Alkyd Resin dye-based Coating on Surfaces in order to Produce Hydrophilic/Hydrophobic Properties and Increase Water Harvesting Performance from Fog or Steam

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Abstract

Today, due to the severe decline of water resources and the crisis of freshwater scarcity, the use of new methods for water production and recovery is of particular importance. The presence of high humidity and fog in many parts of the world has potential for water collection. In this research, using of super-hydrophobic /hydrophilic surfaces for water harvesting from the humid air as a simple method with minimum energy consumption is investigated. The material of the plates, the use of meshed plates, the angle of plate placement and the distance from the steam flow were investigated for the cold and hot steam flows. The results of the experiments revealed that the polymeric plate has an acceptable performance of 893.062 $g/m^2.h$ and they can be used because of its lightness, cheapness and easy malleability. The results of hot and cold steam systems showed that the plates with one face exposed to hot steam and one face exposed to the environment perform better compared to ultrasonic cold steam and the plate placement at an angle of 75 degrees with the horizon can increase the water harvesting efficiency 3 times compared to the plate with 90° angle. Plates coated with dye material obtained better results than simple hydrophilic plates in the hot steam system due to their super hydrophobic/hydrophilic properties. Among the surfaces used,

the hydrophobic aluminum meshed plate and solid plate were the plates with the best performance that achieved water harvesting performance of 55 g/m^{2}h.

Keywords: Water harvesting, Contact angle, Hydrophobic/hydrophilic surfaces, Droplet condensation.

1. Introduction

The lack of water resources in the right amount, right quality, right place and right time has made it difficult to manage water resources [1]. Approximately half of the inhabitants of the planet face the problem of access to sufficient sources of clean water and sanitation, and more than two billion people do not have access to clean water sources [2, 3]. 70% of the earth's surface is covered by water. However, most of the water on the planet that is stored in the oceans and seas is salty and a very small percentage of it is fresh water that is either in the form of ice in the poles and natural glaciers or out of reach and cannot be used [4]. Water desalination, ground water harvesting and collection and preservation of rainwater are of the methods around the world that employed to answer the water demand. Of course, to use these methods, water needs to be in the liquid phase, and in the absence of liquid water, atmospheric water as the air humidity becomes useful [1, 2, 5]. Fog and humidity are great sources of potable fresh water. Recently, new methods have been used to extract water in nature and industry. The continuation and updating of these methods can be an important step towards helping the environment and restoring water and answering huge global crisis of fresh water supply [6, 7]. In last decades attempts have been made to use the fog and humid air as a water resource. The first experience of harvesting water from fog dates back to 1978 [8]. Ghosh et al [9] investigated the performance of fog capture from thermal power plant cooling towers. They proposed a fog harvesting strategy that can reach the recovery of water loss of the tower as 10.5 m^3/h. Wang et al [10] used a new surface with wedge-shaped patterns modeled on desert beetles to facilitate the nucleation of water droplets. They obtained a synergistic effect for water droplet nucleation and droplet transfer that resulted in 11 times of the water harvesting performance compared to the hydrophobic plates. Yang et al [11] utilized the Nanosecond Laser ablation to fabricate a super-hydrophobic surface from Inconel alloy. They described how the airborne hydrocarbons can be attached onto the surfaces ablated by the laser, which reveals the generation mechanism of air-exposed super-hydrophobic surfaces.

In this study the hydrophilic hydrophobic surfaces were formed using alkyd resin base paint to improve the performance of water extraction by metal plates and mesh from the flow of ultrasonic cold and hot steams.

2. Methodology

In this research, laboratory equipment including laboratory scale, thermometer, hygrometer and fan were used. Also, 3 steam production systems were used to produce atmospheric humid resource for water harvesting as:

1) Hot steam production system for simulating industrial hot steam loss in order to analyze the performance of plates facing hot steam. Therefore, a heating element that boils water in the kettle tank at a temperature of 96 °C (due to the longitude, latitude and altitude of the laboratory) was used. In the first method, the steam is directed by the pipe from the galvanized cubic chamber of the steam generator to the water collection plate, and due to the heat loss from the surface of the pipe, the temperature of the steam reaches 85°C. The steam hits the collection plate at ambient temperature (22 to 27°C). The second method the produced steam was transported through the pipe into the galvanized cubic tank containing the sample plate under the same temperature conditions as 96 °C to hit the plate placed in

the direction of steam flow. Third, creating a hot steam system by moving the steam generated from the boiler by the fan in order to exchange more steam with the surfaces.

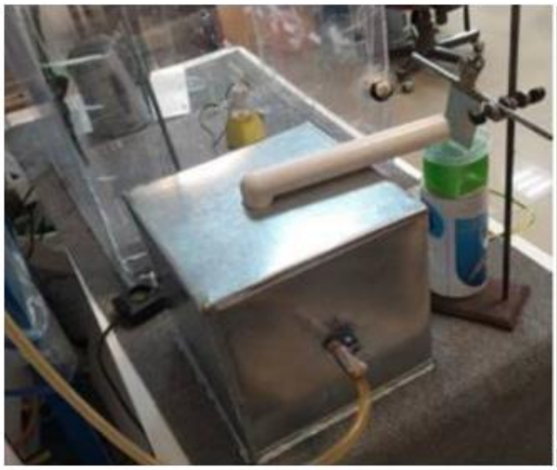
2) An ultrasonic humidifier or cold humidifier consists of several piezoelectric ceramic discs that oscillate in the presence of electric current at an ultrasonic frequency, resulting in water oscillation in fact ultrasonic humidifiers use ultrasonic vibrations to create a fine mist of water droplets that evaporate into the air, increasing humidity. They are quieter and more energy-efficient than traditional humidifiers. Subsequently, the water molecules try to follow the high frequency oscillation of the plates, but due to their inertia and relative weight, they cannot oscillate at the same frequency, and the water wave moves behind the disk wave with a delay. As a result, a low-pressure area is created between them, which creates a cavity. The created cavity can be a vacuum or it can be filled with water dissolved air flashed into the low-pressure area. Bursting this cavity creates a lot of energy. On the other hand, the vibration of the disc also creates capillary waves on the water surface. When the cavity bursts, a transverse capillary wave is formed on the surface of the water and creates very small water droplets on top of the wave, which have enough energy to break the surface tension and leave the surface of the water. Since the ultrasonic atomizer creates steam by oscillating, the temperature of the water does not increase. Ultrasonic technology produces humidity instantly in cold steaming and does not need time for water to evaporate. The steam produced by the ultrasonic atomizer is easily absorbed by the air and does not move upwards in the air unlike hot steam. This unique feature is the best option for simulating the conditions of natural fog production in laboratory conditions.

3) Controllable steam generating system (curing) with humidity and temperature control system in different temperature range from 21 ± 2 to 50 ± 2°C and humidity from 50 ± 15%

to 90 ± 5%. The main goal of this system is the feasibility of water recycling and production in environmental conditions and different temperatures similar to different weather conditions. With this system, it is possible to simulate different weather conditions received from meteorological organizations.

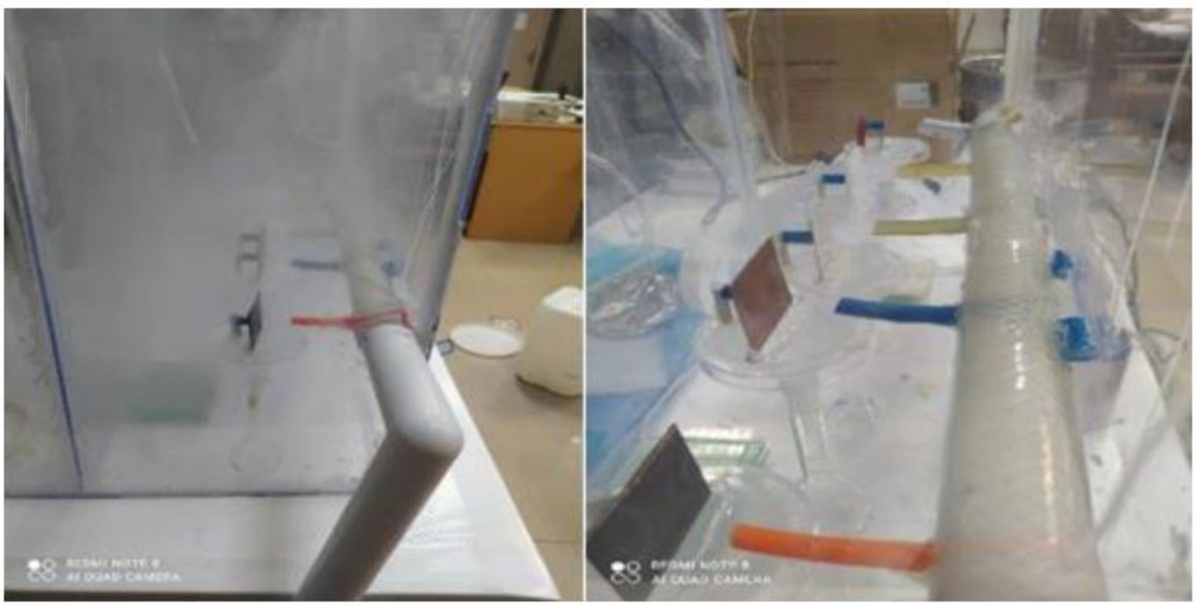
2.1. Coating procedure

The chemical structure of the material used and the obtained surface roughness are two important factors in the use of coatings and dyes in order to achieve a hydrophobic property of the plates. It worth noting that the creating a contact angle greater than 120° on a surface only by relying on its hydrophobic chemical structure is impossible, without any structure in nano or micro dimensions. Therefore, surface roughness is an important factor in hydrophobic coatings. In this method, thin layer of alkyd-based dye is coated on rough surfaces due to their thermal and chemical resistant, hydrophobic and anti-corrosion properties. Figure 1 shows Experimental set up and the meshed plate of steel coated by alkyd resin-based dye as a hydrophobic/hydrophilic surface. The samples were sprayed in the same way by a type of paint gun and at the same time under the conditions of temperature and pressure (25 °C and pressure of 1 atmosphere) and with a spraying distance of 30 cm. Since the presence of a uniform layer on the metal surface causes fully hydrophobicity and does not provide the hydrophilic/hydrophobic property of surface; therefore, for coating with dye, rolling the sample in the dye bath and heating the dye by the furnace were avoided. But in the method of spraying, nano and micro fragments on the surfaces (as shown in Figure 1), remains without dyes, which strengthens the creation of a hydrophilic-hydrophobic structure.



Hot vapor set up

Hot vapor set up with fan



Cold vapor set up

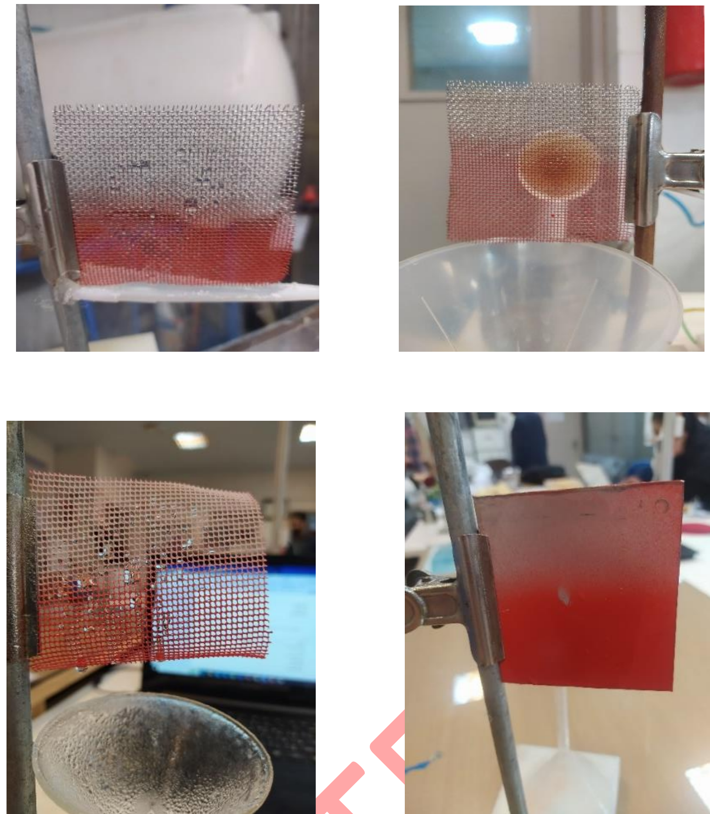


Figure 1. Experimental set up and three mesh samples (polymer, 304 stainless steel and aluminum) and a coated aluminum plate sample by alkyd resin-based dye.

2.2. Sample preparation and experimental procedure

In the experimental system, double distilled water was used. The aim is to investigate the performance of surfaces for two types of cold and hot steam. Therefore, the efficiency of water harvesting through the changing of the surface structure, dye coating and water-repellent coatings, was investigated in both the cold and hot steam laboratory systems. After that, by analyzing the results obtained from the experiments, the best option for building a suitable Setup was determined. The parameters studied in this research are time, temperature, humidity level, material, mesh number, angle of the collector, steam direction, steam volume, contact angle, wettability properties, and comparison of cold and hot steams. After setting up the ultrasonic cold steam laboratory system and reaching the saturation humidity, which is confirmed by indicating 100 by the humidity sensor, the plate samples made with the desired conditions are placed in the chamber in the vicinity of the steam for a period of three hours. Then the resulting water was weighed. After ten minutes of system started, its chamber was saturated with steam, and at this stage the humidity sensor reached the HH (High Humidity) mode, which showed the saturated humidity above 95% in the ambient temperature. After reaching these conditions experiments of water harvesting are started. After three hours, the samples were taken out and the device was turned off and the collected water samples were weighed. It should be noted that in order to achieve acceptable results with the real conditions, the system has been considered open so that the existing humidity interacts with the surrounding air and transfers, which is an example of the movement of fog in nature.

2.3. Plates materials

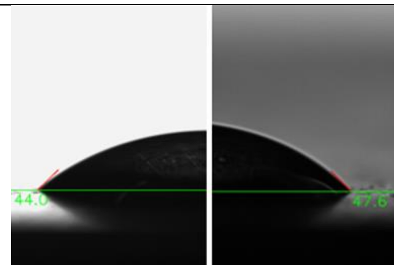
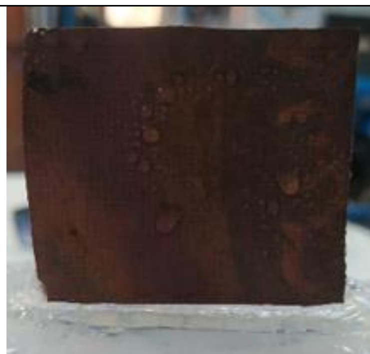
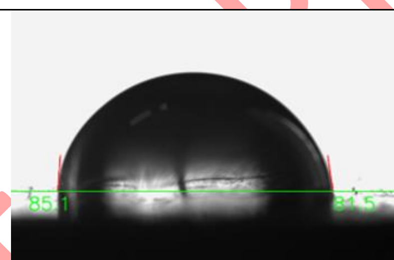
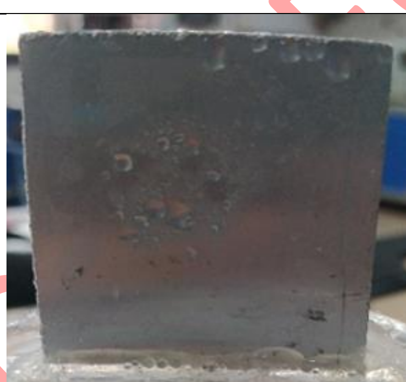
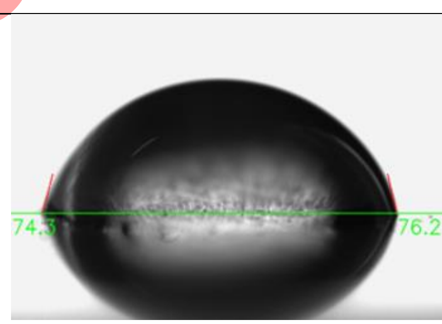
One meshed plate sample and four plate samples with dimensions of 80×80 mm^2 and under the same conditions were used in order to investigate the effect of different parameters. The reason for net samples and plate samples is that it is not possible for steam to pass through the sample in a plate sample. which is on increasing the efficiency of extracting medical water. Also, sprinkling of steam on the screen causes its reflection and in the natural process of movement of fog in nature and industries.

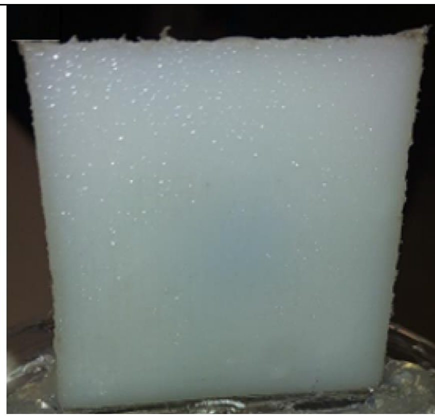
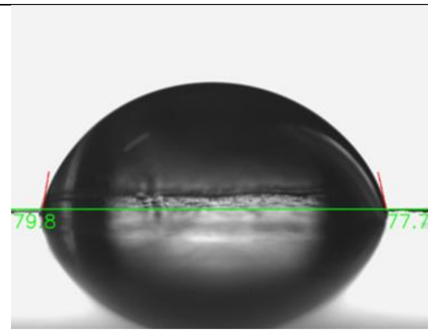
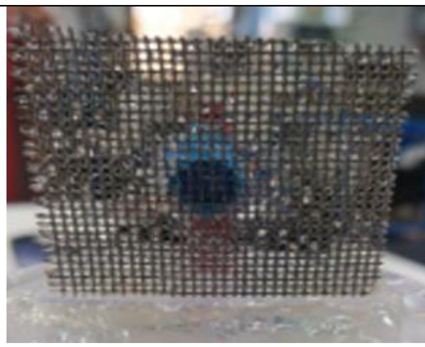
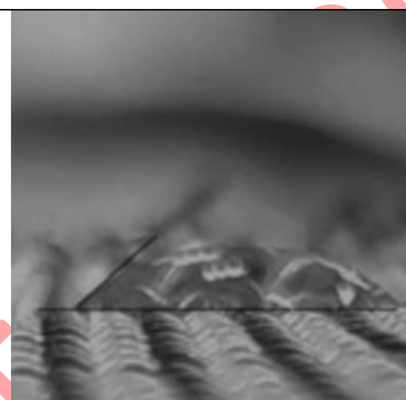
3. Results

3.1. Wettability and drop contact angle

The droplet contact angle measurement was done on different plates and meshed plate are presented in Table 1. It can be seen that the plates have different wettability properties.

Table 1. The water droplet contact angle measurement was done on different plates.

Fe			44-47.6
Cu			81.5- 85.5
Al			74.3- 76.2

PE			77.7-79.8
meshed steel			--

The meshed plate cannot be tested by the contact angle method, but since their sheet sample has hydrophilic properties, it can be argued that the meshed plates have the same wetting properties. The metal mesh sample, an angle of nearly 45° was obtained, which indicates the super hydrophilicity of the steel surface. Of course, the contact angle of steel is generally below 90°, which indicates its hydrophilic property.

3.2. Nozzle diameter

The behavior of water harvesting by different plates were investigated. In this system, by creating nozzles with different diameters in the steam distribution path on the plates, the effect of steam ejection dynamic pressure was studied. The results are shown in table 2.

Table 2. The results of water harvesting experiments for type of materials of plates and nozzles (cold) in 90°

Tag	Cross section area of steam outlet pipe (mm^2)	Water harvesting rate ($gr/h.m^2$)				
		Fe	Cu	Al	PE	meshed steel
D1	132.66	297.68	24.50	285.62	445.29	704.42
D2	63.58	275.48	198.00	115.67	94.093	181.71
D3	50.24	271.07	34.64	237.51	250.45	631.56
D4	28.26	30.92	53.75	75.56	65.76	32.20
D5	7.85	24.50	24.50	34.68	58.35	30.12
total	-----------	907.10	349.42	749.07	913.95	1580.01

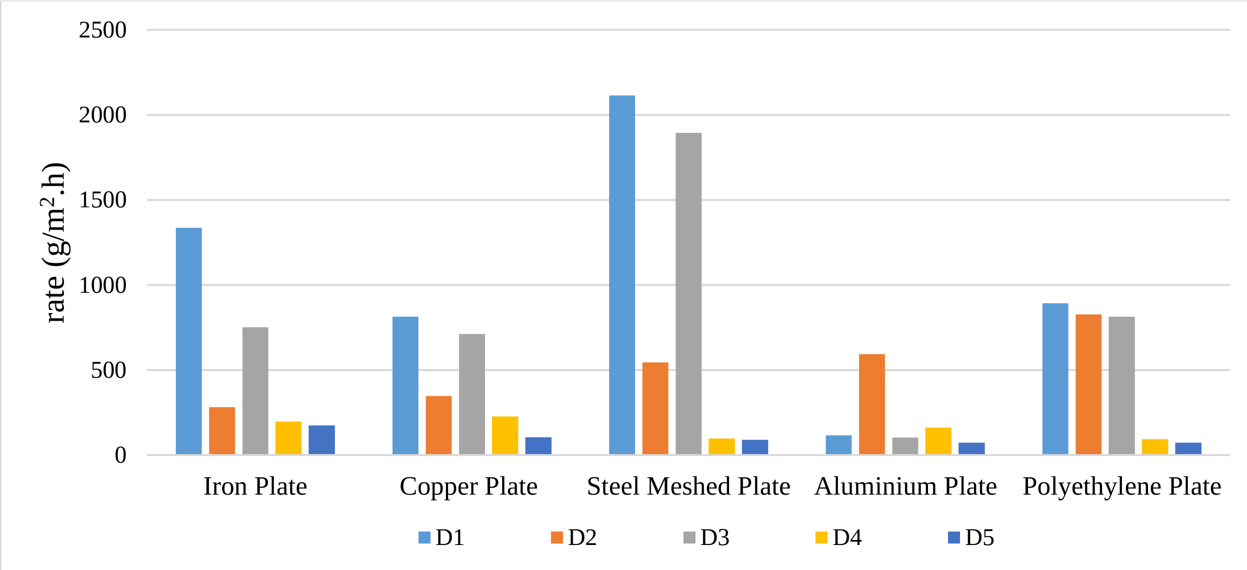


Figure 2. The effect of nozzle diameter on water recovery rate for different plates. D1, D2, D3, D4 & D5 refer to nozzles with diameters of are 5, 6, 8, 9, 13 mm respectively.

In Figure 2, all the samples have been examined in different diameters of the steam outlet, the area of the water collecting surfaces has also been converted into square meters, and since the tests were conducted in 3 hours, this time effect is also calculated in hours. Became which was finally reported in terms of g/m^2h. According to the obtained data, which was obtained in the presence of a steel mesh sample along with 4 aluminum, copper, iron and polymer plate samples, the mesh sample with 1580.01 was the most extracted amount. The copper sample had the lowest amount of 349.42. The iron sample is not suitable for this research due to corrosion and oxidation. On the other hand, due to the high density of iron oxide compared to water, there is a possibility of error in the calculations of the collected water. Aluminum and polymer samples provided good performance. But compared to lace, their amount was less, so lace was examined as an optimal level, and several other types of lace were also tested. It seems that the presence of a network structure of a sample causes air circulation inside the mesh networks, which leads to water deposition in the mesh structures and finally droplet condensation. The details of these samples are presented in Table 2.

3.3. Time of harvesting

Three samples of steel, aluminum and polymer meshed plates were used in saturated humidity and after the formation of the first drop to test water harvesting during a period of four hours. Figure 3 shows the time dependence of water harvested in time of 240 min.

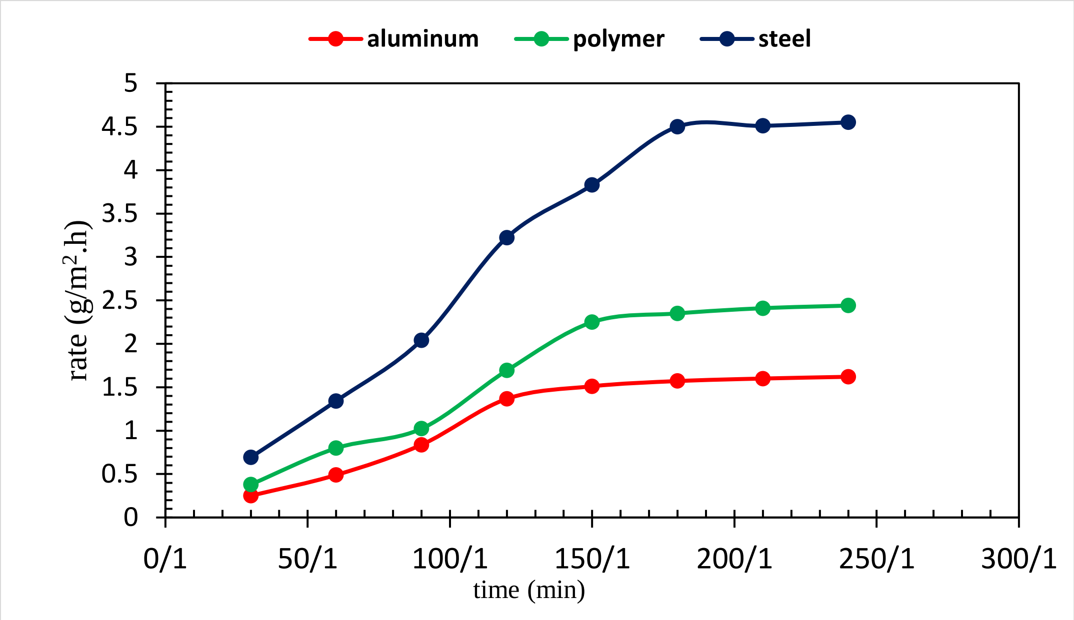


Figure 3. The rate of water harvesting for three different meshed plates during 240 minutes.

The difference in the amount of water harvesting depends on the two phenomena of water condensation and its transfer from the surfaces. The increase in condensation speed is a function of the thermal conductivity of the surface. If the speed of condensation due to the high thermal conductivity of the surface is higher than the speed of water transfer from the surface, a layer of water is gradually forms on the surface, which transfers the condensation from droplet condensation to film condensation. Hence, the heat transfer rate decreases due to the heat transfer resistance of the liquid film. [12]. In droplet condensation, most of the heat transfer occurs through droplets with a diameter of less than 100 µm, and the rate of heat transfer is more than 10 times that of film condensation [13]. Therefore, spray surface coatings are usually used. These coatings prevent the surface from getting fully wet and accelerate droplet condensation. This case is clearly visible in the Figure 3. In the case of the aluminum sample, despite its high thermal conductivity of 237 $W.m^{-1}.K^{-1}$ [14] a layer of water immediately is formed on the surface, which reduces the overall heat transfer coefficient and lowers the heat transfer rate compared to the steel sample that is around 55.4 $W.m^{-1}.K^{-1}$ [15]. Also, the low conductive heat transfer coefficient of the polymer is the reason for the mismatch the trend of diagram between 25 and 100 minutes compared to other plates, because the conductive heat transfer coefficient of metal samples (aluminum and steel) is high. Therefore, the presence of air inside the mesh networks and the purity of the steel mesh and the polymer plate caused droplet condensation in them, which compared to the aluminum film condensation, had a higher efficiency in a certain time and of course in cold steam. The high efficiency of aluminum in hot vapors is due to its high conductive heat transfer coefficient [13, 16].

3.4. The volume of steam entering the plates

The increase of steam volume entering the plates dramatically increases the efficiency of water harvesting process. Between three meshed plates as Aluminum, steel and polymer; the steel meshed plate has a better performance at the output of 50.24 mm^2 compared to 63.58 mm^2, which is due to the thickness of the strings of its meshes compared to the other two samples, but the high efficiency of all samples in the high volume of steam with the same operational conditions is visible (Figure 4). This Figure indicates the impact of inlet steam volume on water collection rate can be explained by considering the following mechanisms such as saturation and condensation, increased vapor concentration, a higher inlet steam volume increases the concentration of water vapor in the chamber and also, enhanced saturation that this increased concentration brings the vapor closer to its saturation point, making it more likely to condense on the cold surfaces of the collector. Finally, accelerated condensation, as the saturation point is approached, the rate of condensation increases, leading to a higher water collection rate.

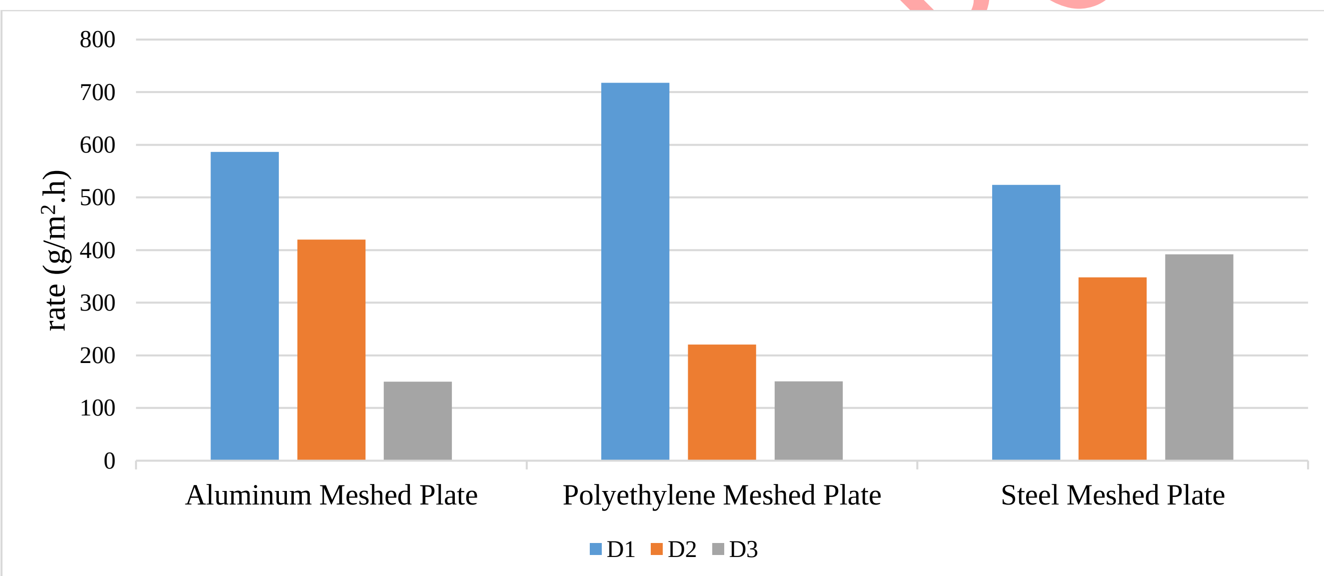


Figure 4. Diagram of changes in the volume of incoming steam.

3.5. Distance test

The effect of mist spraying distance to the plate was investigated using aluminum meshed plate with five tests with different distances from 1 to 5 cm. The dimensions of the plate were 40×40 mm^2 and the diameter of the steam spray was 12 mm (Figure 5). While increasing the distance between the nozzle and the collector surface primarily affects the speed and flux of the input, it can still have indirect effects on the collection rate. This issue is important and how increased distance can lead to decreased efficiency by optimizing collection efficiency, minimizing water loss, improving system durability.

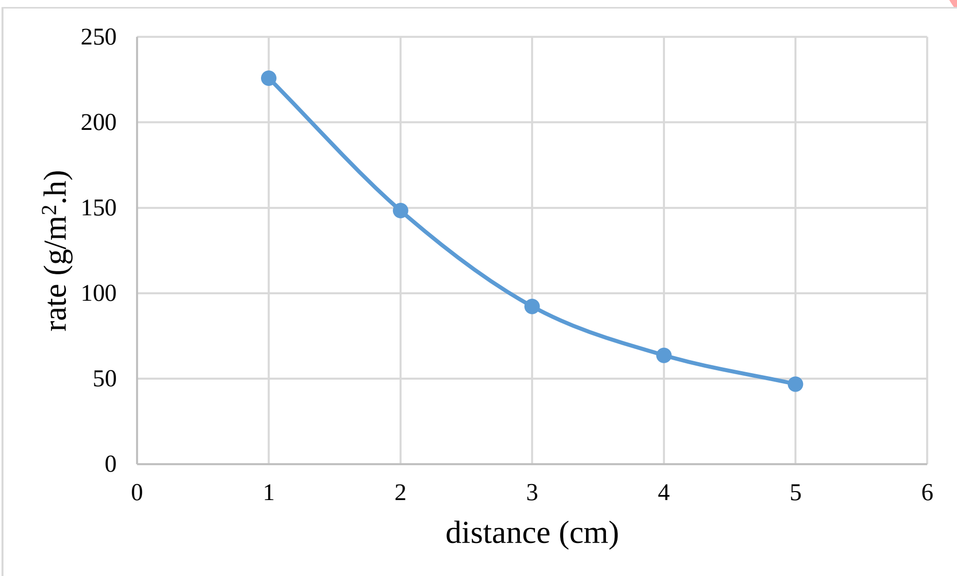


Figure 5. The effect of distance between fog spray and the surface.

The greater the distance between the water collecting surfaces and the mist spray nozzle, the less the amount of water collected. This issue fully manifests itself in industrial steams, but it cannot be true in steams in nature, because in nature, steam will radiate to the sample from all directions, but in industry, as steams come out of stacks, or as steam tracing or they move through pipes with certain pressures and temperatures, so this case is true there. Figure 8 shows droplet rolling and dripping from the surface of the mesh. Since droplet pinning on the mesh and clogging depend on the interaction between the droplet-weight and the CAH force between the liquid and the mesh surface, it is intuitive that the (rc) is a function of α. For each mesh inclination, the experiment was repeated 5 times. As the inclination of the fog harvesting mesh increases, the barrel-shaped pendant droplet becomes hemispherical [17, 18]. However, as the liquid rolls down the mesh, it sometimes drips off before reaching the collector at the bottom, likely due to the momentum of the rolling droplet. The frequency of such drip off is irregular and increases progressively as increases from 15° to 35°, influencing the drainage efficiency.

3.6. Fog spray angle

In all the experiments, the spraying angle and the collection angle were set vertically, then the effect of the placement angle was investigated. It should be kept in mind that factors such as gravity and the placement of the liquid droplet collection container have a direct effect on the amount of water collection.

Figure 6 examines how to place and align the angle and look at how to place the mesh and screen at different angles.

Also, the possibility of water depositing in the opening of the mesh at an angle of 90° or water dripping out of the container at angles between 45 and 0 degrees with the horizon is significant. The experiments showed that the angle of 55 to 75° is the best angle for the movement of liquid drops into the water collected container. Because it prevents sedimentation and water dripping out of the container, this amount of gentle slope brings the movement of the water drop towards the water container to the maximum possible state. At this particular angle, the time it takes for a drop of water to reach the top of the sample until it reaches the water collection container is the shortest time. In the experiment, the desired angle has been investigated in two ways. The first view is the angle that the sample makes with the horizon, and the next view is the angle that the surface makes with the normal vector of the horizon surface. In Figure 6, this effect is well shown and the angle is analyzed from both horizontal and vertical directions. For example, when it forms an angle of 75° with the horizon, it actually forms an angle of 15° with the vertical surface. In this experiment, the speed of the droplet movement from the highest part of the surface to the lowest part, when the droplet drips into the container, has been examined. The placement of the plate samples has been measured with an error of ±5 degrees. In this experiment, water drops were injected from the top of all plates and the time was taken to reaching the inside of the container. At angles of 15 to 35°, the drop of water moved into the container in less time. The drop transfer time at 75° is three times compared to 90°. For large values of α (From 0° to 45° angle with the horizon), droplets drip-off from the mesh prematurely, before rolling down the mesh.

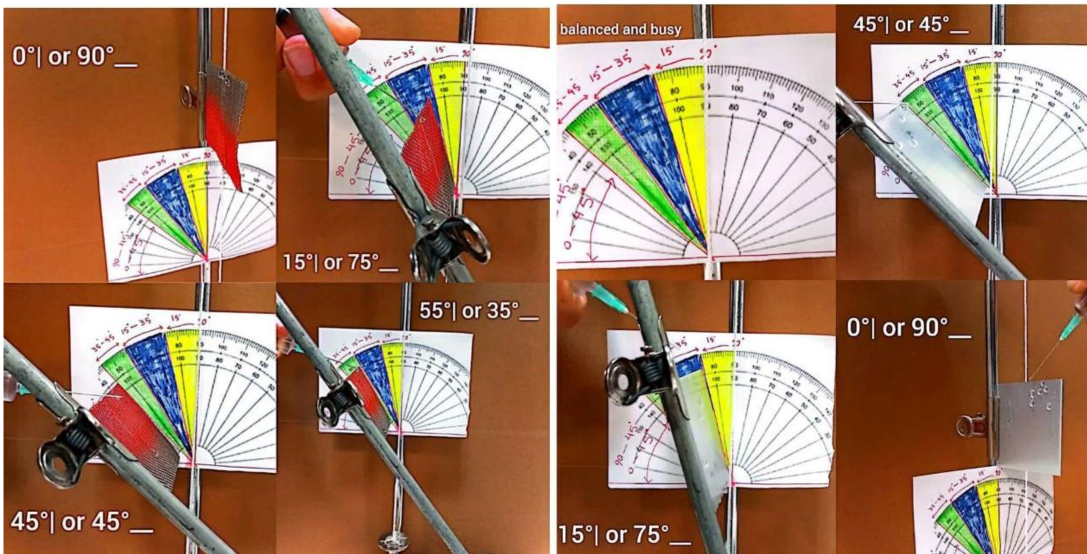


Figure 7. The placement angle of the water collection plate, the right side of the plate sample and the left side of the mesh sample.

Table 3. Investigation of the effect of droplet movement speed at different angles for copper

	90° to the horizon	75° to the horizon	55° to the horizon	45° to the horizon
The speed of water movement on the mesh (m/s)	0.072	0.230	0.117	Dripping and non-slip
The speed of water movement on the plate (m/s)	0.098	0.307	0.153	0.025

According to the results of the experiments related to the cold steam, it is clear that the highest amount of collection in the average period of time belongs to the steel meshed plate. The least amount of collection is for the metal plate made of copper. Polymer, aluminum, and iron plates have almost the same efficiency, and according to the supply costs and economic efficiency, they can be chosen according to the project considerations. Hydrophobic solvents and their coating on the surfaces have a high probability of obtaining the desired results, which is discussed in the continuation of this research. The property of being hydrophobic and the force of gravity plays an important role in collecting more water. The good performance of polymer meshed plate helps to use it as an optimal surface in this temperature range, in the cold steam system, which is often the source of fog moisture in the environment.

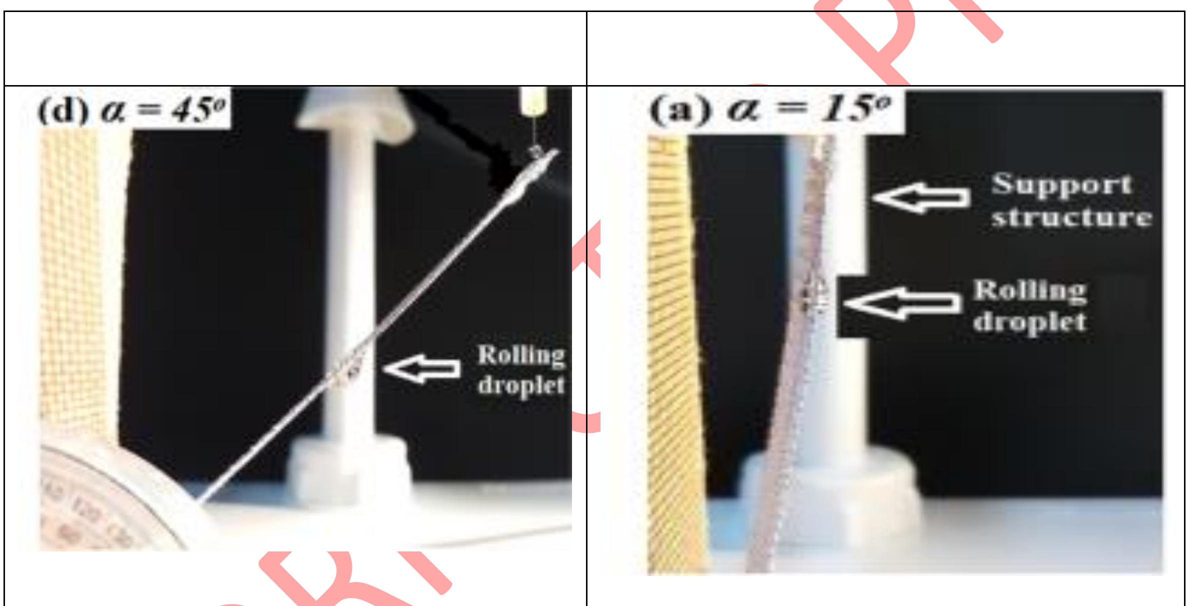


Figure 8. Rolling of deposited droplets on the surface of the HPL-TiO_2 coated mesh placed at different inclinations between (a) 15° – (g) 75° [19].

The volume of the deposited droplets needed to start draining into the net increases with the increase in the time of the sample being in the vicinity of the steam, and at the right angle, the speed of its transfer into the water collection container also increases[17]. In this research, in addition to examining the placement angle of the screen, the time of the drop moving from the highest part of the screen to being poured into the water collection container was investigated and at the end it was reported as the speed of water movement on the mesh (m/s). The placement angle of two mesh and plate samples were compared under the same conditions. The purpose of this experiment was to check the speed of droplet movement on the water collecting sample, so in order not to create a lot of time for nucleation and droplet formation in the hydrophilic part, the hydrophobic part of the net sample was placed at three angles of 45, 55, and 75 degrees in the opposite direction of the driving force, i.e., up. But at an angle of 90 degrees, because basically the particles are deposited inside the mesh, according to the procedure of this research, the hydrophobic part was towards the bottom, that is, in favor of the force of gravity. Since calculating the radius for a barrel-shaped droplet is not straightforward, we have considered the droplets to be hemispherical for all the cases, which is consistent with literature for droplet radius analysis [19]. In order for the force of gravity to have the most help in increasing the amount of water collection, the coated part is placed towards the ground and at the bottom. So, the drops that are in the upper part of the sample, i.e. in the completely hydrophilic environment, nucleate and are collected and enter the hydrophobic coated environment and are quickly transfer to the water collecting collector.

3.7. Hot steam

The tests were performed in the hot steam system at a temperature of 85 degrees Celsius. The existing hot steam system has two modes. In one mode, the output temperature of the steam pipe, which is installed outside the welding machine, reaches the 85 ℃ exchanging with the environment. This steam reaches one side of the plate to 85 ℃ and the other side, which is in the ambient temperature, varies between 22 and 27℃, and this action helps the rapid formation of droplets due to rapid condensation due to the temperature difference on both sides of the surface.

In the second case, steam is injected into a galvanized chamber, where the steam temperature reaches 96 degrees Celsius according to laboratory conditions. In this system, four plates of different materials were used in the form of a plate surface and a meshed plate, and the efficiency of the samples was determined.

Unlike cold steam, due to the wet nature of hot steam, in a fraction of a second and at the moment the steam hits the surface, the first liquid drops are immediately created. Therefore, the test time is considered from the moment of the start, and by using a dropper valve that is connected to a cold-water source container, water drops slowly enter the water boiling container, and in this way, the amount of evaporated water is compensated. With this drip injection flow, the possibility of evaporation of the entire volume of water in the container has been prevented, which reduces the possibility of burns and safety hazards. The dimensions of the plates are unchanged and the same as before, i.e. 80×80 mm. The angle of placement of the plates in front of the flow was 15 degrees.

Table 4. Comparison of plates in the hot steam system in the vicinity of the ambient temperature in 15°

Material	Type	Temperature	Rate (g/h.m^2)
Aluminum	Meshed Plate	85 & 25 $\pm$ 2	1575.53
Aluminum	Plate	85 & 25 $\pm$ 2	1579
Copper	Meshed Plate	85 & 25 $\pm$ 2	977.68
Copper	Plate	85 & 25 $\pm$ 2	1307.5
Iron	-----	-----	-----
Polymer	Meshed Plate	85 & 25 $\pm$ 2	256.46
Polymer	Plate	85 & 25 $\pm$ 2	819.57

Steel	Plate	85 & 25 $\pm$ 2	330.68
Steel	Meshed Plate	85 & 25 $\pm$ 2	291.70

All the experimental tests have been carried out in the same temperature and structural conditions, and the highest amount of water extraction in these conditions, unlike the cold steam, was obtained in the plate, and the highest amount also happened in the aluminum plate with 1579 g/hm^2.

Steam results inside the hot tank

In the hot system of a container made of galvanized sheet, hot steam was directed into a closed chamber through a kettle tube. The water obtained in the form of perspiration moves from the walls to the bottom of the chamber and exits from there. The steam exited from the bottom of the plate, which was two to five millimeters away from the surface, and the same amount was exceeded from the surrounding area. The tank hot steam results are compiled in Table 5

Table 5. Tank hot steam results

Sample	Rate of water harvesting (g/m^2.h)	Ref
Polymeric plate	445.2	This work
Aluminum plate	785.21	This work
Copper plate	629.29	This work
Copper meshed plate	814.71	This work
Aluminum meshed plate	965.37	This work
Steel meshed plate	726.87	This work

wire-to-plate electrostatic	388	[20]
micro-structured metal meshes	341	[21]
Modified zinc plate	570	[22]

One of the capabilities of the system is a temperature of 96 ℃ according to the boiling point of water in the conditions of hydrate laboratory, Faculty of Chemical Engineering, Semnan University. Due to the small volume of the chamber, which is in the cube shape and measures 30×30×30 cm^3, the percentage of saturated humidity is close to 100%. One of the disadvantages of this system is the non-condensation of the surface, and because the entire chamber has a temperature of 96 ℃, it is not possible to condense, and this causes less drops to be created. Therefore, the efficiency of the surfaces is lower compared to the state of being exposed to the environment, and sedimentation on the surfaces can be considered as one of the disadvantages of this system.

The nature of steam in two cold and hot steam systems is different. The cold steam system is based on ultrasonic and in this system, water is in the form of suspended particles in the air. The steam coming out of this system is similar to the steam in nature or natural fog. In the hot steam system, the nature of steam is wet and it is completely different from ultrasonic steam. Figure 8 shows a comparison between the two cold and hot conditions, i.e. when the samples were exposed to saturated humidity inside a chamber full of saturated humidity. In this comparison, it has not been compared for the case where the hot steam system is located in the vicinity of the ambient air, because this comparison is based on the same experimental conditions.

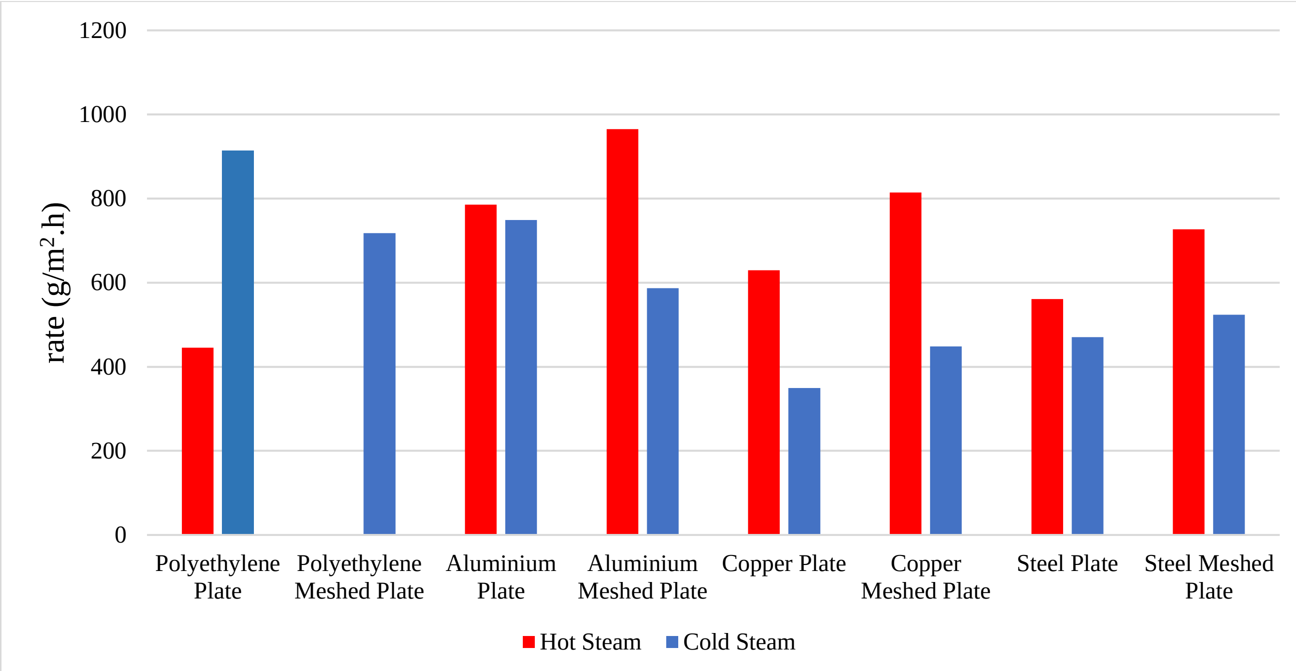


Figure 9. Comparison of samples in hot and cold steam systems

Investigating the effect of hydrophobic dye coating on the samples

The effect of hydrophobic dye based on alkyd resin has been investigated, and considering that the dyes used in this study have hydrophobic properties, by this coating, changes can be made on the surface of the samples and their wettability, consequently increase the efficiency of water harvesting. By creating the mentioned coating on half of the surface area of the samples, according to the organisms in nature, a hydrophobic property can be created in them. With this change, a hydrophilic/hydrophobic structure is created. In these experiments, first the samples are tested in the vicinity of cold steam and then with hot steam. In hot steam conditions, when the surface of the plate is exposed to the ambient temperature and the other surface, is in the vicinity of the hot steam, it has a very high efficiency. In this case, nucleation and production of droplets occurs in the uncovered part, which becomes hydrophilic. Also, creating a coating guides water drops into the collection container faster, and these two factors increase the efficiency of samples for water collection. The results obtained from this study are shown in Figure 10. In this investigation, the polymer mesh changed its physical state due to the high temperature of the steam, so its results are not recorded.

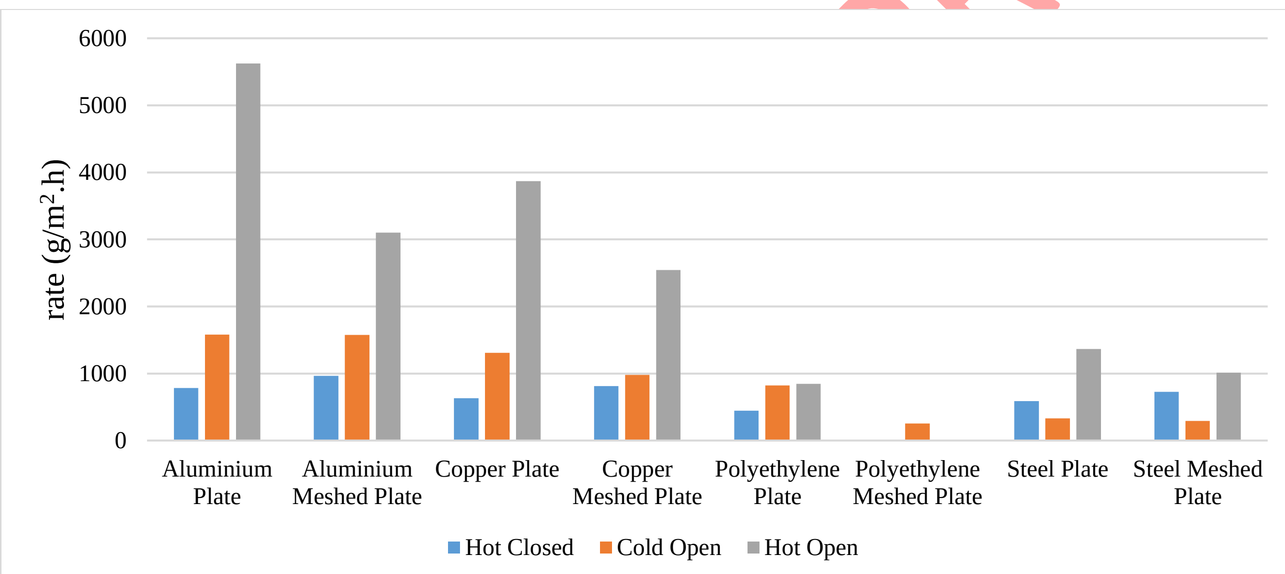


Figure 10. Aluminum plate and meshed plate to be the samples with the optimal efficiencies.

The experiments results determined the aluminum plate and meshed plate to be the samples with the optimal efficiencies. X-ray diffraction analysis on aluminum plate in plate and meshed one processed with hydrophobic alkyd resin-based dye was carried out compared with the raw sample. The presence of peaks at 2θ angles equal to 38.4, 44.6, 65.0 and 78.2 degrees is related to the crystalline structure of the aluminum phase, and the addition of peaks in the range of 17 to 30 degrees is due to the addition of alkyd resin-based dye coating, which indicates the presence of aluminum hydrophilic phase and the hydrophobic phases of alkyd dye in vicinity of each other. Figure 9 shows the XRD pattern of aluminum meshed plate coated with alkyd resin-based dye.

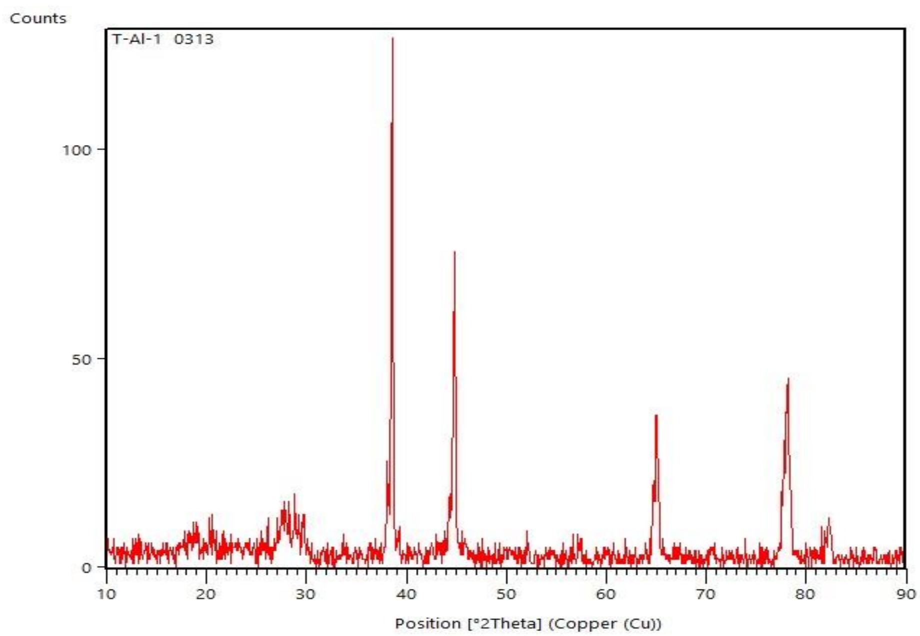


Figure 11 a. The XRD pattern of aluminum meshed plate coated with alkyd resin-based dye.

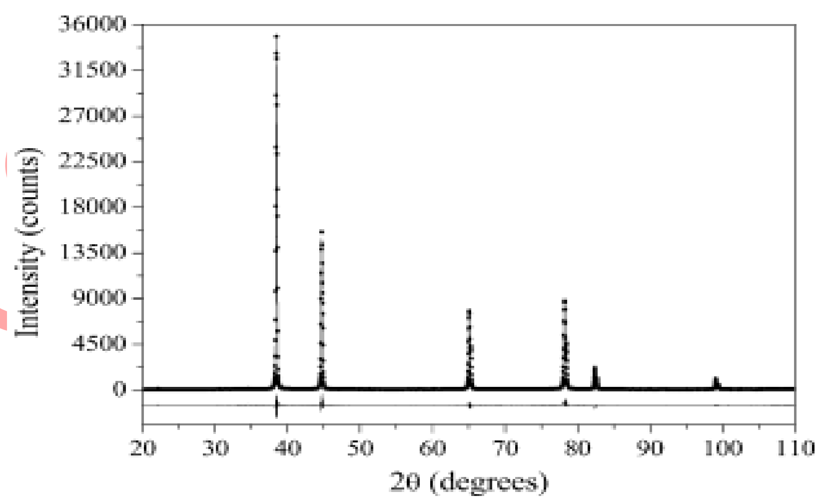


Fig. 11 b. Plot output from the Rietveld analysis of the X-ray diffraction pattern corresponding to the standard Al powder. Points are the experimental X-ray diffraction data, whereas the solid line is the calculated pattern.

The reason for conducting X-ray analysis on the samples is whether the sample that is covered has the structure of the water sample or not, because in this research, a completely hydrophobic surface that is Teflon was not created, but the surface of the hydrophilic property of water. It is hydrophobic and its pure hydrophilic part was placed in the upper part and the hydrophobic part was placed in the lower part. The XRD peaks taken from the painted sample clearly show the angles related to aluminum and alkyd resin. which corresponds to sample [19].

Figure 11 a, b shows the image of the aluminum plate processed with soft and rough sanding and its surface smoothed and polished, as well as the same surface covered by the alkyd resin-based dye, which can be seen that the aluminum surface is in neighboring with the alkyd resin coating. And the hydrophilic and hydrophobic surfaces are placed next to each other.

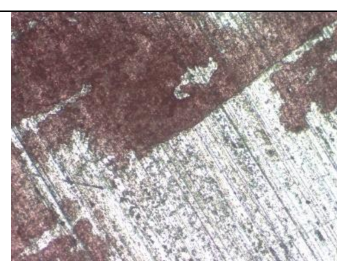
	
(a)	(b)

Figure 12. Optical microscope image magnified 20 times (a) sanded aluminum (b) aluminum plate coated with alkyd resin dye.

Many regions around the world, particularly arid and semi-arid areas, have implemented large-scale fog collection systems. These systems have proven to be effective in providing a reliable water source for communities, agriculture, and other applications. The long-term durability of hydrophobic coatings is a critical factor for the successful implementation of fog collection systems. While significant progress has been made in developing durable coatings, long-term field studies are still needed to fully assess their performance under various environmental conditions.

The cost of producing and coating plates with alkyd resin is generally affordable, especially when considering the potential benefits of fog collection. However, the specific cost will depend on factors such as the scale of production, the cost of raw materials, and the complexity of the coating process. To improve the cost-effectiveness of fog collection systems, researchers are exploring alternative materials and coating techniques.

Conclusions

The nature of the steam produced in the systems mentioned in this research, including ultrasonic cold steam and hot steam are different. Therefore, the efficiency of plates varies through the different experiments. All the tests were carried out in 3 hours and the dimensions of the plates were produced in 80×80 mm^2. Experiments showed that in the cold steam system, polymer plates have a relatively favorable capacity of 893.0625 g/m^2h, and the advantages of these samples include their availability, high structural diversity, easy formability, and their reasonable price compared to metal samples. The plates used in the hot steam test show better performance and the highest efficiency is observed in the aluminum plate. Meshed plates also perform better in this system compared to non-meshed plates, but polymeric meshed plates are not suitable in this experimental system because their shapes quickly change at the high temperature of these vapors. The wettability of all plate samples was analyzed by contact angle analysis. Since the said plates are hydrophilic, they were coated with alkyd resin-based dyes, and the hydrophilic-hydrophobic property has been created on the plates, which increases the efficiency of water harvesting process. The angle of the steam flow to the plates was investigated. The 75 degree angle of the water collection sample with the horizon increases the speed of water movement towards the water collection container and ultimately leads to an increase in efficiency up to three times. The optimal state in this research belongs to the aluminum sample in the hot steam system and in the vicinity of the ambient temperature with an optimal angle of 75 degrees and the property of hydrophilic-hydrophobic wettability due to the creation of a coating with the capacity of 5623.0625 g/m^2h.

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