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Dew extraction from air using Nanocomposites

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Abstract - *This work examines the fog-harvesting ability of patterned samples in spray chamber experiments. The sample has channels, hydrophobic patches and hydrophilic patches of contrasting wettability to mimic and optimize the alleged natural fog harvesting ability of the Stenocara Beetle. Fog-harvesting results based on amount of collected water has showed significant differences among all samples, as the influence of wind was found to be the more dominant factor when compared to sample's wetting characteristics. Importantly the coating of patterned surfaced was done using hydrophobic patterns for water channeling and with maximum wettability characteristics using hydrophilic coating. The hydrophilic and hydrophobic surfaces was coated on PC sheet and glass, both the materials showed satisfying adherence and in particular glass showed higher adherence and higher cooling performance. Analysis of experiment were done in real world the results were concluded to be successful and were an improvement of existing work and proved as a possible viability and alternate source of fog extraction.*

Key Words: Nano-technology, Condensation, Computational fluid dynamics (CFD), Biomimetics, Passive dew-condensers.

1. INTRODUCTION

Dew extraction is possible when there is considerable moisture in the air. Due to the phenomenon of phase transition, droplet condensation occurs i.e. change of physical state of matter from the gaseous phase to liquid phase.

In the process of selecting materials suitable for dew extraction, we consider the various terminologies, methods, factors, and limitations for dew extraction from the air.

1.1 Nanocomposites

A composite material is a blend of two or more constituent materials with considerably different physical and chemical properties to exhibit a unique property different from the properties of individual constituents. When this Composite material has one of the phases at a dimension less than 100 nanometers or at a Nanoscale, we refer the composite material as nanocomposites. Nanocomposites are different from the conventional composite material with regard to their reinforcing phase which has an extremely high surface to volume ratio or aspect ratio.

1.2 Condensation

The phase transition is a very common phenomenon. Phase transition can be classified into two types, homogeneous transition, and heterogeneous transition. Heterogeneous transition, a much common in daily life phenomenon, includes crystallization, coating film, surface cooling and so on. The processes of droplet condensation and evaporation (vapor to liquid) are typical phenomena in the phase transition. Condensation is the change of physical state of matter from a gaseous phase to liquid phase. Here we refer to change of state of water from its vapor state to liquid state. In nature, cloud droplets are formed with the help of cloud condensation nuclei or CCNs which are small particles typically 0.2μm, on which water vapor condenses. Hence, water requires a non-gaseous surface to make the transition from a vapor to liquid. In spite of the unremitting advance and the wide application for the study in droplet condensation, the theoretical research on the processes of droplet condensation and evaporation on the solid surface still has some drawbacks:

1. Almost all prevailing models are only apt for the specific size ranges of droplet and solid surface;

2. Many previous models only considered the effect of the solid surface on the energy transfer, however, the effect of the solid surface on the mass transfer is also noteworthy, which has been proved in the study of heterogeneous nucleation [5].

These drawbacks may be attributed to two main reasons. One is that how to categorize and incorporate different regimes of mass and energy transfers in the processes of droplet condensation and evaporation on the solid surface is still challenging. The other is that it is difficult to consider the effects of the solid surface on the droplet condensation and evaporation, especially in the non-equilibrium region near the droplet surface where the effects of the solid surface have a significant influence to the droplet condensation and evaporation, surface to volume ratio or aspect ratio.

1.3 Water harvesting

Dew harvesting is simply collecting the water vapor or moisture in the atmosphere to obtain clean and potable water through condensation. When there is any humidity present in the atmosphere, with the help of a surface which is cool enough to provoke condensation is used to condense the water vapor in the air into its liquid state or simply due. This process is being used every day in nature by plants and insects to obtain water for their survival in dry conditions. Humans have been using this process since ancient times in areas where water availability is scarce. We look at exploiting the same process to tap into the water resource of moist air or humidity in the atmosphere by the use of hydrophilic-hydrophobic hybrid patterned surfaces for enhancement of heat transfer and collection of dew, as homogenous model is found out to be unsuitable as referred from development of a new model for condensation[3]. This is analyzed by studying the performance of hydrophobic and hydrophilic materials and their nature from the journals on heat and mass transfer[1] as well as the performance characteristics of radiative cooling materials[4]

Table -1: Sample Table format

Table for water collected hours graph		
HOURS	24/05/2018	25/05/2018
23	10Gms	12Gms
0	16Gms	17Gms
01	19Gms	17Gms
02	38Gms	37Gms
03	42Gms	50Gms
04	60Gms	67Gms
05am	67Gms	70Gms
06am	82Gms	74Gms
07am	81Gms	75Gms
08am	64Gms	66Gms
09am	30Gms	23Gms

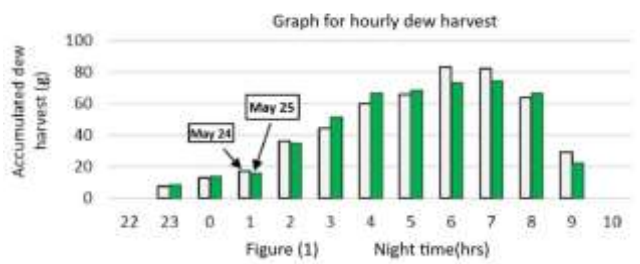

Chart -1: Graph of hourly dew harvest

1.4 Radiative cooling

Radiative cooling is an approach to dissipate excess heat into distant heat sinks by means of thermal radiation. Radiative cooling is generally experienced on cloudless nights when heat is radiated into space from the surface of the Earth. The effect can personally be felt on the skin of an observer on a cloudless night. In India nocturnal cooling was common before the invention of artificial refrigeration technology for preparing ice. The apparatus consisted of a shallow ceramic tray with a thin layer of water, placed outdoors with a clear exposure to the night sky. The bottom and sides were insulated with a thick layer of hay. On a clear night, the water would lose heat by radiation upwards. Provided the air was calm and not too far above freezing, heat gain from the surrounding air by convection was low enough to freeze the water.[6]

Radiative cooling is an important aspect of efficient loss of heat in the form of thermal or infrared radiation from the surface of the structure for optimum cooling of the surface to initiate condensation and harvest dew. For this, we have referred the journal on dew condensers [2] for various radiation cooled condensing devices and their properties which have been studied and analyzed with the help of CFD. Ansys Fluent and CFD help in determining thermal behavior, condenser shape and varying scales of the system in different assigned conditions without any practical approach [7].

1.4 Hydrophobic and Hydrophilic Surfaces

Hydrophobicity

Hydrophobicity is the physical property of a molecule to repel from a mass of water. Hydrophobic molecules have a tendency to be nonpolar and, thus, prefer other neutral molecules and nonpolar solvents. Because water molecules are polar, Hydrophobes do not dissolve well among them. Hydrophobic molecules in water habitually cluster together, forming micelles. Water on hydrophobic surfaces will exhibit a high contact angle. Owing to their water repellent properties, hydrophobic and super-hydrophobic surfaces have been studied as a promising solution to several challenges, such as drag reduction, anti-icing, and enhancement of two-phase heat transfer performance. These surfaces are widely studied to endorse dropwise condensation and thus boost condensation by heat transfer. The hydrophobic interaction is mostly an entropic effect originating from the disruption of the exceedingly dynamic hydrogen bonds between molecules of liquid water by the nonpolar solute forming a clathrate-like structure around the non-polar molecules. This structure formed is more highly methodical than free water molecules due to the water molecules positioning themselves to network as much as possible with themselves, and thus results in a higher entropic state which causes non-polar molecules to bundle together to reduce the surface area exposed to water and decrease the entropy of the system. Examples of hydrophobic molecules include the alkanes, oils, fats, and greasy substances in general.

Thomas Young defined the contact angle θ by analyzing the forces acting on a fluid droplet resting on a solid surface surrounded by a gas. A liquid droplet rests on a solid surface and is surrounded by gas. The contact angle 'θ', is the angle formed by a liquid at the three-phase boundary where the liquid, gas, and solid intersect. The formation of the droplet for different contact angles is shown below;

Hydrophilicity

Hydrophilicity is the physical property of a molecule to attract a mass of water. A hydrophile is a molecule or a molecular entity that is attracted to water molecules and tends to be dissolved by water. During condensation the droplet spreads, wetting a large area of the surface, and then the contact angle is less than 90 degrees and that surface is considered hydrophilic. Hydrophilic substances diffuse in water, which is they move from areas of high concentration to areas of low concentration. This is caused by the attraction of water molecules to the hydrophilic molecules. In areas of high concentration of the molecules, water moves in and pulls the molecules apart. The molecules are then distributed to areas of low concentration, where more water molecules interact. Diffusion is a very important property of most hydrophilic substances to living organisms as it allows them to dispense substances with little to no energy on their part. Hydrophilic coatings are particularly effective in environments of extreme condensation and to shield the exchanger from the corrosive effect of water. The hydrophilic coating also exhibits a fine performance in providing protection against water in high temperature and salty environments. Examples of hydrophilic substances are sugar, salt, alcohol etc.

1.6 Breath figures or condensed droplets

Breath figures are nothing but the tiny water droplets formed on a cooler surface due to condensation of water vapor or moisture present in the atmosphere. It is the arrangement of the drops that are obtained by condensation of a liquid from a gaseous phase on a surface that is not wet by the liquid itself. Condensation occurs either in the form of drop-wise or film-wise due to surface wettability and it is concluded that drop-wise condensation is more productive and economical for harvesting dew. Drop-wise condensation occurs when the water vapor comes in contact with the cooler surface which is below the saturation temperature, thereby releasing the latent heat of condensation.

Traditionally the breath-figures method has been used since the 1850s by photographers as a simple yet, effective way to identify oil contamination on glass substrates. The notion of "breath-figures" refers to the set of fog droplets that form when water vapor comes into contact with a cold surface (solid or liquid). Breath-figures are a phenomenon commonly observed in daily life. One example is the surface fog that appears on a window when we breathe on it. Another example is the formation of dew on the leaves of the plants. The thermodynamic affinity between polymer and solvent is a key parameter for breath-figure formation, along with other solvent characteristics such as water miscibility, boiling point, and enthalpy.

2. Bio-inspiration or Biomimetics

Biomimetics or biomimicry is the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems.

Living organisms have evolved well-adapted structures and materials over time through natural means. Biomimetics has given rise to newer technologies inspired by biological solutions at macro and nanoscales. Nature has answered to humans for most of our problems throughout our existence and solved many engineering problems.

One of the early examples of biomimicry was to study birds to enable human flight, Leonardo da Vinci, a noted figure in the history of mankind worked extensively to mimic the flight of birds though he could not succeed in that triumph to build a flying machine. The Wright Brothers later succeeded in flying the first ever aircraft in 1903, apparently derived inspiration from observing pigeons in flight.

One particular insect to our interest is Stenocara gracilipes, also known as the fogstand beetle, is a species of beetle that is native to the Namib Desert of southern Africa. This is one of the most arid areas of the world, receiving only 1.4 centimeters (0.55 in) of rain per year. The beetle survives by collecting water on its bumpy back surface from early morning fogs.

To drink water, the beetle stands on a small ridge of sand using its long, spindly legs. Facing into the breeze, with its body angled at 45°, the beetle catches fog droplets on its hardened wings. Its head faces upwind, and its stiff, bumpy outer wings are spread against the damp breeze. Minute water droplets (15-20 μm in diameter) from the fog, gather on its wings; there the droplets stick to hydrophilic bumps, which are surrounded by waxy, hydrophobic troughs. Droplets flatten as they make contact with the hydrophilic surfaces, preventing them from being blown by the wind and providing a surface for other droplets to attach. Accumulation continues until the combined droplet weight overcomes the water's electrostatic attraction to the bumps as well as any opposing force of the wind. When the droplet grows to roughly 5 mm in diameter; at that point, it will roll down the beetle's back to its mouthparts.

Hence the beetle successfully condenses dew on its back and directs it towards its mouth with the help of Hydrophilic and hydrophobic surfaces, crucial for its survival.

3. Passive dew condensers

Access to water has become difficult in the ongoing race of urbanization and industrialization since the availability of freshwater resources is less than 3% of all the water available on the planet. Access to clean drinking water has become one major concern since pollution is on the rise and meeting the demand of an ever-increasing population is an uphill task. Considering the acute shortage of water in arid regions and across the globe, the method of dew extraction from air seems to solve the water crisis to some extent.

Many scientists, inventors, and students from around the world have come up with various inventions and methodologies to harvest dew.

Passive-dew-condenser is a device designed to extract moisture from the humid air without the use of any external energy. Under a clear sky at night, the condenser surface gets cooled simply by radiative exchange with the sky, becoming colder than the dew-point of the surrounding humid air. Due to which the vapor contained in the air condenses on its surface. The condenser surface is set at an angle from the horizontal to permit draining of condensed water droplets by gravity. When conditions are favorable condensation could occur over the good part of the night yielding a significant amount of water which is potable.

4. Recent notable experimentation and models

A team from The Indian Institute of management, Ahmedabad developed a condenser made up of several materials including polyethylene film, polyethylene mixed with titanium-oxide and barium-sulfate film, fiber reinforced plastic sheet and polycarbonate sheet. It had a panel, mounting frame and collection accessories. The test was conducted in the coastal arid regions of Kutch in Gujarat over a period of 8 months from October to May. For an area of 1m2 and 25mm thick square panel, the yield was found out to be 16042 ml or roughly 16 liters in total[7].

The international Organisation for dew Utilization[8], a non-profit organization has selected and displayed various inexpensive models from across the world for harvesting dew. These models are

MODEL CRSQ – 0.25 : Surface 0.25 m^2, semi-quantitative, light, portable and inexpensive. Tested already during R.O.R. intended for measurements of short duration.

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MODELE CRQ – 1 : Surface 1 m^2, metal base and arm supports. Already working in Croatia, Israel, Holland, French Polynesia, India, Ethiopia, and Morocco. For precise daily long-term measurements.

MODELE CRQ – 30 : Surface 30 m^2, reinforcement anchored in the ground. This model is in operation in Vignola, Corsica (France) intended for the production of large volumes of dew.

5. Experiment Conduction

The glass substrate was cleaned with Acetone. The glass slide was exposed to Plasma using Plasma cleaner. This cleaned the surface of the glass slide to micron level and the surface also had a layer of OH molecules after removing from the Plasma cleaner. A gap of 0.7cm in the center is covered using a scotch tape. This is to prevent the chemical to overflow to the center region. Two parts of the glass slide with approximate of 1cm and 0.7cm is coated with Octadecyltrichlorosilane (OTS) using a dropper. Using the dropper, it is evenly spread. Then it is left to dry for 1 hour. Due to the scotch tape the OTS did not flow into the center region. Figure 1. Now the chemical covered region is covered with an air tight sheet. Then the slide is placed into the Plasma cleaner to get a coating of the OH molecules. The slide is subjected to Plasma rays for 2 minutes. The slide is removed and the we get a specimen as in fig 1. The experiment was conducted on the night of May 24th and May 25th. The weather on those days was clear of any clouds and rain. High humidity was reported on that day. Which made the presented results maximize and present it at high output? The high humidity contributed to high output of the presented which beat the previously presented research by out other researchers. One of the major obstructions for present research was the effect wind and smog. The experiment was started on 11 pm and ended at 9 am the next morning. Same was the experiment was conducted on 25th may night 11 pm and ended on next day morning 26th morning 9 pm. Both day experiment results are provided in the results section. The coated surface was placed plated at an angle 30 degree from a flat reference point. A Beaker was placed was placed at the lower end so that the water could collect and can be analysed for further higher analysis. The conduction was a success. The collected sample results are presented in grams per hour rate as weighing bridge was placed under the beaker so that the water that water collected can be analysed and stored.

6. CONCLUSIONS

From the experimentation we found out that the coating of Hydrophobic-Hydrophilic substance on the substrate was successful in extracting dew from the atmosphere. We conducted the experiment for two days in night conditions. The experimental setup was highly influenced by weather

Fig -1: Dew condensing over the surface of prototype

Conditions like wind speed, temperature, humidity, rain, light and heat in the atmosphere. The green bar in the graph represents the experimental data on 25th May 2018 and white bar on 24th may 2018. The water collected during the experiments is represented on grams per hour basis. The purpose of representing the data in grams per hour is that impurities may change the volume of water, water collected was easier to measure as grams as weight was must easier quantity the measure than volume. Conduction of the experiment may depend on the season, place and the month. The following results were obtained represented on the graph for dates 24th and 25th of May 2018. We conclude that our project can help in solving the water crisis in dry areas where water availability is scarce.

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Fig -2: Nanocomposite coated Sample

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