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Review Article

Fog collection - materials, techniques and affecting parameters - A review

Abdullah Ali ELSHENNAWY[1,2], Mohamed Mahmoud AWAD*[1], Magdy Youssef ABDELAAL[3], Ahmed Mohamed HAMED[1]

[1]*Department of Mechanical Power Engineering, Mansoura University Faculty of Engineering, Mansoura, Egypt*
[2]*Department of Mechatronics Engineering, Horus University in Egypt Faculty of Engineering, Damietta, Egypt*
[3]*Department of Chemistry, Mansoura University Faculty of Science, Mansoura, Egypt*

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ABSTRACT

Water scarcity has shown a great challenge during the past decades with millions suffering from lack of potable water. Although, people try to benefit from the water naturally existing in air by two sources: fog and humid air. In this paper, we mainly allot the work on fog water. Fog collection is undergone using fog mesh collectors. There are lots of methods to rate the quality of fog water collection. Most used method is the quantity of water collected in kilograms for a one square meter harvester mesh per one hour. However, sometimes water contact angle on a flat surface of the mesh's material is also reliable. Both give an indication of hydrophobicity or water repellency which is significant for high fog collection efficiency. In addition, drop falling velocity and deposition time of water on the harvester measured in seconds are both indications for fog collection efficiency but rarely used. The scope of this article is to make a helpful guide for fog harvesting technology with the parameters that control the efficiency of this water resource. In addition, there is a detailed review in the chemistry of some of the previous researches on fog water collection inspired by natural existing plants and animals that survive in arid zones where only fog or humid air is found. Concerning the fog harvesting surface material, there will be a comparison between different essential parameters as mentioned above or other general indications. Some of the procedures to create the material will also be explained.

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1. INTRODUCTION

All-natural existing living organisms cannot sustain living in an environment that doesn't include water. This makes different organisms to contest for the minimal amount of water even fog water. Lots of living organisms depend mainly and sometimes only on fog water. As an example spider, beetle, lotus leaf, butterfly wings, cactus, geese feather, Nepenthes, rice leaf etc. (Zhang et al., 2016). Although water is almost the highest demanded natural resource, only 3% of the world's water is fresh water, less than 1% of total water is available and the rest is unreachable, in forms of atmospheric vapor, soil moisture (Hamed et al.,2011). Today, shortage of fresh water is a wide-spread crisis in arid and semi-arid areas of the world. However, the minimum quantity of water for a human body to survive properly per

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***Corresponding author.**
*E-mail address: m_m_awad@mans.edu.eg

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day is 2.5 liters according to World Health Organization (WHO) (Gleick, 1996). Some of the ways which can be considered for fresh water supplies in these areas are:

1. Transportation of water from other locations (Hamed, 2000).
2. Desalination of saline water (ground and underground) (Hamed, 2000), (El-Dessouky and Ettouney, 2000).
3. Water recycling (Gupta et al., 2012).
4. Extraction of water from humid atmospheric air (Salehi et al., 2020).
5. Rainfall water (Villarreal et al., 2020).
6. Ground water.
7. Fog harvesting.

Transportation of water through these regions is usually very expensive, and desalination depends on the presence of saline water resources, which are usually rare in arid regions. Water recycling and extraction from humid air need high technology and cost multiples more expensive than other ways for the same quantity of water prepared. Ground water requires a high standard of filtration due to micro and nano impurities found in water resource. Lastly rainwater and fog sometimes are rare in some regions and also are seasonal, but still cost only initial cost for the basement. No electricity bills or other sources of energy are present and a few other expenses would be expended for maintenance.

According to the world water development report 2019 produced by UNESCO (UNESCO WWAP, 2019), more than 4 billion peoples suffer from scarcity of water for a month per year as a minimum. Water is a major identity worldwide generally, but is a greater issue for people living in the desert and remote regions. Fog harvesting or fog collection, as usually known, is an effective way that can solve the water scarcity crisis as the technology can contribute in catching between 5.3 L/m^2.day and 13.4 L/m^2.day depending on the time of the year, location on earth and other parameters that will be discussed later (Bertule et al., 2018). Fog harvesting technology was installed as water resource in many countries as a national project as in Morocco Dar Si Hmad (Domen et al., 2014) (Dodson et al., 2015) where the average yield all over the year can reach 7.1 L/m^2.day. Dar Si-Hmad and its engineering cooperators installed UV filtration system for the collected water (Dodson et al., 2015). Furthermore, fog harvesting is a cheap method (Park et al., 2013) and may not need running cost such as electricity or fuel during processing or transportation. The most used maneuver to catch fog is by fixing a permeable mesh perpendicular to the wind flow.

Hence, the fog will be precipitated on the mesh as coalesced water. Figure 1 shows the fog collector mesh in reality.

Not only does the fog exists in cold humid regions, but also can exist in different situations. One type is the industrial fog or steam fog (Sampurno et al., 2005). This type can be found due to industrial applications that waste steam. Humid air or steam at high temperature when collides inside the cooling tower with low temperature will condensate forming a shape of cloud (Ghosh et al., 2018). These clouds can be caught as a source of water as shown in Figure 2. The other types are naturally existing (Sampurno et al., 2005) (Dunn et al., 1989). The fog can appear in the evening due to heat radiation transfer from earth's surface to air and this is called Radiation fog. Also, it can appear in warm areas near to cool surfaces as oceans and this type is called advection fog. Third type is valley fog which exists usually in winter and can form because humid air is not able to leave the space because of the mountains. The last natural type is the freezing fog. During winter and in very cold countries like Finland and Sweden, clouds at high elevations freeze to form freezing fog.

In order to properly catch fog, there are some operating parameters that may immensely improve the harvesting ability. Like Mesh geometry, shade coefficient, mesh surface

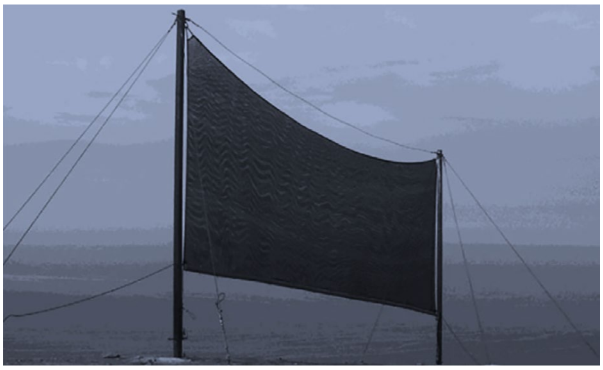

Figure 1. Fog harvesting mesh in the large scale (LFC) (Holmes et al., 2014).

LFC: Large Fog Collector.

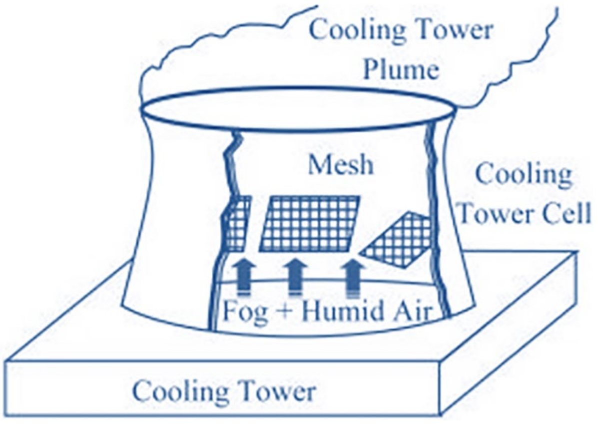

Figure 2. Schematic diagram of cooling tower fog collector (Ghosh et al., 2015).

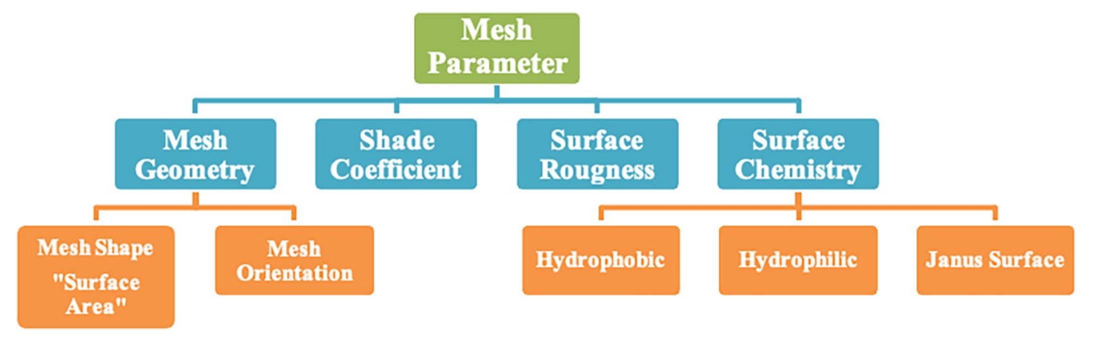

Figure 3. Parameters influencing fog collection.

roughness. In addition, mesh surface material which is determined by water contact angle. The property is described physically by surface tension with contact with water (Munson et al., 2013).

For the fog collection projects two main sizes of mesh are being used (Klemm et al., 2012). The Standard Fog Collector (SFC) which is 1 m×1 m, while the larger form used is the Large Fog Collector (LFC) normally 4 m×10 m. The mesh is tightened over rigid poles strongly fixed to the land and the mesh should be hung as high as possible to increase the fog collection rate. From the downside, a gutter is attached to collect the water and transport the captured amount into a collecting tank as shown in Figure 1. In this paper, the aim is to make a brief guide review for fog harvesting technology with the parameters that controls the efficiency of this water resource. Furthermore, a detailed review for fog collection using many surface materials used in recent papers.

2. FORMATION OF NATURAL FOG HARVESTING EFFICIENCY

When the temperature of humid air decreases, the relative humidity increases as the quantity of water carried by air will be reduced according to psychometry chart. When the humid air becomes saturated and relative humidity reaches 100%, the water vapour particles start to appear in the atmosphere making water droplets form in the size of 10μm droplet diameter. As much as the temperature cools down, the formed fog droplets increase. Fog collection occurs when fog meshes are supported in a foggy zone where fog droplets collide and coalesce together forming a larger drop and drops to the pipe below the mesh.

3. PARAMETERS INFLUENCING FOG HARVESTING EFFICIENCY

The hydrophilicity (wettability) of any surface can vary according to the microstructural geometry and chemical composition of the surface (Feng et al., 2002). Parameters that control fog harvesting are too many. Some are controllable and others are not. Some depends on the mesh physical properties, which are controllable, and the rest might depend on the boundary conditions of the mesh as ambient temperature and humidity that may result in better condensation of water above the surface (Cengel et al., 2002) and height of the mesh above sea level (Olivier et al., 2002). Also strong wind can affect fog harvesting (Peng et al., 2015). However, these uncontrollable features are not easy to modify as people living in a specific region might face difficulties to immigrate. Though, other parameters might be helpful to improve fog harvesting like mesh geometry, surface roughness, shade coefficient and mesh material. In this section, the four previously mentioned parameters that have the greatest influence on fog harvesting will be explained. Figure 3 shows a hierarchy chart of parameters that controls fog collection.

3.1. Mesh geometry

Different mesh patterns were used and are being used as shown in Figure 4. New patterns are still being manufactured and developed. However, some are still dominant to these days as Rectangular, Raschel, or other woven textiles like fiber networks, plain textile, etc. Each one can contribute with different fog harvesting efficiency even when the other parameters are controlled (Fernandez et al., 2018).

3.2. Shade coefficient

Shade coefficient is the complementary to free flow area ratio. Free flow area ratio is the ratio between the mesh openings area to the total mesh area (Rivera et al., 2011). Figure 5 shows the meaning of shade coefficient and the difference between two meshes of different shade coefficients.

Shade coefficient is a dependent variable to the fog water collection. To calculate the shade coefficient SC for a mesh, equation (1) can be used:

$$SC=1-\frac{A_f}{A_t}$$

Where A_f is the free area where the air can flow through the mesh and A_t is the mesh total area.

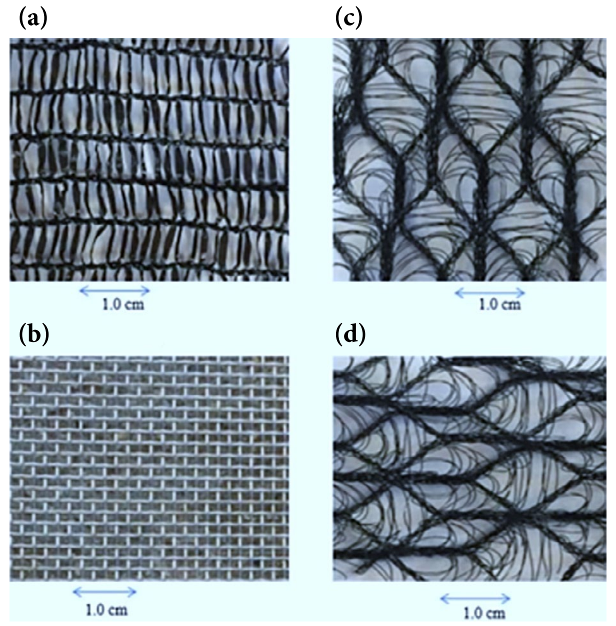

Figure 4. Some of mesh shapes with different geometries, (a) Stainless steel Raschel mesh which is weaved like trapeziums integrated together. (b) Rectangular mesh. (c, d) Woven textile mesh with different orientations (Fernandez et al., 2015).

Shade coefficient can be roughly estimated mathematically for regular shape meshes like rectangular and Raschel mesh and other.

3.3. Surface roughness

Surface roughness is an important physical property in surface wettability to obtain surface with a high hydrophobicity. It affects the way the liquid droplet acts thermodynamically and hydro-dynamically. The surface roughness can stimulate the surface contact angle making the surface water repellent. The rougher the surface, the more micro holes it has, the more water absorbed to these holes (Villarreal et al., 2005), the less collected water to the gutter of fog harvesting. Take two stainless steel surfaces, one is coarse and the other is fine surface that has surpassed all finishing processes. The coarse one has holes on its surface, even if these spaces aren't seen by naked eyes. Therefore, when it is exposed to water, the water sticks to the holes between the pillars as shown in Figure 6. On the other hand, the fine one would never change in weight if immersed in water. This proves that the rough surface, the coarse surface in the previous example, is less qualified to be a fog catcher.

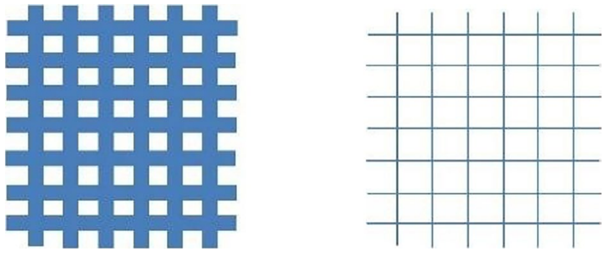

Figure 5. Typical difference between two rectangular meshes with different shade coefficient, the left one is the higher in shade coefficient and the right one is the lower in shade coefficient.

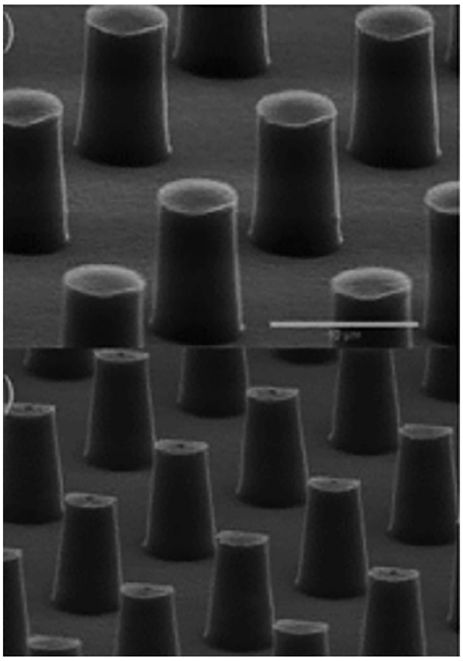

Figure 6. Scanning electron microscope SEM micrographs of pillared (rough) surfaces (Forsberg et al., 2011).

SEM: Scanning Electron Microscope.

The way water particles adapt themselves when water drops on a surface differs with unlike surfaces because the surfaces have unlike chemistry, morphology and physical properties (Forsberg et al., 2011). Only two states can exist when the water is in contact with a rough surface. The first is to completely fill the holes with water. And this is called the Wenzel state. The second has a differing interaction as the water only stands on the surface micro pillars without filling the holes with water so that air is trapped inside the holes. And this state is called Cassie-Baxter state and usually referred to as Cassie state.

There is a more advanced form of Cassie-state impregnate the surface more slippery as the pillars shown in Figure 7 are not rectangular. Instead, they are in the shape of hierarchical microstructures and nanostructures. This state is called the Lotus state (Zhu et al., 2019).

3.4. Mesh surface material or coating (Surface chemistry)

The Mesh surface material might be the most important factor on the fog collection process. The surface chemistry

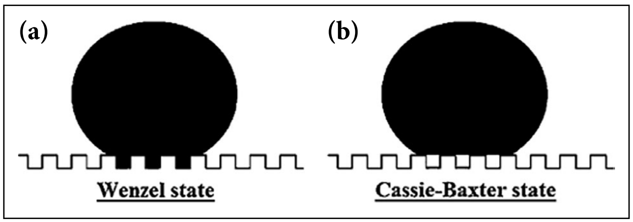

Figure 7. Typical wetting behavior of a droplet on rough surface (a) Wenzel state. (b) Cassie-Baxter state (Darmanin et al., 2015).

defines a fundamental property to fog harvesting, which is surface attraction and repulsion to water molecules. This property is called hydrophobicity or water-repellency. A hydrophobic surface, as Lotus plant leaves, is a surface that expels water (Neinhuis et al., 1997). Surface tension has a great effect on the hydrophobicity and hydrophilicity of the surface. The more the hydrophobicity of the surface, the less the water will stick to the surface. The less the hydrophobicity, the more water adheres to the surface. The opposite of hydrophobicity is hydrophilicity. A hydrophilic surface is a surface that tends to attract water to it (Odian et al., 2004). Darmanin et al.

(Darmanin et al., 2015) have made a great review on superhydrophobic surfaces that naturally exist on the external surface of different animals, insects and plants.

The contact angle and wettability of a surface are strongly influenced by the hydrophobicity of the surface. Therefore, a plain surface of the investigated material might be tested for contact angle. The higher the contact angle, the more the adhesion force (Good et al., 1992), the more the hydrophobicity of the surface. As a result, droplets of water seem to act as a sphere standing on the surface (Odian et al., 2004).

Surfaces that have water contact angle of higher than 150° is recommended for many engineering applications and researches nowadays (Feng et al., 2002). Moreover, in order to obtain such a surface with the required high contact angle or low sliding angle, integration between chemistry and nanotechnology is required.

3.5. Other orientation parameters

The way in which the fog collectors are fixed affects enormously the amount of fog water that can be collected. The most popular fog collector orientation is that stands vertical orthogonal to the direction of fog (Damak et al., 2018). Rivera et al. (Rivera, 2011) suggested that concaving the mesh might induce higher collection efficiency. The mesh also can be installed in the shape of a tower as in Figure 8.

Ghosh et al. (Ghosh et al., 2015) also proved by experimental data that inclined mesh at angle 15° can lead to aerodynamic efficiency enhancement.

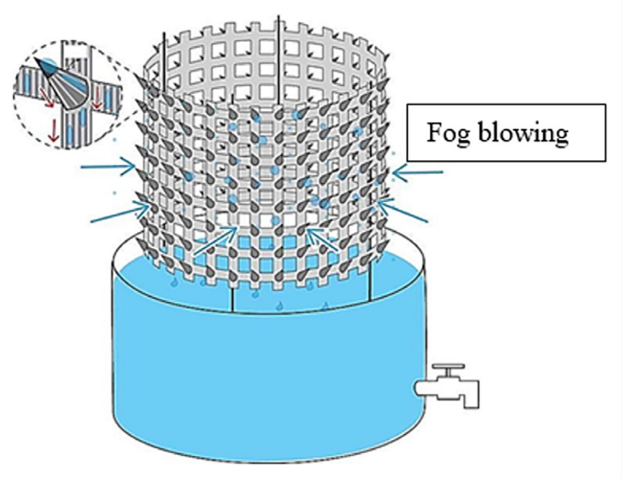

Figure 8. Schematic diagram of fog collection tower and the collecting tank (Bhushan, 2020).

4. MESH MATERIALS AND COATINGS

Fog harvesting is a non-old technology that mimicked many plants and animals that have different physical properties. The higher the contact angle, the better the material is. The higher the water collection rate, the more recommended the material is. Lots of the related publications for the fog collection method include the study of the surface chemical structure to collect and transport more water and most of them are bio-mimicking. As it is mentioned above, the contact angle is an indication to decide whether the surface is reliable for the fog collection or not. Lotus leaf is considered a superhydrophobic surface because it shows a water contact angle of 159° approximately (Guo, 2011). In this section, some previous researches on different mesh materials and coatings will be presented. Not only were all of them done by researches on fog harvesting technology, but also they include some that were pure chemistry that describes new surfaces with new materials that are recommended for fog harvesting process and other applications requiring hydrophobic and hydrophilic surfaces. Fog collection experiment can be done by two methods. Either the experiment is done naturally, where the fog collection mesh is kept in a cloudy region to catch natural fog, or the fog is produced in a laboratory artificially. The amount of water collected is the indicator of fog collection efficiency. The material used for the mesh is usually nylon, stainless steel or polypropylene netting (Fessehaye et al., 2014). A brief history of mesh materials and coatings will be presented.

Wang et al. (Wang et al., 2015) unfolded in their work a cheap and effortless methodology to create a compatible fog harvester of hybrid hydrophilic–superhydrophobic surface as shown in Figure 9. They thermally pressed a metal mesh with a hydrophilic polystyrene flat sheet in a described process at different temperatures. They compared the water collected for each mesh, some were raw copper meshes and

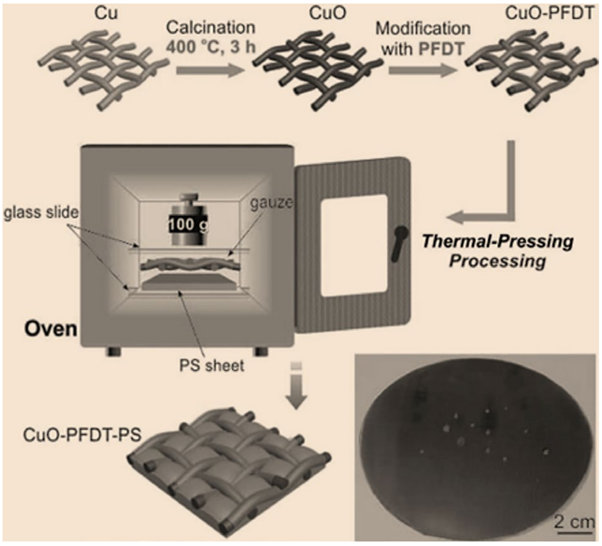

Figure 9. A brief arrangement that is required to manufacture the required hydrophilic-super-hydrophobic surface of CuO-PFDT (Wang et al., 2015).

PFDT: 1H,1H,2H,2H-Perfluorodecanethiol; PS: Polystyrene.

some were modified using the described method. In their work they used chemicals like ethanol, deionized water and other. However, CuO-PFDT imposed with the highest water contact angle and water collection rate 161°, 1.59 kg/m^2.h when tested for hydrophobicity and harvesting efficiency.

Huang et al. (Huang et al., 2019) effectively developed a water harvesting collector from hydrophobic and hydrophilic combination. This procedure was done by a uni-step approach of electro-spinning PVDF/PAN composite solutions. The harvester was responsible to boost the water harvesting efficiency. The water collected from PVDF/PAN harvester can reach 3.15 kg/m^2.h. This can be estimated to be triple the amount of water collected by an untouched PVDF membrane.

Imitating the structures of trichomes (hairs) of Sarracenia, Li et al. (Li et al., 2020) issued a superhydrophobic surface to provide a high quality method collect more water. Aluminum alloys samples were brought and some were polished with superhydrophobic coating, while the other sample underwent cleansing and was roughened ultrasonically and treated by laser, this approach was described in that work to result in a superhydrophobic that can reach a contact angle of 160° The researchers set up apparatus to collect fog by using the two samples and the time after the start until large droplets of coalesced droplets can be seen was recorded. The time needed for the polished surface 210 s. on the other hand, it only took 10 s for the laser treated sample. This was magnificent for the second sample described previously. The narrated description by the researchers of laser treatment can also be applied to other materials like stainless steel.

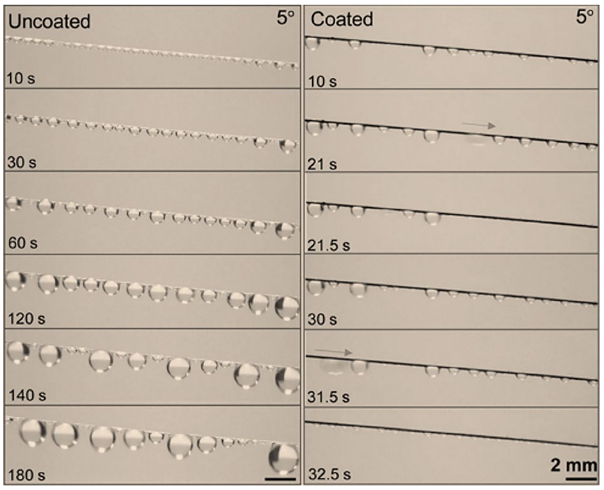

Figure 10. Water droplet transport mechanism on tilted fiber with tilt angle 5°, a coated and an uncoated fiber (Zhang et al., 2018).

Zhang et al. (Zhang et al., 2018), instead, investigated the time needed for the water to be transported, along a bare and a carbon nanoparticles-coated microfiber, and collected after being captured by the microfiber. The microfibers used were tilted to give a gradient for the water to drop as shown in Figure 10.

Park et al. (Park et al., 2016) suggested a technique to create a surface with tunable wettability wherein stainless steel surface was etched and oxidized to create a passivation layer. This monolayer provides the surface with durability and stability. The two fundamental steps to achieve the surface are etching and oxidation. Etching is carried out by immersing the 304 stainless steel surface in 40% ferric chloride solution for one fourth of a day. This results in the fabrication of bare superhydrophilic surface. The surface is then washed for a moment with deionized water. In order to oxidize the superhydrophilic surface, the surface was kept in a 35% hydrogen peroxide for 1 hour. Finally, the surface was analyzed for corrosion in a sea water solution and was found that the achieved superhydrophobic stainless steel surface is a good corrosion resistant. This stainless-steel surface can be used in many applications as fog harvesting.

The following work was to improve the self-driving force of the water and boost the transporting velocity using a hybrid surface. Chen et al. (Chen et al., 2018) manufactured a bioinspired superhydrophilic-hydrophobic integrated conical stainless steel needle (SHCSN). They processed a conical surface in the shape of needle that was partially hydrophobic and partially hydrophilic. They demonstrated the chemical way that created their prototype. They shed the fog upon the needle and photographed the needle and monitored the deposition time and transportation velocity. The SHCSN has shown an appropriate Laplace pressure for fog collection larger than pure superhydrophilic and

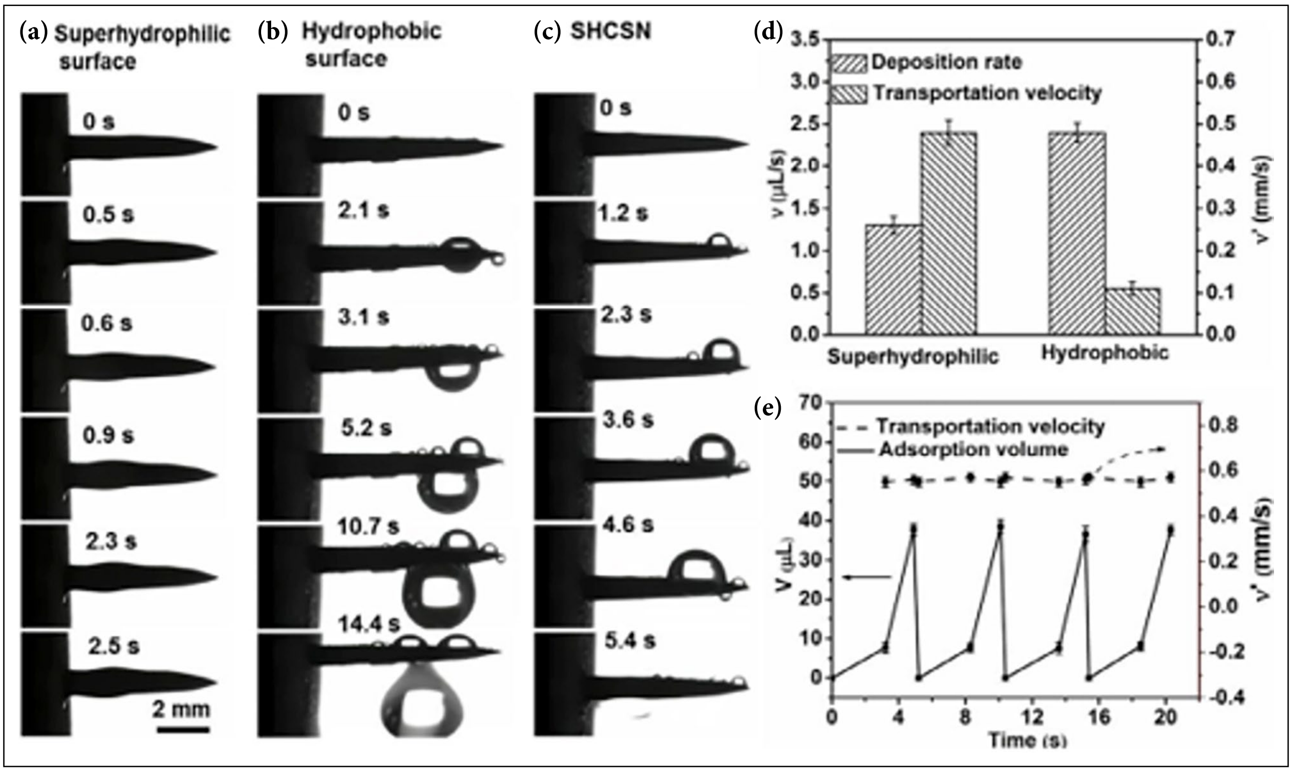

Figure 11. (a-c) Microscopic contemplation of typical droplets acquisition and transportation procedures for the examined surfaces. (d, e) fog collection statistical analyses acquired by the researchers (Chen et al., 2018).

SHCSN: Superhydrophilic-hydrophobic integrated conical stainless steel needle.

pure hydrophobic surface. Figure 11 illustrates how the SHCSN is better. As the superhydrophilic surface transmits the water in the shortest time but it absorbs the water, making the water collection drawn to the gutter less. The hydrophobic surface takes the longest time and collects the water at the needles tip. This may lead to the droplet waste as it is not transmitted to the root of the needle so no water to the gutter. The best surface was the SHCSN as it collects water rapidly and bulky at the tip and then the water is self-driven to the root and dripped to the gutter.

Janus surface is a surface that has both chemical hydrophobic (nonpolar) and hydrophilic (polar) group on the surface (Gennes, 1992). According to Zhong et al. (Zhong et al., 2019), Janus membranes can result in a 8 times improvement than usual superhydrophilic membranes because of its wettability contrast (Söz et al., 2020). They created a novel fog harvesting mesh by combining a copper mesh with a nanoscale pattern of different wettability regions (hydrophobic/hydrophilic) by liquidus surface modification. They tested 2D flat mesh and Janus Membrane style mesh. Figure 12 shows a schematic illustration of fabricating the Janus membrane. Many meshes with different shapes were tested for fog collection. The highest fog water collected was for the 2D flat mesh prepared with octadecyl mercaptan (ODT) 0.5 mM with 5 g/h for a mesh of 2 cm×2 cm used.

Zhou et al. (Zhou et al., 2018) offered an integrated polyethylene terephthalate (PET) Janus membrane with conical structures and a micro/nanostructured conical spine (MNCS). The surface may have the two different features in the same side of the surface or opposite sides. Aluminum wire was cleansed with ethanol and deionized water, then corroded electrochemically and underwent hydrothermal processes described in their paper to get the surface with the required properties, inside hydrophobic with 151° contact angle and outside hydrophilic with 16.2° contact angle. Harvesting ability investigation was investigated in a similar manner as that done by Park et al. (Park et al., 2016). The conditions were 90% relative humidity (RH) and fog was flowing with a velocity of one meter per second. The experiment was to know the needed time for water droplets to be captured by the spine, transported through it and then coalesced. Figure 13 shows how the process of collecting water by the spine is done.

Wang et al. (Wang et al., 2018) created an intelligent superhydrophobic elastomer skin made polydimethylsiloxane (PDMS). The fabricated surface was tested for water contact angle after applying bending and stretching forces. The practice shows a high contact angle in the range of 150° to 155°. The idea was cited and improved in the field of fog collection by Su et al. (Su et al., 2019) to suggest a conversion to a Janus membrane made of the

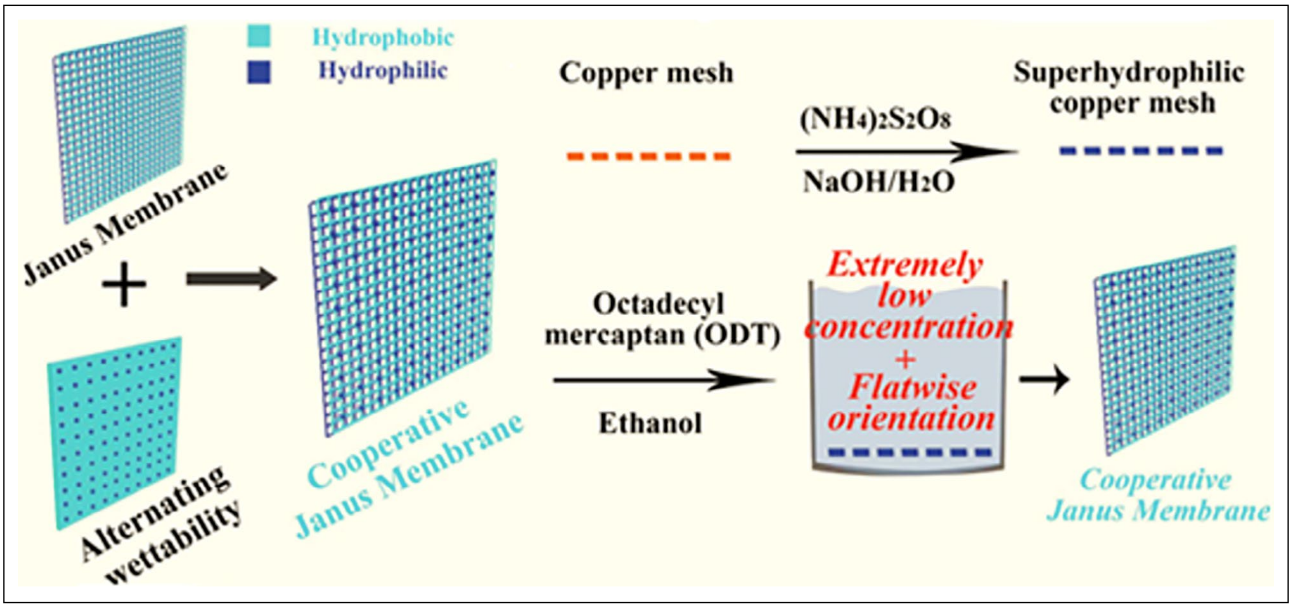

Figure 12. Schematic illustration of Janus membrane fabrication (Zhong et al., 2019).

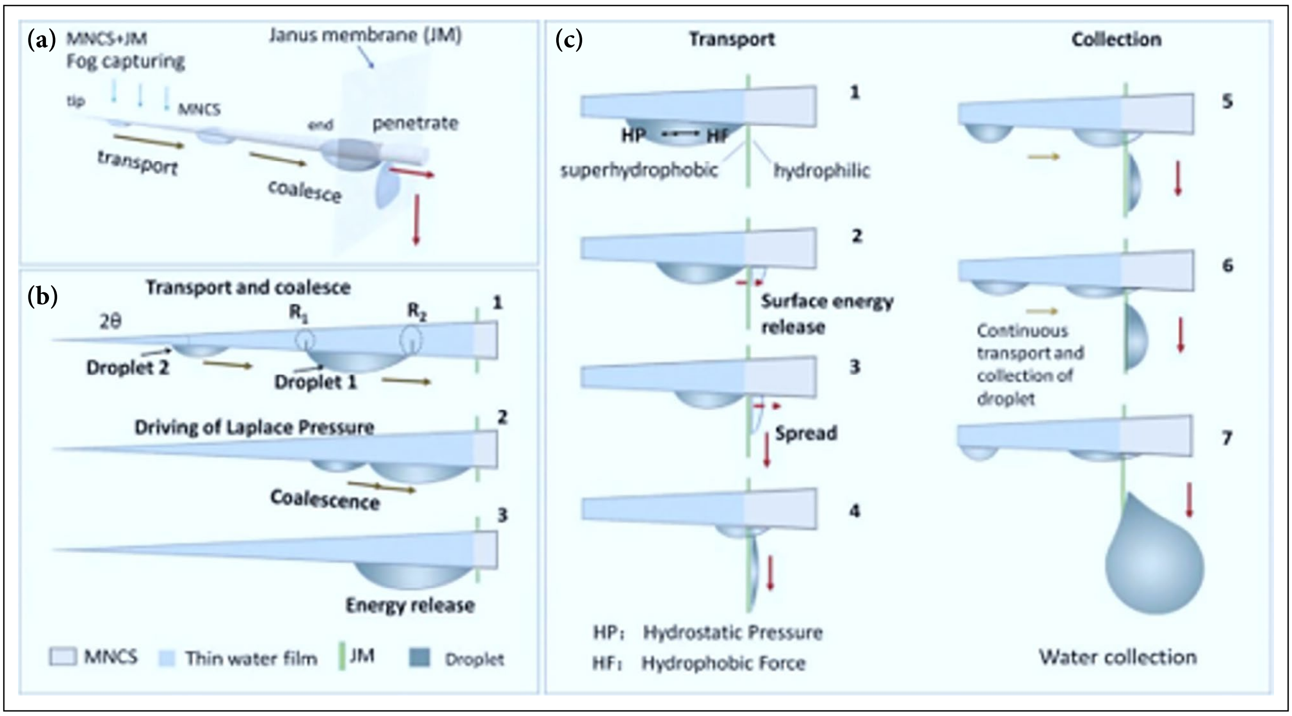

Figure 13. (a) General illustration of collecting method by the spine, (b) Transport and coalescence of water droplet captured, (c) Forces applied on the droplet due to Laplace pressure and the energy release when the droplet reaches the Janus membrane (Zhou et al., 2018).

MNCS: Micro/nanostructured conical spine.

same material polydimethylsiloxane (PDMS) by applying a uniaxial tension force. Figure 14 shows how the tested surface was fabricated. The tension applied on the mesh results in a strain and for each strain there was a different water collected during the fog harvesting experiment. Figure 15 demonstrates the maneuver used by the researchers to test for fog and the water collected for three different meshes of different strains at 3 successive moments.

Wan et al. (Wan et al., 2019) focused on the pine needle and its ability to harvest fog and transport water along the pine. Laplace pressure was the investigated phenomenon. They spotted fog with a flow speed of 1.2 m/s. Pine needle was

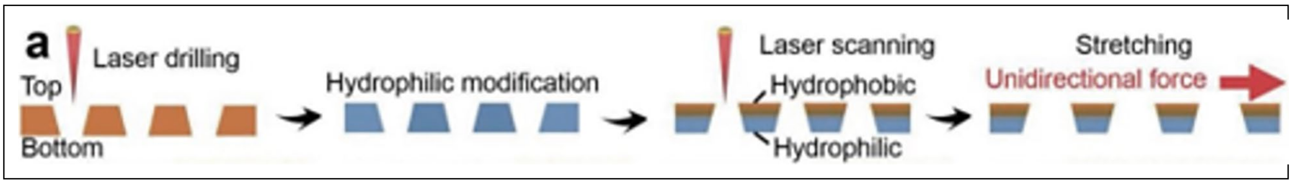

Figure 14. Production of Janus surface and unidirectional stretching (Su et al., 2019).

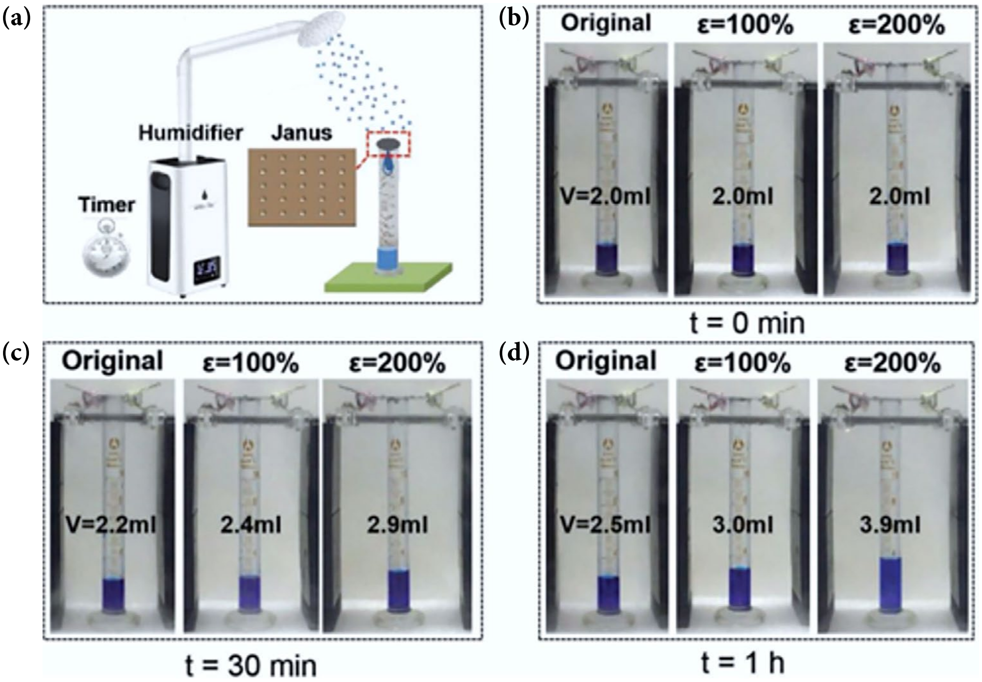

Figure 15. (a) Schematic illustration of fog harvesting measurement system. (b–d) Snapshots of dynamic collection volumes at t=0 min, 30 min, and 1 h for JMs in three typical strains (ε=0%, 100%, and 200%)(Su et al., 2019).

found that it can collect 1.2 ml of water every ten minutes at this speed. However, a pine needle alone is not to be exposed to fog alone. There might be attached to a standard fog collector to catch more water particles.

Mahmood et al. (Mahmood et al., 2020) tested for the ability of a flat and conical surface to catch fog and recorded the results as shown in Figure 16. They experimented a hydrophilic and a hydrophobic surface of flat and conical surfaces during the fog water collection experiment that undertaken by a commercial humidifier. The surface hydrophobicity was created by coating the substrate with a glue-like material. To prepare the hydrophobic material (glue), 1 g of perfluorooctyltriethoxysilane (PTES) was added to a 99 g solution of absolute ethanol. The mixture was then stirred for 2 h and the glue is formed. The required surfaces to be coated were then put in this glue for half an hour and then dried thermally in an oven at almost 80° C for half a day. It can be deduced from Figure 16 that the conical surface printed by a 3D printer affords a higher contact angle than the flat surface with and without the hydrophobic coating.

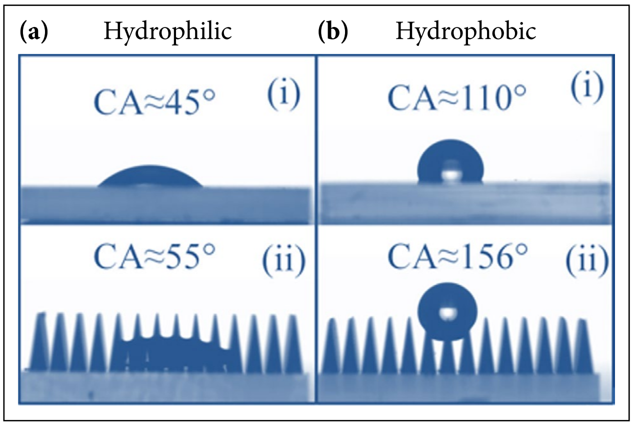

Figure 16. Wettability characteristic using contact angle measurements (CA) of flat (i) and conical structured (ii) 3D printed acrylic substrate (a) untreated hydrophilic surface (b) surface treated hydrophobic surface (Mahmood et al., 2020).

Deke et al. (Li et al., 2021) synthesized some Janus membranes with different wettabilities by spraying and etching methods inspired by cactus spines. Two main components were used on opposite sides. The highest water contact angle was shown for the designated surface as $W_{1/1}$ with Cu $(OH)_2$ nanofiberes (CNF) on a side and

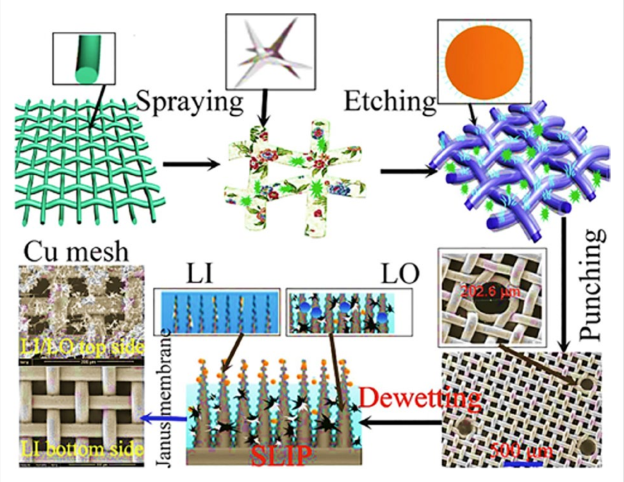

Figure 17. Preparation methodology of the Janus membrane (Li et al., 2021).

LI: Lyophilic; LO: Lyophobic.

ZnO- tetrapod/ polydimethylsiloxane (PDMS) on the other side. The contact angle was 153.1°. Figure 17 shows the procedure of making the Janus membrane illustrated.

Raut et al. (Raut et al., 2019) worked on polypropylene harvesters and compared hierarchically- textured surfaces, consisting of micro-lenses arrays covered with high aspect-ratio nano fibers, with planar surface. Four surfaces were involved in this comparison. Contact angles and water harvested for each surface per hour. The four surfaces were manufactured and described in their work.

They were named as follows: plane polypropylene surface, clustered fibril (CF), lens array on clustered fibril (LACF) and clustered fibril on lens array (CFLA). CF and CFLA were proved to have the highest contact angle approximately 150°. Water harvesting experiment was carried out at 23°C and water harvesting efficiency was recorded for each surface as 1.8, 4.5, 7.5, and 10 kg/m^2.h for planar, CF, LACF and CFLA, respectively.

Zhao et al. (Zhao et al., 2020) produced two superhydrophobic copolymer coatings including micro- nanoparticles shaped like raspberry. The intended application was to cover cotton for resisting water, coffee and milk. However, it was suggested to use the coating in different applications. The water contact angle recorded by the two fluoride-free copolymer composite coatings was 151.22° and 154.85°.

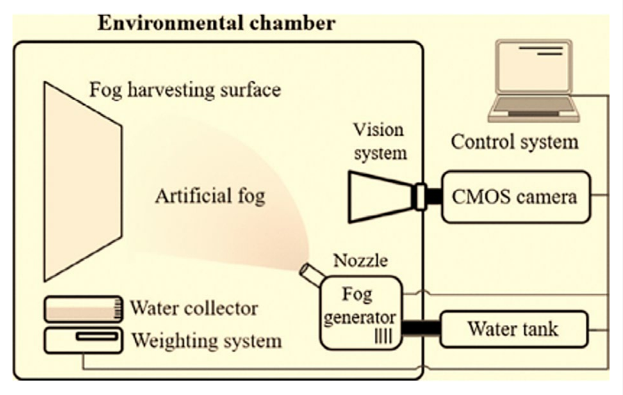

Figure 18. Schematic illustration of the experimental set up for fog harvesting system (Kim et al., 2019).

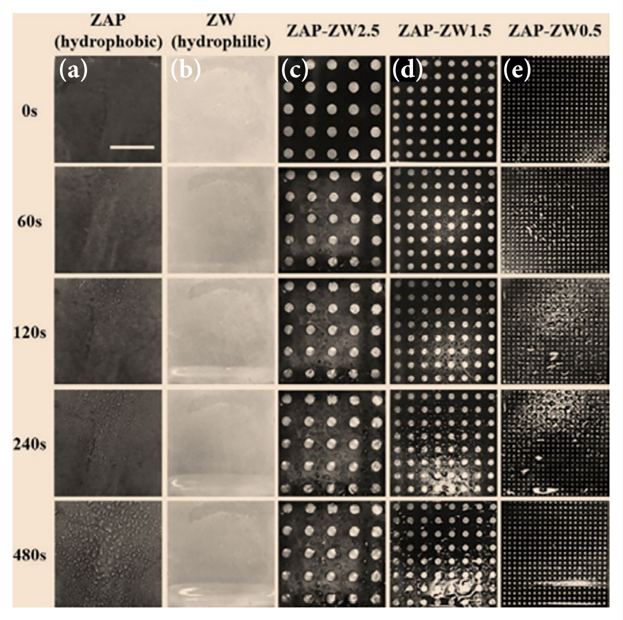

Figure 19. How water is collected on (a) ZnO NW-Ag NP surface (hydrophobic property), (b) ZnO NW surface (superhydrophilic property), ZnO NW-Ag NP surface with (c) 2.5 mm, (d) 1.5 mm, and (e) 0.5 mm diameter ZnO NW patterns. Scale bar is 10 mm.

ZAP: ZnO NW-Ag NP: Zinc oxide nanowires-silver nanoparticles; ZW: ZnO NW.

Kim et al. (Kim et al., 2019) manufactured a new methodology for fog harvesting utilizing nanostructures made of zinc oxide-silver hierarchy. They chemically formed a patterned surface initially made of zinc oxide nanowires that were made by a convenient hydrothermal process to create the superhydrophilic region. The zinc oxide nanowires are then undergone the exposition to UV rays in order to form hydrophobic surface made of silver nanoparticles. Their work involves different surfaces with different UV rays exposure energies. Contact angles of some surfaces were recorded at different UV exposure time. The peak was at approximately 9 J/cm^2 was an outcome contact angle 138°. Figure 18 illustrates schematic illustration of the experimental set up for fog harvesting system. Finally, the surfaces were tested for the amount of water collected per hour with artificial fog shed on each surface as shown and the time was recorded. Figure 19 shows the behavior of water collection with respect to time.

All the surfaces were sampled in a patterned shape in a square form with dimensions 25 mm x 25 mm but different hole sizes. Results were recorded in mg/h.

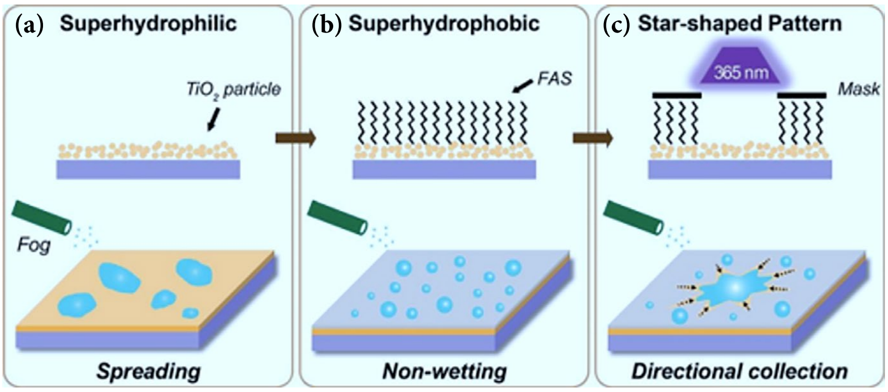

Figure 20. Schematic demonstration of the fabrication procedure of the bio-mimicked surfaces. (a) Superhydrophilic surface. (b) Superhydrophobic surface. (c) Bio-mimicked gradient surface (Bai et al., 2014).

FAS: Heptadecafluorodecyltrimethoxysilane.

Liu et al. (Liu et al., 2019) who are researchers from National Engineering Laboratory of Eco- Friendly Polymeric Material from Sichuan University in China have suggested the production of a fog harvester made of a naturally-existing polymer, soy protein. This surface is capable of collecting 9.176 kg/m^2.h.

Bai et al. (Bai et al., 2014) allotted their work on bio-mimicked surfaces. Superhydrophilic surface was formed, as shown in Figure 20 by coating TiO_2 slurry onto an exposed square glass plate using spin-coating method. The surface was then processed by heptadecafl-uorodecyl-trimethoxysilane (FAS) to give different wettability characteristics. The surface was kept under selective illumination of UV light for a selective time in a specific manner to form a geometric shapes in the middle that is hydrophilic and the boundaries is hydrophobic. The 5-pointed star shape yielded the highest fog collection rate at nearly 2.7 g/cm^2.h

The superhydrophobic FAS-modified TiO_2 film was converted to superhydrophilic by being undergoing exposure to ultraviolet rays for one hour, due to the photocatalytic decomposition of the FAS monolayer.

The study also showed the contact angle of the given surface at several intervals of time during exposure to UV rays giving approximately 160° highest contact angle at zero minutes illumination time. Figure 21 shows the schematic diagram of the system of fog collection used by the researchers with inclined plate.

Huang et al. (Huang et al., 2018) initiated a new electrospinning way to collect water imitated by spider silk and desert beetle. Nanowires in the form of spider silk and beetle like structure were produced by utilizing Polyacrylonitrile (PAN) and expanded graphite (EG). Figure 22 presents a) the electrospinning setup, b) the methodology to carry out the experiment and how they formed fog and harvested it again.

Water harvesting efficiency was recorded and they found that the composite membrane, PAN & EG, resulted in 7.44 kg/m^2.h. While the untouched PAN membrane could only collect water slightly more than half of the composite membrane. The capacity of the bio-inspired water collector can reach 179 kg of water for every square meter per day.

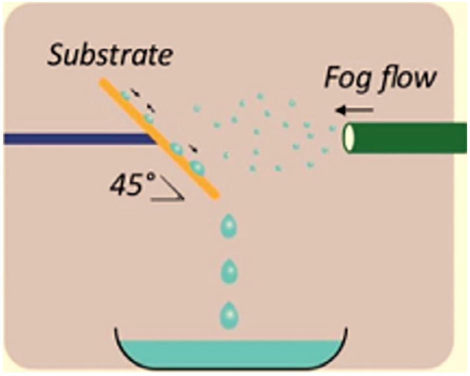

Figure 21. Schematic diagram of the system used by the researchers (Bai et al., 2014).

Rajaram et al. (Rajaram et al., 2016) worked on the effect of the geometry of the surface and non- wetting surfaces. Two rectangular meshes and one Raschel mesh, which has the orientation shown in Figure 23, were investigated to discuss the surface geometry. However, in order to investigate the surface coating material and the non-wetting surfaces, five Raschel meshes were tested where four stainless steel meshes were painted with four coatings, Teflon, ZnO nanowires, NeverWet, and hydrobead and the fifth was kept as it is. Figure 23 shows the Raschel mesh geometry used by the investigators.

After performing six various tests on each mesh, the investigations showed that hydrobed is the one with highest water harvesting efficiency and amount of water collected, then NeverWet, Teflon, ZnO nanowires and least one was the non-coated mesh, respectively.

On average investigation that took place during a whole hour virgin mesh, Teflon, NeverWet, hydrobead and ZnO

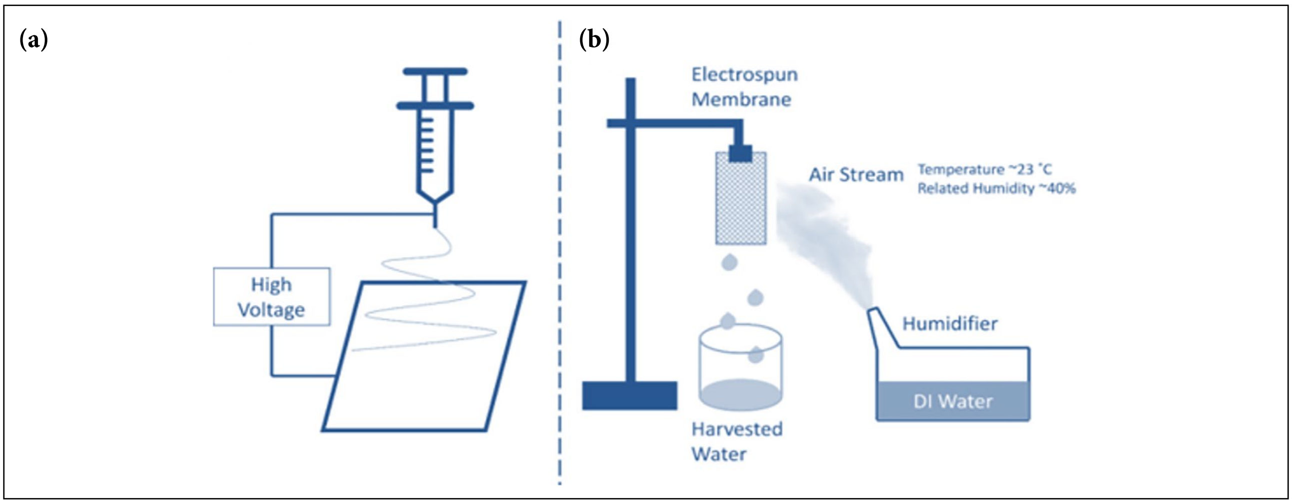

Figure 22. Electrospinning process and water harvesting test (Huang et al., 2018). (a) The electrospinning setup (b) the methodology to carry out the experiment.

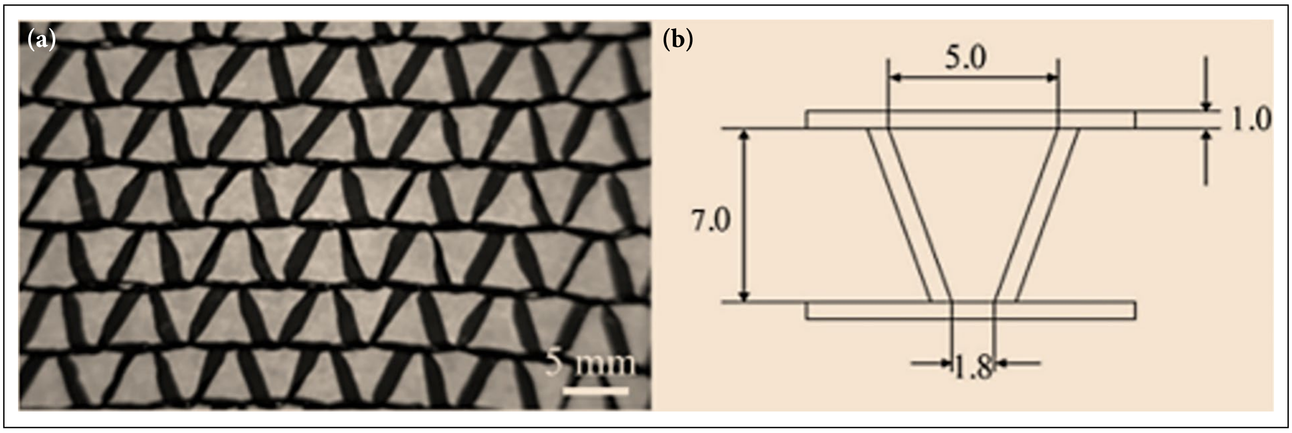

Figure 23. (a, b) The Raschel mesh configuration and dimensions (Rajaram et al., 2016).

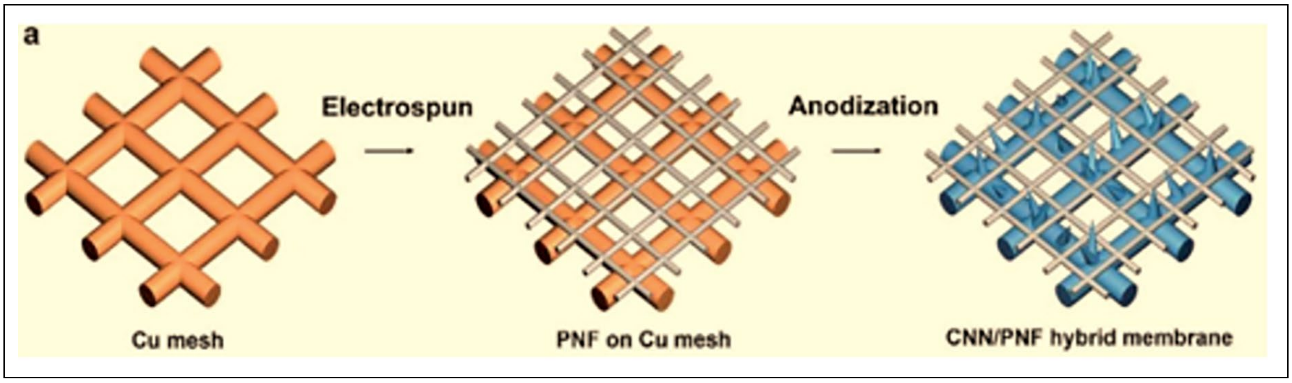

Figure 24. The fabrication of hybrid mesh (Hu et al., 2019).

PNF: Poly(vinylidene fluoride-co-hexafluoropropylene) nanofibers; CNN: Copper hydroxide Cu(OH)2 nanoneedles.

nanowires meshes collected 11, 14, 16, 17 and 13 mL of water, respectively, for mesh dimensions of same length of 3.3 cm and width of 2 cm.

Hu et al. (Hu et al., 2019) designed a hybrid hydrophilic-hydrophobic mesh. Ultrasonically cleaned copper mesh was undertaken two fabrication methodology to create the hybrid wettability mesh as shown in Figure 24. First, copper mesh was to be covered with electrospun poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) nanofiberes (PNFs). Second, the covered mesh was

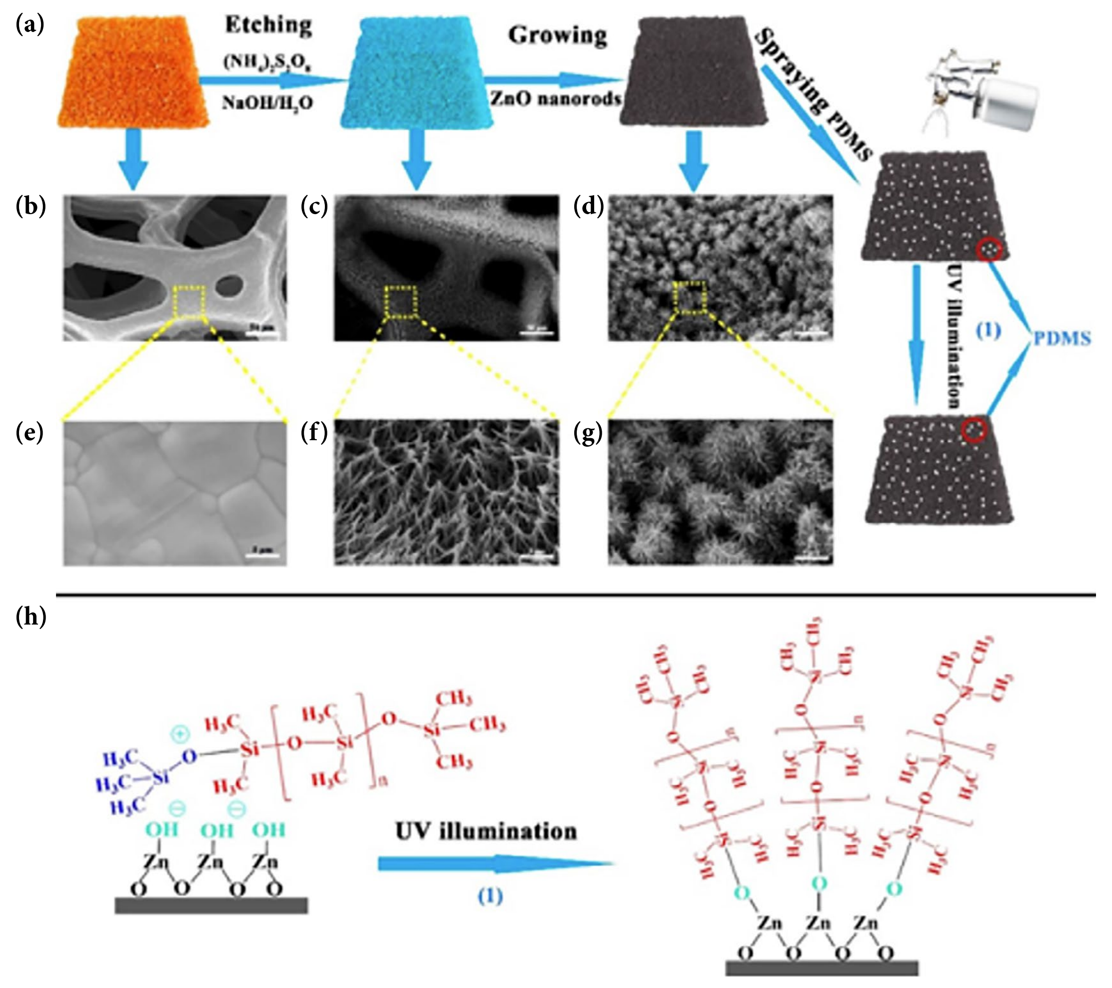

Figure 25. Procedures required to fabricate the hybrid hydrophobic-hydrophilic surface (Zhou et al., 2020). (a) Scheme of the HB-HL+JCF formation. Hydrothermal method is used to grew the ZnO nanorods on $Cu(OH)_2$ nanowires and light-catalyzed reaction to graft the PDMS brush on ZnO nanorods. (b) The SEM image of original copper foam. (c) The SEM image of $Cu(OH)_2$ nanowires on copper foam after treatment in ammonia solution. (d) The SEM image of ZnO nanorods diffused on $Cu(OH)_2$ nanowires. (e–g) The SEM images magnified of (b–d). (h) The chemical reaction of grafting in ZnO nanorods with PDMS.

SEM: Scanning Electron Microscope; PDMS: Polydimethylsiloxane.

anodized electromechanically to form a layer of copper hydroxide Cu $(OH)_2$ nanoneedles (CNN). The (CNN)s spread between the PNF networks to form the differing of wettability throughout the total mesh. The PNF network revealed water contact angle of approximately 141.3°. The researchers also studied the relation between the fog collection efficiency and the time taken for electrospinning and anodization process. 7 and 10 minutes were the optimum time for electrospinning and anodization processes respectively.

Zhou et al. (Zhou et al., 2020) performed a hybrid hydrophobic-hydrophilic surface via a facile hydrothermal maneuver demonstrated in Figure 25. The structure was micro/nano structured. Janus copper underwent photocatalytic activity to achieve Janus performance. The combination of the hydrophobic-hydrophilic surface with the Janus copper foam resulted in an integrative system called HB-HL+JCF. This surface indicated higher fog collection efficiency than each surface alone. Figure 25, as described in their work, shows the ideology to create the wanted surface.

The experiments done by the researchers, (Zhou et al., 2020), also showed probably an unprecedented stability for the harvester for long time exposure to sun rays and variable cold and hot conditions over which there weren't big noticeable changes for the fog collection efficiency after UV rays exposure.

Sample meshes of the intended surface of dimensions 3 cm×3 cm were utilized for the experiments to be tested

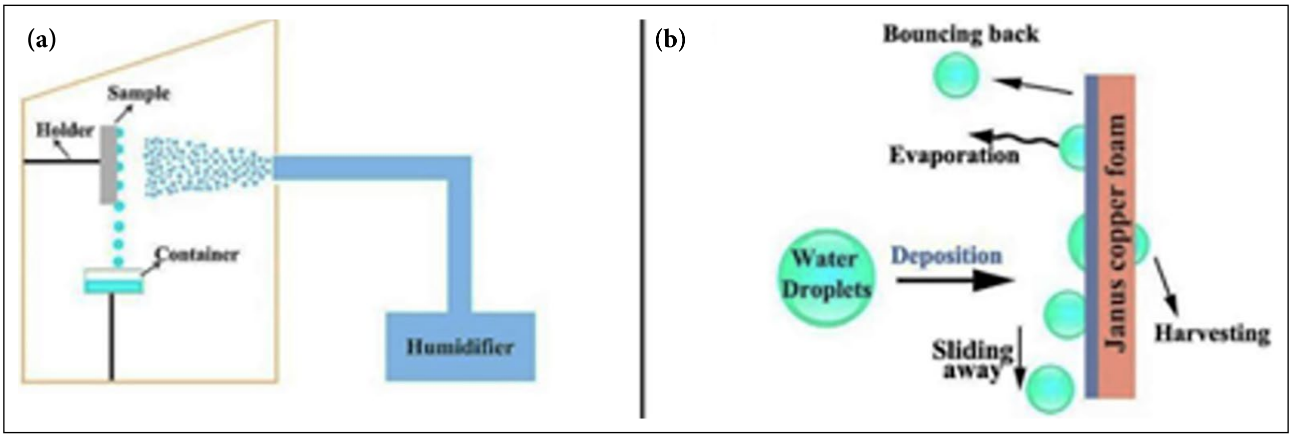

Figure 26. (a) The schematic diagram of the fog collection system used. (b) The schematic illustration of water transport routes during water harvesting (Zhou et al., 2020).

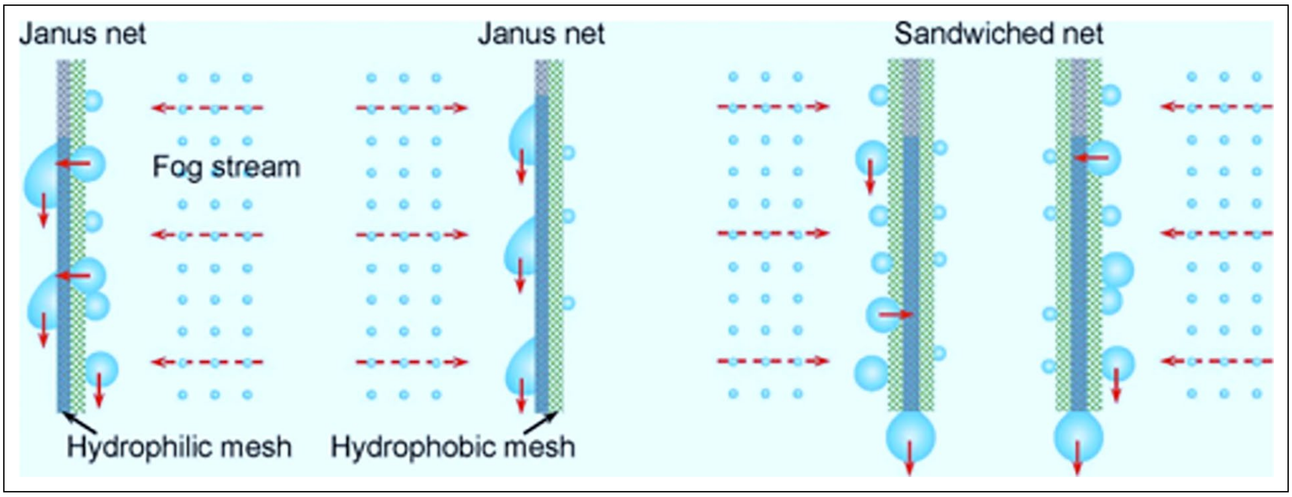

Figure 27. Difference in water drainage trajectory for Janus membrane from both sides and the Sandwiched net (Li et al, 2020).

for stability by measuring the fog collection efficiency in addition to water and oil contact angles. Figure 26 illustrates the system of fog collection used and the mechanism of water collection on the Janus foam.

Apart from Janus membrane, which has two different surfaces oppositely on a flat plate as lotus leaf (Liu et al., 2020)(Liu et al, 2019), Li et al. (Li et al, 2020) suggested a sandwiched net that is comprising three flat layers. These three layers have two hydrophobic (SHB) meshes with a hydrophilic (HL) sandwiched in between. A better result was achieved in both water drainage process and water collection rate for the sandwiched net than the Janus net and single hydrophobic or hydrophilic nets. Figure 27 shows the dissimilarity between Janus nets with fog shed from both sides and Sandwiched nets. It shows the variation of fog collection efficiency for each net used. SHB and HL are superhydrophobic and hydrophilic meshes. The hydrophilic meshes used were polyester filter nets. The superhydrophobic mesh was fabricated by coating the hydrophilic mesh with a superhydrophobic coating and kept drying for one hour. The simple hydrophobic, hydrophilic and Janus membrane were also tested and the sandwiched mesh (SHB/HL/SHB) showed a higher collection efficiency of more than 0.33 g/cm^{2}h.

Liu et al. (Liu et al, 2020) focused only on hydrophobic surface and contact angle not the water harvesting efficiency. The researchers used a technique called pyrolysis to recycle waste technology products like printed circuit boards. They unveiled a fabrication method of super-hydrophobic surfaces using pyrolytic oils and gases to adjust iron mesh substrates. A super-hydrophobic surface was introduced giving high water contact angle that can reach 150.9°. This is not the only advantage of this surface. The researchers also allege that the surface is a well corrosion resistant.

Qu et al. (Qu et al, 2008) developed a superhydrophobic surface on a titanium-silicon Ti/Si by means of conductive polyaniline (PANI) nanowire film production. Mainly, Electrolysis process was done to deposit the aniline into the pores of an anodic aluminum oxide (AAO) on Ti/Si substrate. The resulted surfaces were to be corroded in many

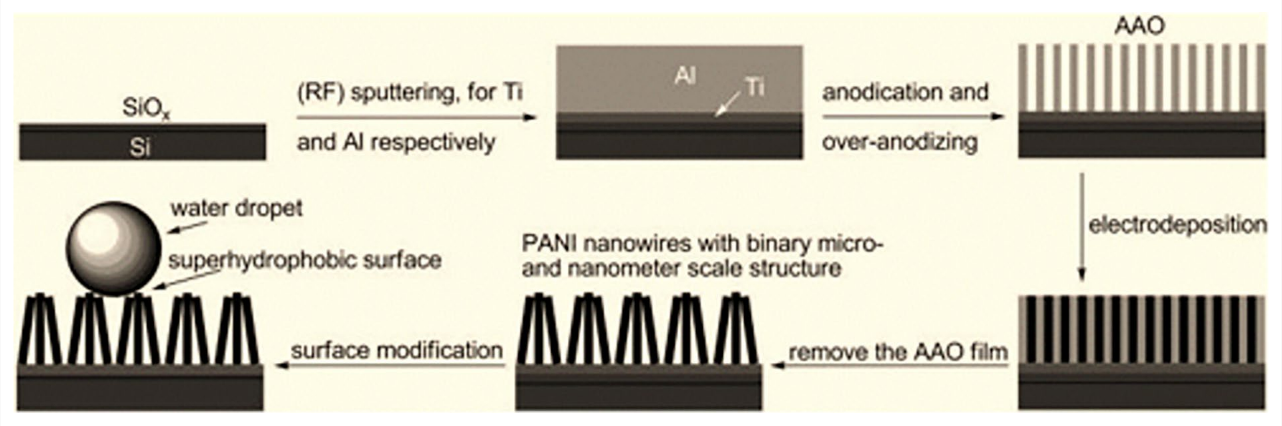

Figure 28. (a) General illustration of collecting method by the spine, (b) Transport and coalescence of water droplet captured, (c) Forces applied on the droplet due to Laplace pressure and the energy release when the droplet reaches the Janus membrane (Qu et al., 2008).

RF: Radio frequency; AAO:Anodic aluminum oxide.

solutions of different pH and showed a stable conductivity and superhydrophobicity over a very wide range of pH. Water contact angle was then recorded for each sample corroded in different solution and the optimum contact angle was nearly 160° at neutral PH region. The method used to fabricate the surface is shown in Figure 28.

Pei et al. (Pei et al, 2020) suggested a way to create a hydrophobic coating that is more stable and applicable to coat and adhere on a surface. The researchers provide in their work that the surface was chemically prepared by free radical polymerization of 2- (perfluorohexyl)ethyl methacrylate (FOL) with γ mercaptopropyltrimethoxysilane (MPS) as chain transfer agent affirm that a contact angle can reach 117°.

Pei et al. (Pei et al, 2020) suggested an easy method to create a hydrophilic/hydrophobic nanosponge-based coatings with the use of fibrous clay mineral. The advantage of this coating is that it is reversible and can be modified when get immersed in CH_2Cl_2 solution to return back as the premier surface. However, this might show a disadvantage of being instable surface and will not sustain for a long time.

Gao et al. (Gao et al, 2006) achieved a surface with a 176° contact angle after performing one of two hydrophobizing processes. The simple methodologies to produce the surface were described in their work either by using the vapor phase dimethyldichlorosilane reaction, to obtain the smothery of the layer, or a solution reaction using methyltrichlorosilane.

Almasian et al. (Almasian et al, 2018) developed a new harvester. This was an unprecedented approach to produce fluoroamine compound by aminating the perfluoroacrylate compound. A Polyacrylonitrile (PAN) surface, which was tested before in many researches for the fog harvesting ability, was altered by the synthesized fluoroamine. The fluoroamine molecules on the nanofiberes surface give a rise to the hydrophobicity surface because of the low surface energy and high water contact angle 159°. The resulted surface was analyzed for fog harvesting ability and results showed that the surface's fog harvesting efficiency was 3.35 kg/m^2.h which is intensely acceptable as a first approach. Compared to the raw PAN surface, the modified surface is capable of collecting fog about tenfold. The fog harvesting efficiency of the mats was also tested at different distances of the to the humidifier nozzle. A simplified schematic diagram of the system is shown in Figure 29.

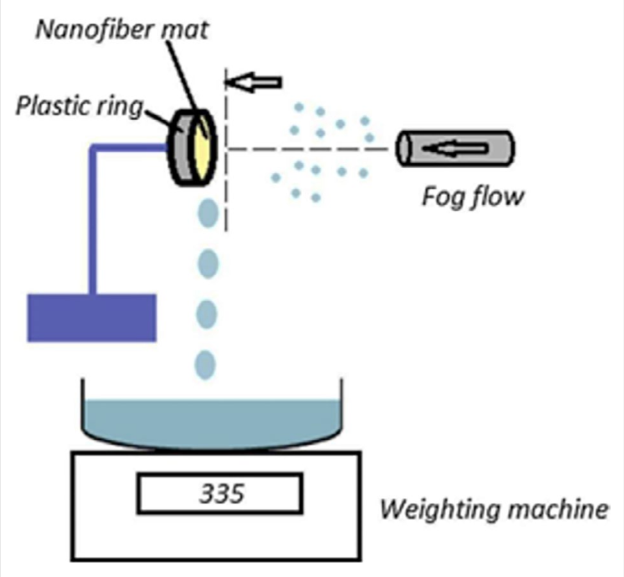

Figure 29. The schematic of the used system (Almasian et al, 2018).

A further test was carried out where they tested the water harvesting efficiency with the distance between the fogger and the mat. However, personally, the authors see the distance test is unrealistic as the natural fog is subjected to the collecting surface randomly and there is no pipe

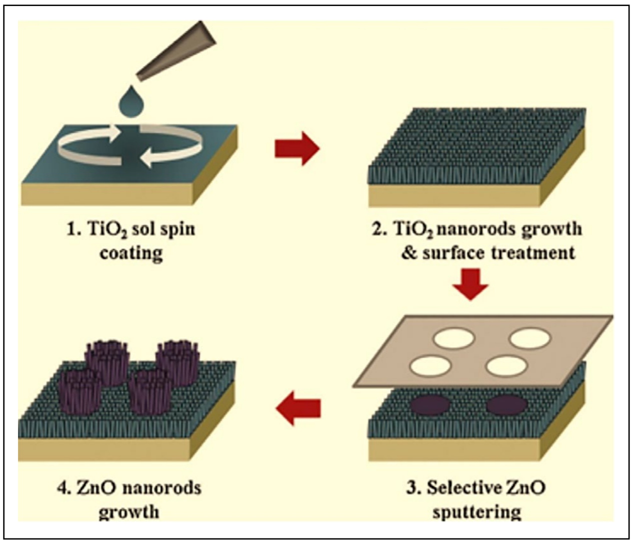

Figure 30. Schematic illustration of the fabrication of a superhydrophilic ZnO/ superhydrophobic TiO_2 surface (Choo et al, 2015).

carrying the fog or water naturally exists. The fog droplets while getting outside of the nozzle have the same as diameter as the nozzle. The droplet after it exits the nozzle will have a changeable diameter.

Upadhyay et al. (Upadhyay et al, 2019) suggested an easy natural methodology to create a superhydrophobic surface using only natural-based ingredients like egg white to treat a copper plate. While the chicken's egg white is boiling, some volatiles are released and deposits microstructures on the copper surface. Secondly, the surface underwent surface modification with stearic acid. The resulted surface is considered hydrophobic with a contact angle of 150°.

Choo et al. (Choo et al, 2015) assembled a superhydrophilic/ superhydrophobic nanorods hybrid surface. The surface was basically fabricated hydrophobically with TiO_2 being spun coated on silicon wafer. Then superhydrophilic ZnO nanorods were precipitated on the hydrophobic surface. Figure 30 gives a brief idea of how the intended surface was fabricated. Water contact angle was measured 161° for a plate surface.

Sharma et al. (Sharma et al, 2019) compared the water harvesting performance of different surfaces of coated and uncoated surfaces. Copper plate surfaces were brought and cleaned ultrasonically and were undertaken different mechanical and chemical procedures to produce a copper oxide nanoneedles surface as shown in Figure 31. The produced surface was also coated with 1H, 1H, 2H, 2H-perflouorodecyltriethoxysilane and kept to dry overnight.

The results of the fog harvesting experiment of the coated surface showed more than double water harvested by the uncoated surface. Nearly 750 mL/m^2/hr to the coated and 500 mL/m^2/hr to the uncoated CuO nanoneedles surface were recorded. The contact angle of the hydrophobic coated surface was also tested and yielded a 165° water contact angle.

Lin et al. (Lin et al, 2020) fabricated a durable superhydrophobic surface that can sustain after a considerable time in different states. The bio-inspired superhydrophobic surface with stomata-like structures (BSSS) can reach water hydrophobicity of high contact angle 168.4°. The durability test suggests the birth of a durable superhydrophobic surface. The brief preparation method of the required surface is illustrated in Figure 32.

Torun et al. (Torun et al, 2019) developed, with the use of eco-friendly and sustainable materials, a superhydrophobic coating. A composite suspension between biocompatible

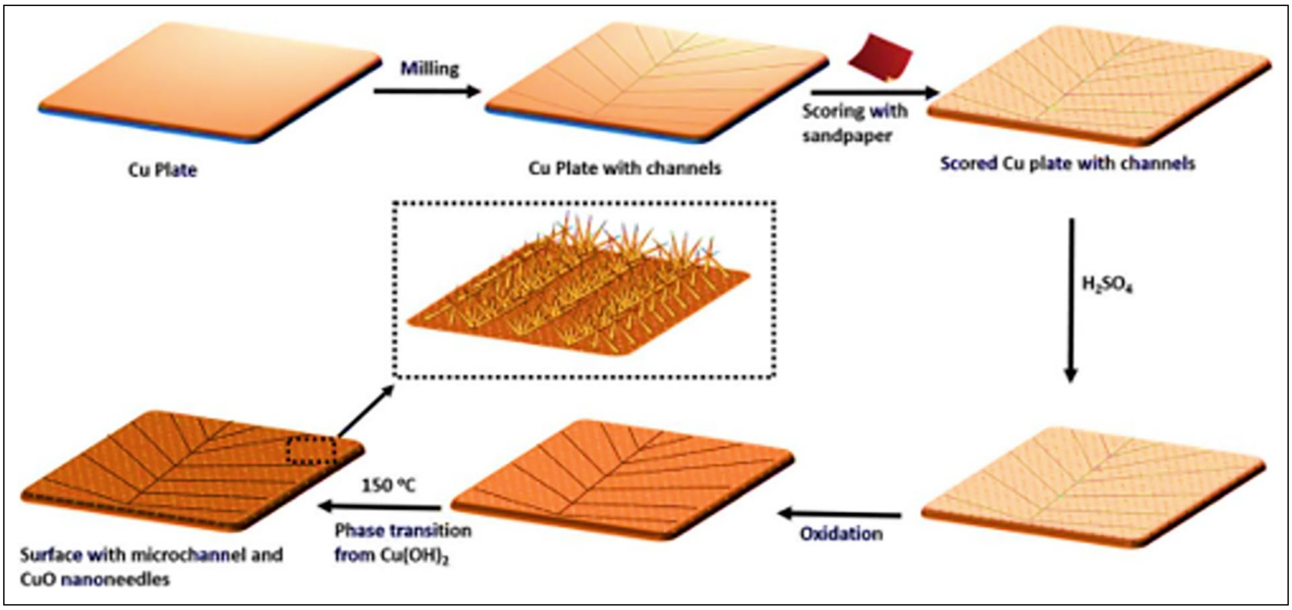

Figure 31. Fabrication steps of copper oxide nanoneedles structure (Sharma et al, 2019).

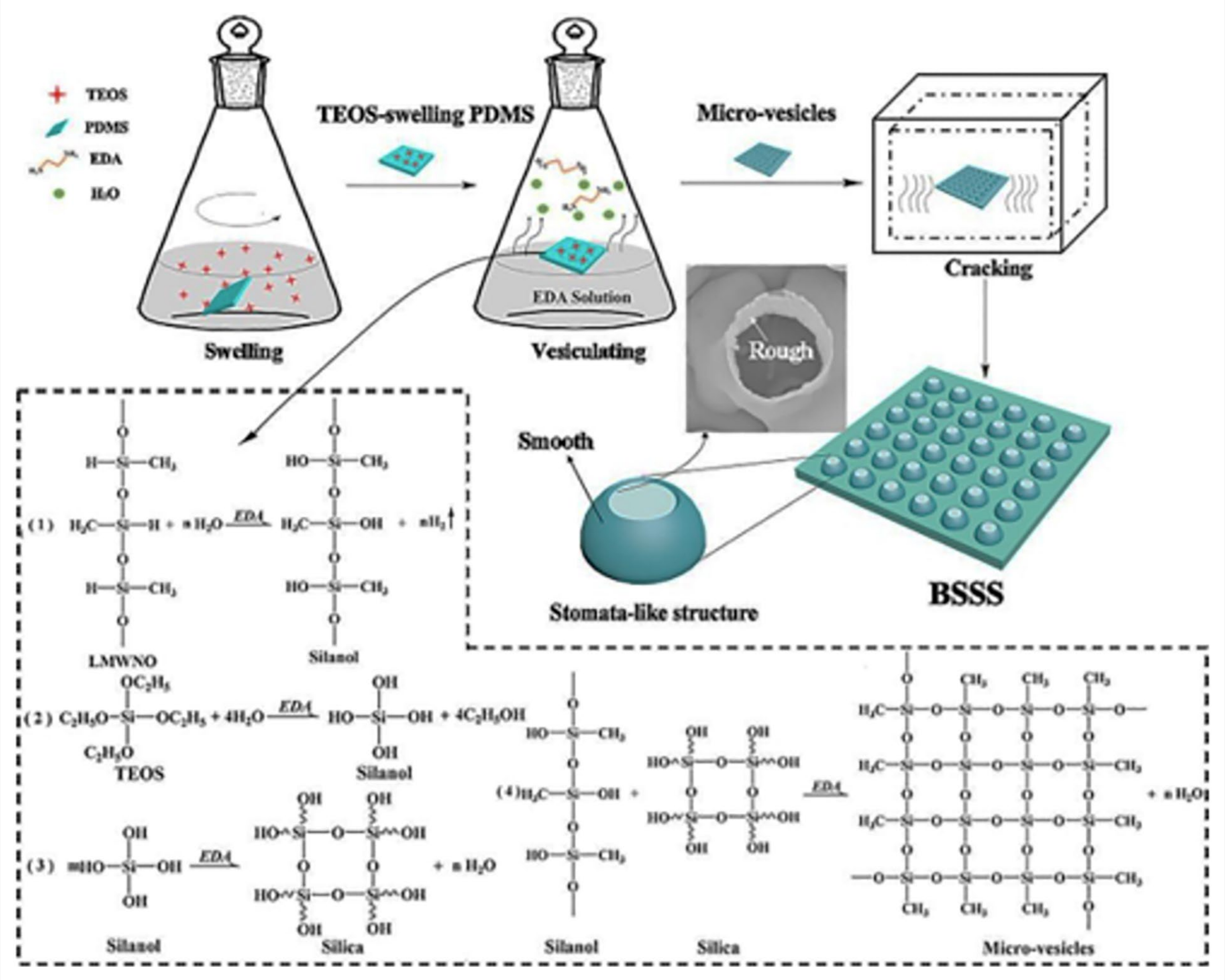

Figure 32. Schematic illustration of the fabrication of BSSS (Lin et al, 2020).

TEOS: Tetraethyl orthosilicate; PDMS: Polydimethylsiloxane; EDA: Ethylenediamine; BSSS: Bio-inspired superhydrophobic surface.

polydimethylsiloxane (PDMS) and wax-based natural material was used. The mixture can be drop cast or spray-coated on glass or paper. Figure 33 shows briefly how they manufactured the hydrophobic spray. Four main points can be deduced to fog harvesting technology from their work. First, the water contact angle reached 170°. Second, spray coating produces a slightly higher water contact angle than drop casting. Third, the highest contact angle was obtained when the ratio between (PDMS) and wax was approximately 2. The fourth point regards the stability and durability of the coated surfaces. Studies showed that the surface coating after half a million of water free falling drops on the surface might get less hydrophobicity due to the breaking of the coating by time. This can put the coating in the category of durable coatings for fog harvesting materials. The disadvantage of this material is that the broken coating will be precipitated in the water. However, (PDMS) is proven to be nontoxic (Park et al, 2008). In addition, fog water collection technology must be accompanied by a filtration system.

Brown et al. (Brown et al, 2016) proposed some superhydrophobic superoleophobic surfaces that can conduct a water contact angle of 172° as shown in Figure 34. Polypropylene (PP) is one of the most common and most used polymers for many applications that need water repellency (Brown et al, 2016). In this methodology, the polypropylene (PP) flat surface was created using the aid of nanoparticles (NP).

Brown's proposed material was created by the use of some chemical and physical processes. Xylene–NP–PP was used to treat a polypropelyne surface heated to 135°C. The formation methodology is represented in Figure 35. SiO_2 NPs, to give the surface more hardness according to tribology book (Bhushan et al, 2013), were also utilized, and the resulted surface is considered mechanically durable.

Feng et al. (Feng et al, 2020) modified the harvesting surface's material utilizing a facile coating method and

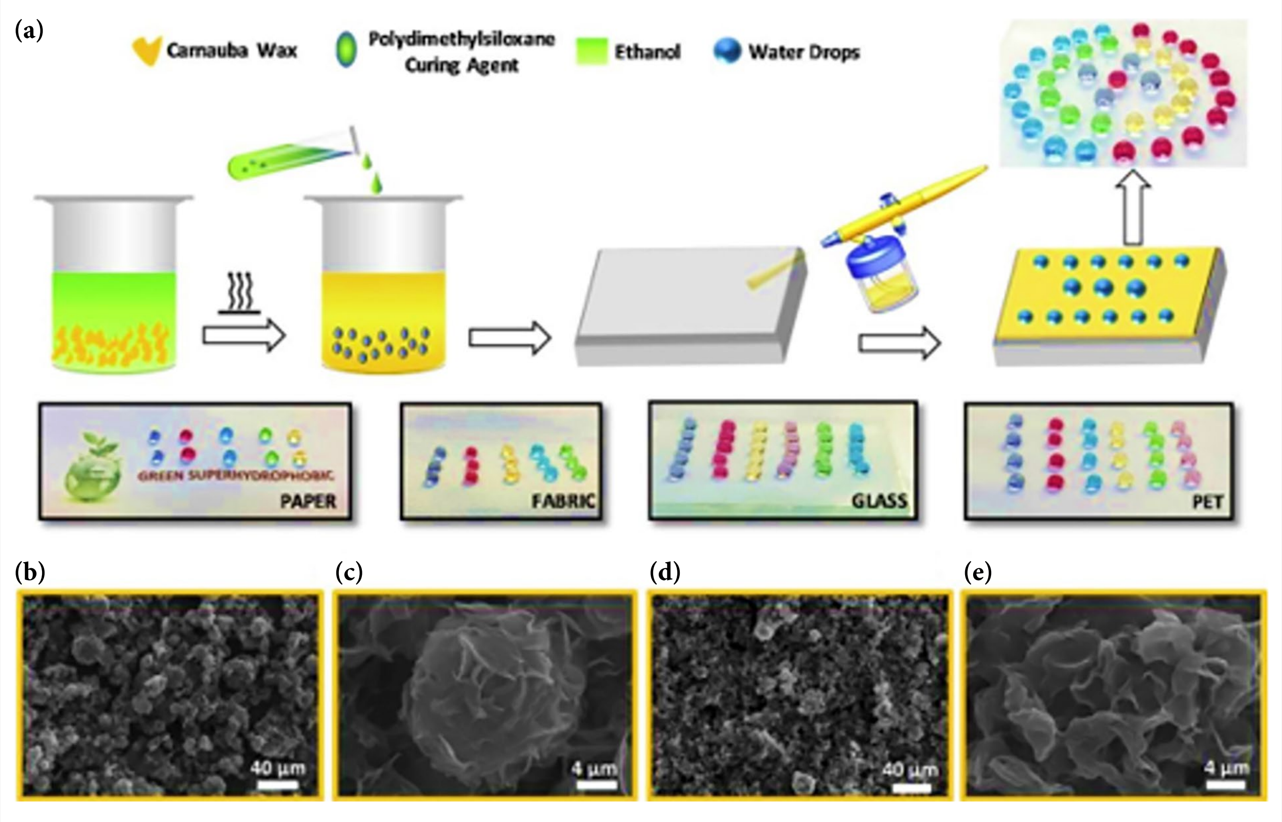

Figure 33. (a) Schematic illustration of the methodology to form the superhydrophobic coating made from biocompatible polydimethylsiloxane and carnauba wax, (b, c) SEM images of surfaces coated with carnauba wax (0.02 g/ml), and (d, e) SEM images of surfaces coated with the composite suspension (PDMS/wax ratio=2) (Torun et al, 2019).

SEM: Scanning Electron Microscope; PDMS: Polydimethylsiloxane.

selective conversion of mercaptan. They successfully produced a bio- imitating surface with differing wettability consisting of a hydrophobic micro- particle/ hydrophilic nano-particle hierarchical structure. The coating material used was mainly of microparticles copper oxide and nanoparticles zirconium oxide. Figure 36 gives the maneuver they used to create the required surface and the fog harvesting apparatus.

The testing procedure was carried out on different samples of differing wettabilities of dimensions 2×2 cm. However, the surface was tested for fog harvesting efficiency and was found that the surface ability to catch fog achieved more than 17 kg/m^2.h when the ratio of ZrO_2 nanoparticles to Cu_2O microparticles in the spraying suspension was 1:8. Thus, this efficiency was their highest achieved.

5. COST ANALYSIS

The cost of fog harvesters' projects depends on the place, material used and other main points. Table 1 summarizes the cost items in a fog harvesting system as described by Batisha(Batisha, 2015).

Figure 34. Water contact angle of Brown's proposed surface (Brown et al, 2016).

Widely-used fog collectors all over the world are made by cutting mesh made of stainless-steel, polypropylene or other materials to produce standard fog collectors (SFC) 1m×1m and large fog collectors (LFC) 1m X 4m. the mesh is vertical facing the wind supported over a non-corrosive copper piping.

The cost depends mainly on the size of the fog mesh, quality of the materials, labour, and location of the site.

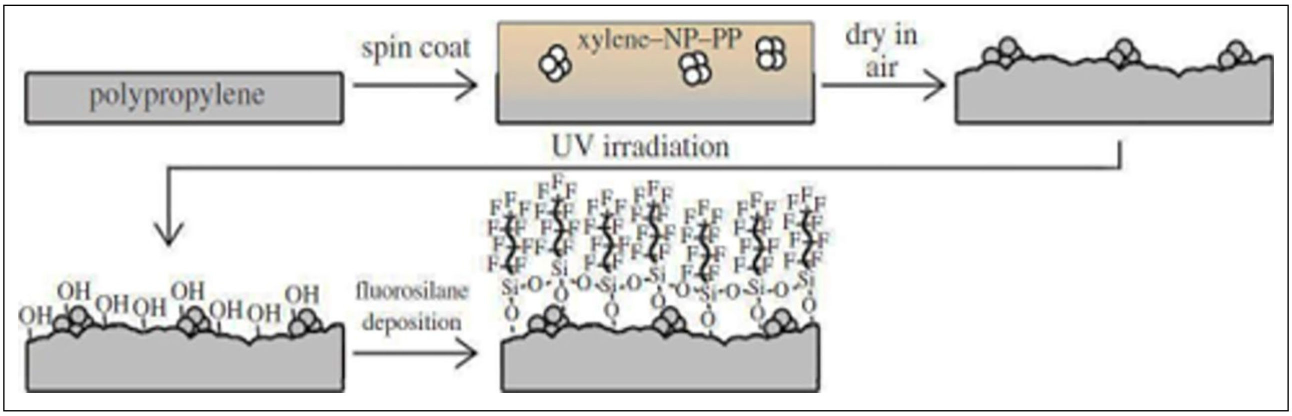

Figure 35. Schematic diagram demonstrating the method of creating superoleophobic superhydrophobic polypropylene (PP) using a xylene–NP–PP mixture (Brown et al, 2016).

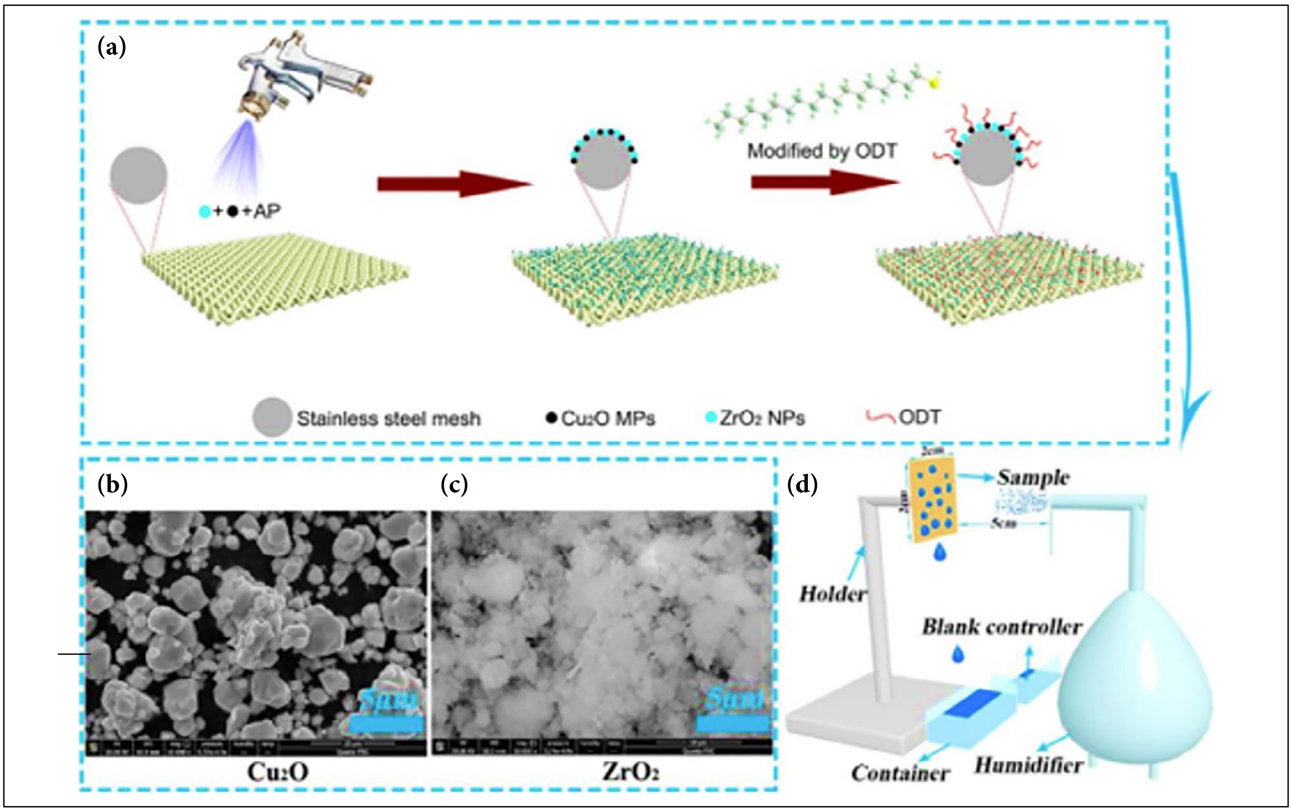

Figure 36. (a) Schematic demonstration of the fabrication process of hybrid super-hydrophilic super-hydrophobic surface (b, c) Scanning Electron Microscopy images of Cu_2O and ZrO_2. (d) The setup apparatus to catch the fog during the fog harvesting experiments (Feng et al, 2020).

AP: Aluminum phosphate; ODT: Octadecyl mercaptan; MPs: Mercaptopropyltrimethoxysilane; NPs: Nanoparticles.

$75 and $200 can be the cost of a small fog collector to build while larger on can reach 40-m^2 and costs nearly $1,000 and $1,500 and lasts for ten years. A 2,000 liters-water-per-day project can cost about $15,000 according to FogQuest.

Fog collectors used commercially as cloud fishers. Cloud fishers of 9 m^2 were developed by German Waterfoundation and applied in Morocco for a year and a half. The results showed a yield of 36 to 126 liters per day depending on the region and season.

6. DISCUSSION

This paper reviews mainly many of the recent papers in the fog collection that focuses on mesh's fog collection rate and

Table 1. Cost analysis of fog collection system by Batisha (Batisha, 2015)

Item	Cost
The materials for one complete SFC setup	US $150
The external expert on meteorology and water supply visit and travel costs	US $4000
The materials for water tanks and pipelines, plus travel and shipping costs	US $36,000
Reliable data and precise recording of daily fog collection rates, the visibility analysis and the time of the observers	US $1000
A field program with anemometers, instrument, and travel costs and data analysis	US $5000
Community involvement analysis	US $3000
Environmental analysis; chemical and bacterial analyses of current or proposed sources of water	US $5000
Construction process and on-going operation	US $3000
Maintenance for a large fog collection project	US $3000/year
Monitoring of the collected water volume and quality	US $3000/year
Salaries, vehicles, and other expenses	US $10,000/year
Routine repairs and the distribution of the water	Hire people

SFC: Standard Fog Collector.

water-surface contact angle. However, some of the reviewed papers have other results which are also described in this review and all the results are briefly displayed in Table 2 to show all the papers reviewed.

Fog density and fog movement speed due to wind are difficult to control while capturing. This can induce unsteady fog water collected with time. Hence, a couple of experiments cannot be fairly compared if occurred naturally. However, the experiments are done by researchers artificially in laboratories by pressurizing water and using narrow diameter nozzles. The water is sprayed in the form of fog. However, the test cannot be expected to be the same by different researchers. Many points are difficult to be controlled from a place to place. Both methods, naturally and artificially, are not fair comparisons if done many times to compare the fog harvesting efficiency. Natural fog is unpredictable and may differ in physical properties as the size of the fog droplets are varying and droplets spacing is also different, in other words, the total volume of fog droplets in a cubic meter is not constant and is changeable from place to place and time to time. In addition to the wind that might play important role to the harvesting efficiency, the wind can result in change in fog collection efficiency from a minute to minute making a profit of collected water but non uniform. Also, the temperature of the fog may lead to difference in fog droplet diameter and surface tension of water on the collecting surface. Moreover, the natural fog is neither found everywhere or at any time. On the other hand, the artificial fog collection experiment is not world widely unified. The experiment needs to get artificial fog which can be produced by a fog machine. Fog machines can differ in outcome physical properties; different in fog droplet size, spacing and fog temperature. The fog machine rated pressure might differ, nozzle diameter and the number of nozzles coming out from the machine also may differ.

Regarding the water contact angle, it is determined by the water droplet size (Good et al., 1979)(Gaydos et al., 1989) different researchers at different places might investigate the contact angle at different size which means that the gravitational force or the droplet weight will vary. In addition, the contact angle depends strongly on surface tension and surface tension is temperature dependent. How can an experiment to determine the contact angle of any similar surface get the same results if carried out in the United Kingdom and China for example? Furthermore, while testing for contact angle is in progress, surface roughness is a key factor when the surface is coated with a coating. It will show different contact angles if the surface roughness is different. Therefore, surface roughness must be controlled as well.

One of the main suggestions here for interested people in this field is to try to unite the way artificial fog collection experiment are undergone. Try to use a fog machine with similar specifications to all researchers in fog harvesting field in the world. Try to unite the same quality of water used to produce fog. Try also to unite the distance between the fog machine hoses to the fog mesh collector. And when testing for a single parameter, the others must be controlled and fixed for better comparisons.

As the material of the harvester or the coating which is spread on the harvester's surface is an important key to enhance the fog collection. Table 2 summarizes previous investigations on mesh materials and coatings used in fog collection.

Enhancing a fog collector is a challenge to water researchers. New materials can be used for the mesh or the mesh can be coated with newly-produced hydrophobic-hydrophilic coatings. In addition, mesh geometry is still under investigation as new shapes of mesh's holes are being developed and tested. Furthermore, nanotechnology is also helping producing a surface of modified properties

Table 2. Summary of previous investigations on mesh materials and coatings used in fog collection

Objective	Specification (Treatment)	Maximum contact angle	Fog collection rate	Other important remarks	Reference
Testing a fabricated mixed wettability patterned surfaces	Coating CuO-PFDT-PS	161°	1.59 kg/m^2.h		Wang et al.
Testing a fabricated artificial hydrophobic/hydrophilic porous water harvester	Coating: PVDF/PAN composite solutions	160°	3.15 kg/m^2.h	NA	Huang et al.
Testing a surface enabling directional slip of liquid	Laser treatment	160°	NA	Sliding time for water droplet on a coated surface and a laser treated surface. 210 and 10 seconds, respectively.	Li et al.
Testing a coated hydrophilic microfiber with super hydro phobic coating	Layers of assembled carbon nanoparticl es	NA	NA	Sliding time for water droplet on a coated surface and a bare 5° inclined fiber. 32.5 and 180 seconds, respectively	Zhang et al.
Fabricating stainless steel surface resistive to corrosion	Etching and oxidation	NA	NA	Good corrosion resistant surface	Park et al.
Experiment ally studied the performance of a superhydro philic- hydrophobic surface	Superhydro philic- hydrophobi c integrated conical stainless- steel needle (SHCSN)	NA	NA	Superhydrophilic-hydrophobic surface is more reliable than hydrophobic only or hydrophilic only for fog harvesting	Chen et al.
Experiment ally testing Janus membrane for fog collection	Copper mesh	NA	5 g/h For a sample 2 cm×2 cm. =12.5kg/m^2.h	8 times improvement than superhydrophilic membranes	Zhong et al.
Measuring contact angles for integrated surface	Integrating hydrophobi c- hydrophilic surface and Janus copper foam	151°	NA	NA	Zhou et al.
Experimental study for fog collection using a stretched	A smart Janus membrane with a flexible PDMS sheet	NA	NA	Stretching the mesh can lead to higher yield	Su et al.
Investigating the ability of the pine needles to directional harvesting fog	Pine needles (Pinus tabuliformis)	NA	NA	Pine needle collected 7.2 ml/hour	Wan et al.
Testing a flat and conical structured hydrophobic surface	Treating a 3D printed surface with nano-particles layer	156°	NA	NA	Mahmoud et al.
Design and fabrication of a multi- bioinspired Janus membrane	Spraying and etching (Cu(OH)$_2$ nanofibers and ZnO- tetrapod)	153.1°	NA	NA	Li et al.
Maximizin g fog harvesting efficiency by improving droplet condensatio n and disposal	Clustered fibril on lens array	150°	10 kg/m^2.h	NA	Raut et al.
Fabricating a superhydro phobic copolymer coatings	CH$_3$-SiO$_2$ and i-Bu-SiO$_2$ copolymer coatings	151.22° and 154.85°	NA	NA	Zhao et al.
Fabricating Vertically aligned zinc oxide nanowires by a cost-effective and scalable hydrothermal method	Zinc oxide- silver hierarchical nanostructu res	138°	1240 mg/h For a sample of 25mm×25mm =1.98 kg/m^2.h	NA	Kim et al.
Testing a hierarchical micro-/nano- crystals constructed on a protein film surface	ZIF-8 on Soy protein	NA	9.176 kg/m^2.h	NA	Liu et al.
Proposing a bioinspired gradient surface with a star-shaped wettability pattern	TiO$_2$, FAS and Ultraviolet rays	160° ±3°	2.7 g/cm^2.h	NA	Bai et al.

Table 2. Cont.

Objective	Specification (Treatment)	Maximum contact angle	Fog collection rate	Other important remarks	Reference
Experimentally testing a membrane made by a new technique	Electrospin ning	NA	7.44 kg/m^2.h	NA	Huang et al.
Enhancing fog- collection efficiency of typical Raschel meshes	Teflon, ZnO nanowires, NeverWet, and hydrobead	NA	17 mL/h For a sample 3.3 cm×2 cm. =25.75 kg/m^2.h	NA	Rajaram et al.
Designation of a hybrid membrane for efficient fog collection	$Cu(OH)_2$ nanoneedles	141.3°	NA	NA	Hu et al.
Analyzing micro/nano -structured hybrid hydrophobic hydrophilic surface	Hydrother mal and photocataly tic reaction	137°±3°	2.5 g/h For a sample 3 cm×3 cm =2.77 kg/m^2.h	NA	Zhou et al.
Developing a three-layer sandwiched collector	Polyster filter nets (Hydrophillic) Glaco Mirror Coat Zero and silica nanoparticles (superhy drophobic)	NA	NA	Sandwiched net can yield extra 50% more than Janus net	Li et al.
Fabricating super-hydrophobic surfaces	Pyrolysis technology	150.9°	NA	NA	Liu et al.
Preparing a superhydro phobic surfaces on Ti/Si substrates	Polyaniline nanowire film	160°±3°	NA	NA	Qu et al.
Fabricating a stable hydrophobic surface	Free radical polymerizat ion of (FOL) (MPS)	117°	NA	NA	Pei et al.
Producing a hydrophobic smooth surface	Dimethyldi chlorosilane and methyltrich lorosilane reaction	176°	0.33 g/cm^2. h=3.3 kg/m^2.h	NA	Gao et al.
Modifying the surface of polyacrylon itrile (PAN) nanofibers for enhancing fog collection	Aminating the perfluoroac rylate compound	159°	3.35 kg/m^{2}h	NA	Almasian et al.
Fabricating copper surfaces with wettability contrast	Eggs	150°	NA	NA	Upadhyay et al.
Examining nanostructu red surfaces with special wettability	TiO_2 nanorods and ZnO nanorods	161°	NA	NA	Choo et al.
Fabricating easy and cost-effective water harvester	Oxidation. High- density copper oxide nanoneedles	165°	750mL/m^2/ hr= 0.75L/m^2/h r=0.75kg/m^2/ hr	NA	Sharma et al.
Constructin g a superhydro phobic surface inspired by stomata effect	Swelling- vesiculatin g-cracking method	168.4°	NA	NA	Lin et al.
Preparation of a superhydro phobic composite suspension coating	Biocompati ble carnauba wax and polydimeth ylsiloxane	170°	NA	NA	Torun et al.
Creating superoleop hobic PP surfaces using NP	Xylene–NP treated PP with fluorosilane	172°±1°	NA	NA	Brown et al.
Fabricating a bioinspired surface with hybrid Wettability	Cu_2O micropartic les and ZrO_2 nanoparticles	NA	17 kg/m^2/h	NA	Feng et al.

FDT-PS: Perfluorodecanethiol- polystyrene; PVDF/PAN: Polyvinylidene Fluoride /Polyacrylonitrile; NA: Not applicable; FAS: Heptadecafl uorodecyl-trimethoxysilane; ZIF: Zeolitic imidazolate framework; FOL: 2-(perfluorohexyl)ethyl methacrylate; MPS: Mercaptopropyltrimethoxysilane; PP: Polypropylene; NP: Nanoparticles

such as roughness and wettability. Using a single or double layer of fog collectors is also a point of research with how layers are aligned together. Pins can improve fog collection efficiency when distributed on the mesh surface to increase mesh surface area and help catching fog droplets. Generally, fog collection is still improving and researchers have many points to work upon. Fog collection is also not studied properly in the field of simulation. Most researches are carried on experimentally. Hence, simulating fog collection will be a part of future studies for researchers.

6. CONCLUSION

In brief, water harvesting technology is a cheap unpopular extraordinary method to solve water shortage in semi-arid regions and arid regions. During the last three decades, Water harvesting technology has improved a lot and many projects were launched all over the world for many purposes. Four predominant parameters mainly control the efficiency of fog collection. The quantity of water collected by the harvester depends on mesh geometry, shade coefficient, surface roughness, surface chemistry (material). It was clear that the combination of hydrophobic and hydrophilic integrated surfaces of mesh was resulting in higher water caught.

For fog collection technology to be enhanced in the future, fog harvesters should be more investigated for different mesh geometries in order to better take advantage of water suspended in air. This can be held by testing untried designs like hexagonal and triangular mesh or design new shapes. In addition, shade coefficient is to be optimized for each mesh geometry.

Regarding mesh surface, surface roughness or finishing contributes efficiently for fog collection rate. Surface chemistry is the most demanded parameter to be more investigated and tested for new materials. The combination of hydrophobic and hydrophilic surfaces was proven to be innovative and productive in fog collection researches. However, most investigated materials were not tested for long-term stability and decomposition. Micro and nanoparticles can be precipitated in water forming harms for humans and ecosystem if used for agriculture and other humanitarian purposes leading to environmental problems and unsustainability.

DATA AVAILABILITY STATEMENT

The published publication includes all graphics and data collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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