all around the world. Although there is only about 1200 km^3 of clean water in lakes and rivers on the planet's surface, the volume of water in the atmosphere is believed to be 14000 km^3. Future development of water extraction techniques is necessary. Due to all of the aforementioned research efforts and the appealing possibilities they have presented, water extraction is capable of extending the boundaries of current technologies and will significantly contribute to reducing water shortages.

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